Student observations and explanations of a physical phenomenon:

The Cartesian Diver

by

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ABSTRACT

This study explored student observations and explanations of the Cartesian Diver. The study was conducted in a Grade 6/7 class in the lower mainland of Vancouver it chronicled and categorized the developing understanding of three pairs of students.

Each dyad participated in four events. Each event presented a unique variation of the Cartesian Diver. The first and third event involved a working Cartesian Diver, while events two and four required the students to construct a Cartesian Diver. Throughout the events, the researcher videotaped each pair's manipulations, observations and explanations. The data was analyzed using two established frameworks (Gunstone, 1998; Frazier, 1995).

Students were able to construct a working Cartesian Diver and offer many explanations for its functioning. Student explanations of the Cartesian Diver were constructed from the data. The number of explanations increased as the students became familiar with the equipment and the variables which determine the behaviour of the Cartesian Diver. While many of the explanations were scientific, the students could only explain what they saw; student theories were context driven. None of the students was able to formulate a comprehensive theory to explain the Cartesian Diver.

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CHAPTER I

The Problem

1.1 Introduction to the Problem

This study examines how children explain a phenomenon new to them. In this, they act as investigators who observe, explain and theorize. Children and scientists have much in common. Both are interested in exploration as an attempt to understand their environment (Gauld, 1989; Kuhn, 1989). Kelly (1969) suggests that everyone is a scientist of a sort from a young age. While children are less conscious of their thinking processes than scientists, Claxton (1982) writes that "both are theorists and experimenters" (p. 4) as children formulate hypotheses, emit behavioural experiments, note consequences and modify the content, scope and theory accordingly.

The difference between a child and a scientist is that a child is not able to think *scientifically* (Moshman, 1979; McCelland, 1984; Kuhn, 1988). A child's thinking is thought to be limited by their level of cognitive maturity, experiences, use of language, and their knowledge and appreciation of the experiences and ideas of others (Osborne & Bell, 1983; Driver, Guense and Tiberghien, 1985; Schollum and Osborne, 1985).

1.2 Problem Statement

Kelly (1955) considered each person to be an *intuitive scientist*, formulating hypotheses about the world, collecting data that confirm or reject their hypotheses, and then altering their conception of the world to include new information. In this way, every person operates in a manner similar to the scientist. The activities developed for this study explore the actions of *intuitive scientists*. Students explain the behaviour of the Cartesian Diver[1] based upon their manipulations and observations. The focus will not only be on student hypotheses but on the ideas they conceive during exploration and discovery.

Many factors influence student explanations such as prior ideas. Research indicates that students cling to their prior ideas when encountering new phenomena (Tiberghien, 1984; Gunstone and Watts, 1985; Osborne, 1985). The Cartesian Diver is a phenomenon new to students that requires them to draw upon prior experiences as well as formulate new ideas.

This study explores student observations and explanations of a physical phenomenon and details their developing understanding of that phenomenon. The intent is to characterize the observations and explanations of six elementary school students, working in dyads, as they progress through the study. The study highlights the similarities and differences between the student dyads.

1.3 Research Questions

This study examines three dyads of Grade 6/7 students and their observations and explanations of the Cartesian Diver, and is guided by the first two research questions with the intention of addressing the third question,

i) What do students observe and how do they explain the behaviour of the Cartesian Diver?

ii) How do student observations and explanations change as they proceed through the stages of the study?

[1]. The Cartesian Diver is a closed system in which an open ended glass vial floats in a flexible cylindrical container filled with water. Pressure applied to the flexible container causes the glass vial to sink. Removing the pressure causes the glass vial to float.

iii) What implications for classroom teaching can be drawn from the understandings gained in this study?

1.4 Scope of the Study

This study was conducted in a Vancouver lower mainland school with a grade 6/7 class. The students were asked to observe and explain the behaviour of the Cartesian Diver while they worked with assembled Cartesian Divers and constructed their own Cartesian Divers. Three dyads of grade 6/7 students were audio/video taped. The students, all volunteers, were articulate, co-operative, and interested in working with the Cartesian Diver and the researcher.

This study provides science educators with insights into the development of and changes in student understanding of physics concepts. The study highlights some of the difficulties students encounter in the development of physics concepts and illustrates the influence of students prior experiences and ideas on their thinking and actions.

1.5 Limitations of the Study

This study has limitations as a small sample of six grade 6/7 students participated in the experiment and is limited to the exploration of one phenomenon displayed in four experiments. Student exploration is examined within a controlled setting with experimental materials selected for the purpose of examining student actions, observations and explanations. In addition, this study is limited as student explanations are categorized according to a single framework.

The behaviour of the interviewer may affect the responses of the interviewees and subsequently the data collected. The situation of the interview as well as the manner and role of the interviewer can strongly affect the interviewee (Becker, 1970). In this case study the interviewer attempted to address these concerns and minimize his effect on the students, their thinking, acting and representation of this understanding.

1.6 Strength of the Study

The Cartesian Diver represented a new event in these six students' lives in which they were able to investigate a phenomenon using simple materials. The informal nature of the interviews allowed the students to play an active role in the experiments. The students were free to repeat experiments and progress at a rate not dictated by the researcher. The students' explanations were not evaluated, and they were free to offer, modify and retract statements.

1.7 Outline of the Remainder of the Thesis

This chapter introduces the study and the rationale for its existence. The following chapters present: a review of related literature (Chapter II); the research methodology (Chapter III); the presentation of the data (Chapter IV); the findings of the study; implications of the research for teaching practice; and suggestions for further science education research (Chapter V). The appendices contain a complete set of one dyad's transcripts.

CHAPTER II

Review of Related Literature

2.1 Introduction

This literature review focuses on relevant research germane to this thesis: the Cartesian Diver; the principles of constructivism; and case study research. The literature review reveals: i) an historical perspective of the Cartesian Diver, and how it became associated with Descartes, along with a summary of the limited research conducted on the device as it relates to science teaching; ii) the principles of constructivism are examined to reveal how individuals construct knowledge, and how that knowledge is used to interpret objects or events; and iii) case study literature is examined to define and articulate the structure of this thesis.

2.2 Cartesian Diver

2.2.1 Historical Perspective

The name, Cartesian Diver, is often attributed to the famous mathematician and philosopher Rene Descartes (1596-1650). However, a documented link between the diver and Descartes does not exist. Some student science textbooks books suggest Descartes is the inventor (Vilenkin, 1980; The Exploratorium, 1987). Provenzo et al. (1989) show that a number of writers have ascribed the invention of the diver to Descartes.

Raffaelo Maggiotti, a student of Galileo's, first described the Cartesian or Devil Diver in writing (Rose, 1970). In a short pamphlet, Maggiotti (1648) speaks of the device as his invention "*L'invention mia non consiste nel caldo, o ned freddo; ma nella Renitenza all Compressione*".

The association between the Diver and Descartes might be attributed to philosophical and scientific advances of the era. Descriptions of hydrostatic phenomena and designs for diving devices appeared in Descarte's era (Tokaty, 1971; Marx 1990; Damerow et al., 1992). Thinkers, like Galileo, used hydrostatics in analogies in the development of concepts of free fall (Damerow et al., 1992) so Descartes would have known of the phenomenon illustrated by the diver (Kleiber, 1961; Shea, 1991; Damerow et al., 1992; Garber, 1992;).

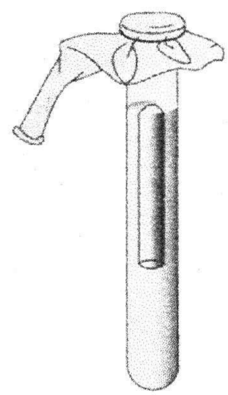
Interestingly, the French do not refer to the diver as Cartesian but rather as *ludion*, a word derived from the Latin meaning actor, jester, wandering entertainer (J. Guillaume, personal communication, October 30, 1995). One might speculate that it is called a Cartesian Diver because it rises and falls along the X-axis, Cartesian Co-ordinates.

2.2.2 Current Literature

A literature search on the Cartesian Diver revealed several published journal articles. The articles typically examine student understanding of the physics concepts involved in explaining the behaviour of the Cartesian Diver.

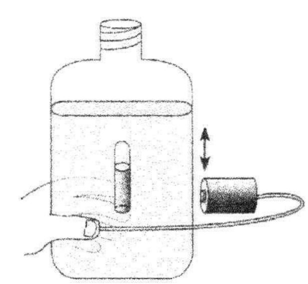
Penick (1993) describes his introduction to the Cartesian Diver when over 20 years ago, as an assignment, he was asked to construct one based on a simple diagram (see Figure 1). Today he asks students to make Cartesian Divers based on models he presents. Through the trial-and-error activities involved in creating the divers the students are prompted to think, observe, and experiment with the model. When the students think they can explain the Cartesian Diver, other models are introduced which challenge their explanations. Penick thinks that his method of inquiry meets Percy Bridgman's definition of science as, "doing one's damnedest with one's mind, no holds barred". (Penick, 1993, p. 30)

Figure 1. The Cartesian Diver (Pennick, 1993)



In support of Penick's pedagogy, Berg (1993) had students construct and manipulate a Cartesian Diver. Throughout the experimentations students formulate theories on how the system operates. As they develop an understanding of the function of the diver, Berg introduces an unusual Cartesian Diver, invented by Michael Abraham (Penick, 1993), by incorporating a wire and a C or D-cell battery (see Figure 2).

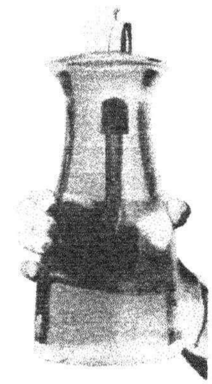
Figure 2. The Flask/Wire/Battery Challenge (Berg, 1993)



Pennick challenges all student explanations, while Berg accepts student explanations and furthers understanding with new devices.

Ann Brandon (1982) published work on a discrepant or Reverse Cartesian Diver[1] using a 22-oz. plastic Palmolive dishwashing liquid bottle (see Figure 3).

Figure 3. Reverse Cartesian Diver (Brandon, 1982)



The Cartesian Diver has existed for a long time as a phenomenon to be explored. While the reason for its existence and origin of the name remain clouded in mystery. The Cartesian Diver has been used in science teaching for 60 years to teach concepts of buoyancy, floatation and pressure and more recently it has been used as a phenomenon to explore student thinking. As this study also explores student thinking, the theoretical framework of constructivism is now examined.

2.3 Constructivism

From the extensive literature on constructivism, a few are reviewed here to illustrate the value and effectiveness of constructivism in examining student thinking.

Constructivism is a way of thinking about knowing (Tobin, 1993). It is concerned with how knowledge is constructed, and how that knowledge is used to interpret objects or events (Segal, 1986).

[1] The Reverse Cartesian Diver is a closed system in which an open ended glass vial rests on the bottom of a flexible cylindrical ovoid container filled with water. Pressure applied to the flexible container causes the glass vial to rise to the surface. Removing the pressure causes the glass vial to sink.

von Glaserfeld (1986) thinks that the concept of the personal construction of knowledge is as old as Western philosophy:

> Pre-Socratics in the Sixth and Seventh Century B.C. were already aware that not everything they knew could be said to come from sensation and that the mind, the specifically human mind, was to a large extent responsible for shaping human knowledge. (p. 106)

Jonasson (1991) believes that objectivism, the antithesis of Constructivism, views knowledge as *out there* waiting to be discovered. Francis Bacon, the "father of *Scientific Method*," (Shaprio, 1994, p.8) is one whose ideas also reflect this belief. His conception of working to arrive at knowledge through a series of prescribed steps embodies images of something akin to a mechanical process. Nadeau and Desautels (1984) believe that such a *Scientific Method* gives the false impression that there is a recipe for producing knowledge, and that knowledge production is a certainty if the procedure is followed. Constructivists claim that the scientific process is not a recipe for knowledge production but a decision-making tool for assessing a knowledge claim.

West and Pines (1985) suggest that there are two sources of knowledge for the learner. One is the knowledge which the learner acquires from interaction with the environment. The primary characteristic of this environmental interaction knowledge is that it constitutes the learner's reality, something the learner believes in. The other source of knowledge is formal instruction. The primary characteristic of formally instructed knowledge is that it is represents another person's interpretation of the world, another person's reality.

According to Mathews (1992) constructivism denies the existence of reality. Conversely, Tobin & Tipps (1993) state constructivists acknowledge the existence of reality from the outset. According to Tobin and Tipps reality is defined in both personal and subjective ways, and does not exist separately from the observer *out there*, needing only to be discovered. Tobin and Tips (1993) write:

> Take gravity for example, a constructivist position is that gravity exists and through our experiences we have come to know gravity. Our knowledge of gravity is both individual and social, and through negotiation, agreement is reached within our social system that the concept of gravity has numerous properties. We construct a model of gravity that is viable in that the model fits experience, but no matter how elegant, that model cannot claim to be an absolute truth. The model has evolved, as all knowledge evolves, through the processes of negotiation and consensus building. As our experiences have changed, so too has the model been explicated. (p. 3)

While constructivists accept reality, they argue that an incorrect but commonly held view is that objectivism is capable of providing a direct access to reality. Some constructivists view objectivism as a representation of reality. They argue that it is not possible to observe reality directly (von Glaserfeld, 1986). von Glaserfeld believes what is observed is actually an individual representation of reality. Illusions which encourage individuals to see or believe events that are *not true*, as in optical illusions, indicate that there is no direct access to reality, and that the process of observing is interpretive.

Critics of the constructivistic reality conjure images of individual realities lacking a common consensus. As Quine (1964) says:

> Different persons growing up ... are like different bushes trimmed and trained to take the shape of identical elephants. The anatomical details of twig and branches will fulfill the elephantine form differently from bush to bush, but the overall outward results are alike. (p. 8)

The strategies employed by individuals in their creation, maintenance and modification of reality, are unique but have a great deal in common. Trusted (1987) suggests that it is likely that all human beings select similar characteristics to construct their basic foundations of reality. Von Foerster claims that:

> We construct or invent reality rather than discover it. He suggests that we fool ourselves by first dividing our world into two realities - the subjective world of our experience, and the so-called objective world of reality - and then predicating our understanding on matching our experience with a world we assume exists independently of us. (Segal, 1986, p. 17)

An *absolute reality* does exist, however some constructivists point out that an individual can never come to realize reality as a truth. von Glaserfeld noted that:

> A basic misunderstanding of constructivism ... springs from the resistance or refusal to change the concept of knowing. I have never denied an *absolute reality*, I only claim, as the skeptics do, that we have no way of knowing it. And as a constuctivist, I go one step further: I claim that we can define the

> meaning of *to exist* only within the realm of our experiential world and not ontologically ... Of course, even as constructivists, we can use the word *reality*, but it will be defined differently. It will be made up of the network of things and relationships that we rely on in our living and of which we believe that others rely on, too. (Tobin and Tipps, 1993, p. 4)

Constructivists emphasize the pluralistic and plastic character of reality. It is pluralistic in the sense that reality can be expressed in a variety of symbols and language systems; plastic in the sense that reality is stretched and shaped to fit purposeful acts of human agents. As Kuhn (1970) and others have pointed out, knowledge changes over time because the goals, problems and the individuals of society continually change, leading to new experiences.

Learning involves making sense of knowledge through an existing conceptual structure (Posner et al., 1982), schemata or mini-theories (Claxton, 1990). Whatever knowledge is constructed it will be an interpretation of experience in terms of extant knowledge. von Glaserfeld (1986) writes:

> Instead of the paradoxical requirement that knowledge should reflect, depict or somehow correspond to a world as it might be without the knower, knowledge can be now seen as fitting the constraints within the organism's living, operating and thinking takes place. From the perspective, then, *good* knowledge is the repertoire of ways of acting and/or thinking that enable the cognizing subject to organize, predict and even to control the flow of experience. From this changed point of view, then, the cognitive activity does

> not strive to attain a veridical picture of an *objective* world (a goal which, as the skeptics have always told us, is unattainable), but it strives for viable solutions to whatever problems it happens to deal with. (p. 108)

Constructivism appoints the learner as the key participant in learning. It is the learner who must do the work of integrating new ideas into his or her thinking. Kelly (1963, 1970) considered that the totality of an individual's experiences constitutes a conceptual framework of reference for perceiving and making sense of new phenomena. New concepts are constructed as a method of processing new knowledge and are assimilated into an individual's existing conceptual framework. According to Hewson and Thorley (1989), when a learner considers a new conception, two possibilities exist; it can be incorporated with existing conceptions in a process called *assimilation* (Posner et al., 1982) or *conceptual capture* (Hewson, 1981). The new conception can also be accepted, lowering the status of the former (and conflicting) conception and raising the status of the new conception in a process called *accommodation* (Posner, et al., 1982) or *conceptual exchange* (Hewson, 1981).

The process of learning as conceptual change is seen as "an adaptive process, one in which the learners conceptual schemes are progressively reconstructed so that they are in keeping with a continually wider range of experiences and ideas" (Bell, 1993, p.26). It is also seen as an active process of *sense making* over which the learner has some control (Driver, 1989).

Research into children's conceptualizations has revealed that prior experiences and ideas have a powerful influence in relation to how new knowledge is constructed.

Gunstone (1988) discussed several findings based on research into conceptualizations of science topics.

> i) When students come to formal science learning they frequently already hold explanatory views of phenomena which are apparently personal and idiosyncratic interpretations of experiences and are often different from the explanatory views taught in the classroom;
>
> ii) These views can be remarkably unaffected by traditional forms of instruction;
>
> iii) Particular views can be quite common ... that is, the finding of these idea/beliefs is not a function of the sample of the students involved and one view can be held by many students; and
>
> iv) Some students can hold the scientists' interpretation given together with a conflicting view already present before instruction. The science interpretation is often used to answer questions in science tests, and the conflicting view retained to interpret the world. (p. 74-75)

Osborne and Freyberg (1985) also found that children's ideas are usually strongly held and often differ significantly from the views of scientists.

In sum, constructivists view the learner as the key participant in learning and learning involves making sense of knowledge. One of the two identified sources of knowledge stems from the learner's interaction with the environment which is the learner's reality. Through accommodation or assimilation it is the learner who integrates ideas, both non-scientific and scientific, into a conceptual framework.

This constructivist's conceptual framework provided a guide for developing the research questions, the research methodology and the data analysis. It was thought that presenting the study as a case would best represent the research. In the next section, relevant literature on case studies is reviewed.

2.4 Case Study

2.4.1 The Case Study

The concept of a case study is the subject of debate (Stake, 1994). When examined from different viewpoints and in different situations the same *case* can be different. A case's definition can change in different ways under different methods of study. Definitions ranging from the simplistic *a slice of life* or a *depth examination of an instance* (Lincoln and Guba, 1985) to such formal statements as Denny's (1978) "intensive or complete examination of a facet, an issue, or perhaps the events of a geographic setting over time". (p. 9)

2.4.2 What is a Case Study?

Biddle and Anderson (1986) distinguish two types of cases: the case study and the case story. The case study is not undertaken to confirm the investigator's prior commitments but to investigate a problem. The case study is bounded by rules of evidence and is rigorous in its observations. A case story should read like a good novel and illustrate conclusions to which the author is already committed. A skillful case story will provide the reader with new insights and understandings. It does not, however, provide conclusions that reflect evidence.

The term case study may also be defined as the intensive investigation of a single object of inquiry such as the classroom (Stake, 1978). Yin (1981a, 1981b) defines a case study as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used. The case study is favoured by some researchers as it highlights the question of what can be learned from the single case. The case is a specific integrated *bounded system* (L. Smith, 1978 and Stake, 1978).

2.4.3 Traditional Prejudices Against a Case Study

Perhaps the greatest concern about the case study is that of the perception of its lack of rigor. Too often researchers have allowed equivocal evidence or biased views to influence the direction of the findings and conclusions (Yin, 1987). The problems are not different from those encountered in other research strategies. They have, however, been less frequently documented and addressed (Yin, 1987).

A second common concern is that the case study does not provide a basis for scientific generalization. Case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes (Yin, 1987). It can be seen as a small step towards generalization (Campbell, 1975). The case study, like the experiment, does not represent a *sample*, and the investigator's goal is to expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization) (Yin, 1987).

A final concern is that the case study is too time-consuming, resulting in massive, unreadable documents. This confuses the case study strategy with ethnography (Yin, 1987). Case studies are a form of inquiry that do not depend solely on ethnography. A case study of high quality can be conducted without leaving a library and or by using a telephone (Yin, 1987).

2.4.4 Types of Case Studies

Stake (1994) has identified three heuristic types of case studies:

i) Intrinsic Case Study

> An intrinsic case study is undertaken because one wants better understanding of a particular case. It is not undertaken primarily because the case represents other cases or because it illustrates a particular trait or problem, but because, in all its particularity and ordinariness, this case itself is of interest. (p. 237)

An intrinsic case study draws the researcher toward understanding what is important about the case within its own world, not so much the world of researchers and theorists, but developing issues, contexts, and interpretations.

ii) Instrumental case study

> An instrumental case study is a particular case examined to provide insight into an issue or refinement of a theory. The case is of secondary interest; it plays a supportive role, facilitating our understanding of something else. The case is often looked at in-depth, its contexts scrutinized its ordinary activities detailed. The case may be seen as typical of other cases or not. (p. 237)

The instrumental case study draws the researcher towards illustrating the concerns of researchers and theorists which are manifested in the case.

iii) Collective case study

> A collective case study is not a study of a collective but an instrumental study extended to several cases. Individual cases in the collection may or may not be known in advance to manifest the common characteristic. They are chosen because it is believed that understanding them will lead to better understanding, perhaps better theorizing, about a still larger collection of cases. (p. 237)

The choice of case is made because it is expected to advance an understanding of an interest. Researchers can simultaneously have several interests which are often changing. There is no line distinguishing the intrinsic case study from the instrumental; rather, a zone of combined purpose separates them.

2.4.5 Educational Case Studies

While acknowledging the many style of case studies, Stenhouse (1988) identifies one style as the Educational Case Study. The educational case study is not concerned with evaluative judgment but rather with the understanding of educational action. It is concerned with enriching the thinking and discourse of educators through development of educational theory or by the refinement of prudence through the systematic and reflective documentation of experience.

2.4.6 The Case Study and the Reader

Both Lincoln and Guba (1985) believe that the ultimate purpose of any case study is to improve the reader's level of understanding of the case. Case studies may be epistemologically in harmony with the reader's experience as they permit the reader to build upon his or her knowledge. They enable the reader to achieve personal understandings, and they encourage detailed probing of an instance in question (Stake, 1978, 1994).

For the reader to achieve personal understanding, Stake (1978) believes that a case study must provide a vicarious experience. The case study takes the reader on a voyage to points unknown and presents the reader with opportunities that most would never encounter. Knowledge of the case study can face hazardous passage as the reader may fail to comprehend personal meanings of events and relations regardless of the cleverness of the writings. Conversely, pre-existing knowledge can lead the reader to reconstruct the knowledge in ways that produce different and more personally useful connections. A *new* case study without distinction may not be noticed as it may lack a commonality of comprehension when compared to other already-known cases (Lincoln and Guba, 1985).

To bridge the gap between the case and the reader, essential similarities to cases of interest must be presented for the reader to establish natural generalizations (Stake, 1978). As each reader may have a different application for the case's findings, the case must include, "a broad range of background features, aspects of the processes studied, and outcomes so readers have enough information to assess the match between the situation studied and their own, especially since their situations might be different" (Firestone, 1993, p.18).

In sum, a case study is an investigation of a problem and is bounded by the rules of evidence. It is not a unique method of investigation as it can resemble other types of research. The case study should provide the opportunity to transport the reader to points unknown, enabling a personal understanding. It should not be a massive unreadable document likely to overwhelm the reader.

2.5 Summary

This study can be described as an Intrinsic Case Study (Stake, 1994) with an *Educational* perspective (Stenhouse, 1988). It is one *experiment* among many but its role is not insignificant. It contributes to a greater understanding of student thinking. The study uses the Cartesian Diver, a well established tool in science teaching, as a way to explore student thinking. The data collection and analysis of student thinking are based on a constructivist view of knowledge construction.

CHAPTER III

Methodology

3.1 Introduction: Overview of the Case Study

This study examines the students' developing understanding of the physics involved in explaining the behaviour of a Cartesian Diver as they observe, manipulate, and construct a Cartesian Diver. The study is presented as a case study of three dyads of students. Relevant literature on case studies was reviewed in Chapter II.

3.2 Research Questions

Two research questions were used to guide the study with the intention of addressing the third question.

i) What do students observe, and how do they explain the behaviour of the Cartesian Diver?

ii) How do student observations and explanations change as they proceed through the three events in this study?

iii) What implications for classroom teaching can be drawn from the understandings gained in this study?

3.3 Context of the Study

The study was conducted in a grade 6/7 class in a elementary school located in the lower mainland of Vancouver. Prior to the study the students had investigated simple machines and structures.

3.4 Selection of the Subjects

To conduct the study, six[1] grade 6/7 students were selected by the classroom teacher based upon agreed criteria:

- students should be compatible in small groups and successful in school studies;
- students would differ in terms of their prior scientific knowledge and in their socio-economic and cultural backgrounds; and
- students should be articulate in English.

The students were not chosen to be representative of the school population but were chosen to provide a rich understanding of the research problem.

3.5 Methodological Assumptions

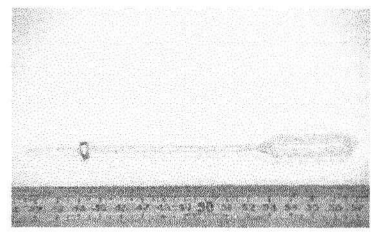
A major assumption of this study is that the experiments the students were asked to perform were at an level appropriate for them. This assumption was thought to be reasonable, as the Integrated Resource Package (IRP) (1995) Prescribed Learning Outcomes (PLO) in grade four focuses on the properties of water and in grade six on forces. Throughout the K-7 curriculum the students are expected to conduct experiments using *scientific methodology*. It is assumed that the students represent themselves to the best of their ability and respond to questions honestly making evident their thinking and understanding.

[1] In case study research much data is collected and analyzed. Six students were chosen to make the job manageable and yet provide a range of student thinking.

3.6 Pilot Studies

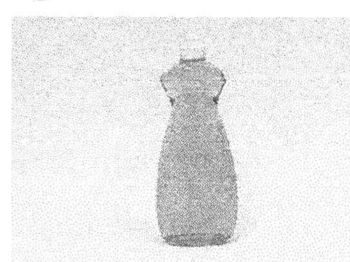
Two pilot studies were conducted with grade school students to determine the workability of the selected equipment. The first pilot study also tested the divers and the video recording equipment. The divers were constructed from a 5ml disposable pipette and a 5/16 brass nut as outlined by Berg (1993) (see Figure 4). It was believed that the translucent nature of the pipette would provide the students with a window into the action inside the diver. A pipette lacking weight will float, horizontally, on the surface. Four millilitres of water and the brass bolt provided sufficient weight to cause the pipette to float vertically at the surface. The children were confused by the addition of the brass nut. The diver's behaviour was thought to be caused by the nut rather than the water in the diver. This discrepancy resulted in abandoning these materials. A soundless video taped interview re-affirmed the need to turn on the microphone when commencing the interview rather than at the conclusion.

Figure 4. Pipette



The second study involved a discrepant or Reverse Cartesian Diver using a 22-oz. Palmolive dishwashing liquid bottle as described by Ann Brandon (1982). The plastic bottle (see Figure 5) proved too rigid, and when accidentally dropped, the bottle cracked and leaked. The unique shape of the bottle proved too difficult to squeeze in order to change its volume.

Figure 5. Palmolive Bottle



3.7 Sequence of the Study

This study had students observe, manipulate and explain the behaviour of Cartesian Divers and to construct Cartesian Divers. The four events of the study can be described as:

i) Assembled Cartesian Diver (ACD). Students observe, manipulate and explain the behaviour of a diver.

ii) Constructed Cartesian Diver (CCD). Students construct a working diver, using available materials, and describe the problems encounter.

iii) Assembled Discrepant Cartesian Diver (ADCD). Students observe, manipulate and explain the behaviour of a diver which is different from the ACD.

iv) Constructed Discrepant Cartesian Diver (CDCD). Students construct a working discrepant diver, using available materials, and describe the problems encounter.

3.8 Data Collection and Recording

Data was collected by personal observations and video/audio tape of student interviews. Each interview was conducted in a classroom with an assistant who helped with the operation of the audio/video equipment. An Equipment Log was written at the end of the interview day. This log recorded deficiencies in the borrowed equipment, and diver materials to be repaired or replaced. The video/audio taped interviews were viewed at the end of the day and transcribed a few days later. Printed verbatim transcripts provided the major portion of collected data.

3.9 Description of Activity

The study is qualitative design based on a combination of the work by Gunstone and White (1980), Biddulph and Osborne (1984) and Freyberg and Osborne (1985). Gunstone and White utilize *Predict-Observe-Explain*, in which a student is presented with a physical situation and asked to predict what would happen when a change is made; observe any changes; and to explain what happened. *Viewfinders*, characterized by Biddulph and Osborne, are questions and statements used to probe students' meanings for words. The researcher does not seek the right answer but asks a genuine question to determine student thinking. Freyberg and Osborne's technique, *Interview-about-Instances*, was employed to explore science concepts mentioned by the students.

3.10 Data Processing and Analysis

A series of steps were required to process the data. The Interviewer's and Students' comments were transcribed and from the transcripts a summary of student actions and explanations was produced. These summaries were called vignettes.

Each vignette was then analyzed to identify:

i) student theories using Frazier's typology;

ii) commonly held theories, across all three dyads;

iii) unique theories; and

iv) frequency of theory use by event and overall.

3.10.1 Transcription

All of the spoken words of each student and the researcher were transcribed. The actions of the participants were described to support the utterances. The transcripts showed the various events of the study. Materials used by the students were assigned numbers in order to track their usage through the experiments. To ensure confidentiality of the students, their names were replaced with pseudonyms.

3.10.2 Frazier's Theories

Frazier (1995) described a range of five possible theories of how the Cartesian Diver works. His five theories are: 1) Heaviness theory; 2) Air theory; 3) Pressure-current theory; 4) Pressure-force theory; and 5) Volume-displacement theory. Frazier's theories reflect experimentation with a typical Cartesian Diver. Based on the pilot studies, a sixth theory, Shape-of-the-Bottle, was added to the list. Detailed descriptions of the six theories are presented in Table 1. The students' theories were identified using Frazier's typology.

Table 1.

Frazier's Theories (1995)

The Heaviness Theory: Squeezing the bottle forces water into the diver. More water makes the diver heavier and causes it to sink. Releasing the bottle allows the compressed air trapped in the diver to push the excess water out. The diver becomes light enough to float again.

The Air Theory: Air makes things float. When the air by volume of an object is reduced to a certain point, there's not enough air to hold the object up and the object sinks. The diver works because squeezing the bottle compresses the air to the point where it cannot hold up the diver. When the bottle is released, the air expands again to the point where it can hold the diver up.

The Pressure-Current Theory: Squeezing the bottle puts pressure on the water inside. The water tries to go up out of the mouth of the bottle. This can be seen when squeezing the bottle without a lid. When the lid is on, the water rebounds and carries the diver down. Releasing the bottle reverses this current.

The Pressure-Force Theory: Squeezing the bottle puts pressure on the water inside. Because the force of squeezing cannot move the water since it is enclosed, the force is transmitted to the diver and pushes it down. This transmitted force disappears when the squeezing stops and the diver returns to a floating position.

The Volume-Displacement Theory: Floating and sinking involves a relationship between the weight of an object and the weight of the water it displaces. For floaters, the weight of the floating object is equal to the weight of the water displaced. For sinkers, the weight of the sinking object is greater than the weight of the water displaced. The diver uses the pressure to cause different amounts of water to be displaced and thus change back and forth from being a floater to a sinker. The different amounts of displaced water seem to go in and out of the diver.

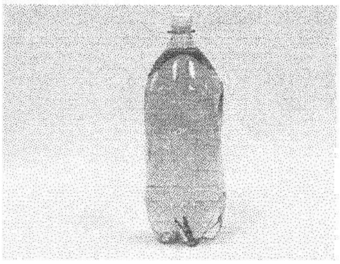
Shape-of-the-Bottle Theory: The shape of the bottle will affect the diver. A circular bottle will cause the diver to sink. A rectangular bottle is necessary to cause the diver to rise.

3.11 The Cartesian Diver

A variety of materials was used in this study and are illustrated with their uses in the four events. Finally, the commonly accepted explanation for the behaviour of the Cartesian Diver is given for both the Cartesian Diver and the Discrepant Cartesian Diver.

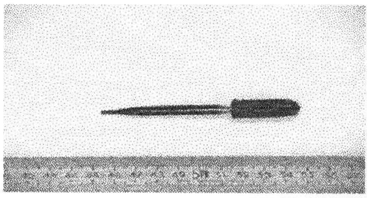
3.11.1 Materials

Figure 6. Pop Bottle



a) Two-litre Polycarbonate (Poly) “pop bottle” or “the bottle” as coined by the participants (see Figure 6). The two-litre Poly Bottle was used in both the Constructed Cartesian Diver (CCD) and Assembled Cartesian Diver (ACD) experiments. In the CCD experiment, the participants were given a bottle filled with water, while in the ACD experiment an empty bottle was given to the students.

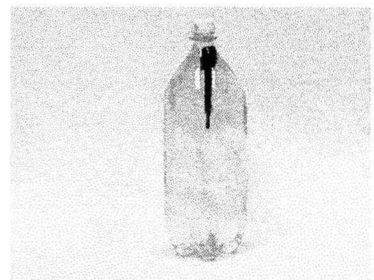
Figure 7. Eye-dropper



b) Five millilitre eye-dropper, or the “eye-dropper” as coined by both the researcher and the participants (see Figure 7). This version has a thick black rubber cap and a clear glass tube. In the Assembled Cartesian Diver experiment, the eye-dropper was filled with an amount of water sufficient for it to float at the surface. In the Constructed Cartesian Diver experiment, the participants were given an array of eye-droppers with varying amounts of water. In the Assembled Discrepant Cartesian Diver (ADCD), two eye-droppers were added to the bottle. One was filled with an amount of water sufficient for it to float at the surface; the other was filled with an amount of water sufficient for the eye-dropper to rest on the bottom in a vertical position. In the Constructed Discrepant Cartesian Diver (CDCD) experiment, the participants were given an array of eye-droppers with varying amounts of water.

c) The Constructed Cartesian Diver, combining the two-litre pop bottle with water and the eye-dropper (see Figure 8).

Figure 8. Constructed Cartesian Diver

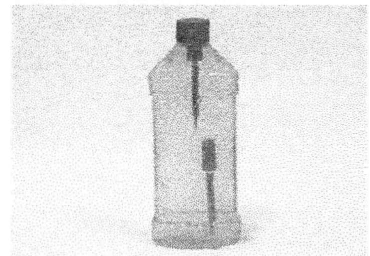


d) A 550 ml bottle made for the Murphy Phoenix Company, Beachwood Ohio (see Figure 9). The Murphy Oil Soap Bottle or the "rectangular bottle" with "sides" and "edges", was used in the Assembled Discrepant Cartesian Diver (ADCD) and Constructed Discrepant Cartesian Diver (CDCD). In the CDCD, the bottle was filled with water, while the bottle for the ADCD was empty.

Figure 9. Rectangular Bottle

e) The Constructed Discrepant Cartesian Diver combining the 550 ml Murphy Oil Soap bottle and the two eye-droppers (see Figure 10).

Figure 10. Discrepant Cartesian Diver



3.11.2 Explaining the Cartesian Diver

The Cartesian Diver is a closed system in which an open-ended eye-dropper floats in a flexible cylindrical container filled with water. The eye-dropper contains a sufficient amount of air and water for it to float vertically at the surface. Pressure applied to the capped, flexible container causes the container to decrease in volume. The volume decrease forces the water into eye-dropper compressing the air inside the diver. The reduction in the volume of air and the weight of the added water causes the eye-dropper to sink to the bottom of the bottle. Releasing the bottle increases the volume of the bottle, reversing the process, resulting in the eye-dropper returning to the surface.

The Discrepant Cartesian Diver is a closed system containing two open-ended eye-droppers, one floating at the surface the other resting on the bottom, in a flexible rectangular or oval shaped container filled with water. The eye-dropper at the surface contains sufficient amount of air and water for it to float vertically. The eye-dropper resting on the bottom contains a sufficient amount of air and water to cause it to rest in a vertical position on the bottom. Pressure applied to the sides of the capped, flexible container produces a Cartesian Diver with the floating eye-dropper sinking to the bottom. Pressure applied to the edges of the flexible container causes the container to increase in volume. The volume increase causes the water to exit the eye-droppers, and the air inside expands. The increase in the volume of air and the reduction in the water and its weight causes the eye-dropper resting on the bottom to float to the surface. Releasing the container decreases the volume of the bottle, reversing the process, resulting in the eye-dropper returning to the bottom.

3.12 Outline of the Remainder of the Thesis

This chapter introduced the research methodology. Chapter IV presents the data in the form of vignettes. Each vignette presents the:

- student actions and explanations as they worked through the four events[1] in the study,
- student explanations held in common with Frazier's Theories.

Chapter V presents a discussion of the data, implications for teaching and suggestions for further research. The data is discussed from two perspectives.

1. Events:

- frequency of theories per event;
- commonly held theories; and
- theories not commonly shared.

2. Findings based on dyad:

- students hold theories in common;
- students hold multiple theories simultaneously;
- student's theories remain unaffected through experimentation; and
- student's theories are both similar and different from the accepted scientific theory.

[1] The Assembled Cartesian Diver (ACD), Constructed Cartesian Diver (CCD), Assembled Discrepant Cartesian Diver (ADCD), and Constructed Discrepant Cartesian Diver (CDCD).

CHAPTER IV

Student - Actions and Theories

4.1 Introduction

In this chapter the three dyads' explanations are presented and categorized according to Frazier's theories presented in Chapter III (see Table 1). Each dyad's ideas are organized under the events of the study: the Assembled Cartesian Diver; Constructed Cartesian Diver; Assembled Discrepant Cartesian Diver; and Constructed Discrepant Cartesian Diver. While each event represents a distinct phase in the study they can be viewed as parts of a whole; the examination of the behaviour of the Cartesian Diver.

Three vignettes are presented in this thesis to show the richness of student responses. Each vignette is divided into Actions and Theories. There is much that is similar in the vignettes and some things which are different. The representations in the vignettes lead to the findings presented in the latter part of the document.

Actions are the events and findings of each dyad, depicting their physical actions and oral explanations. Quotation marks are used to designate actual student comments. Physical actions are included to reflect the flavour of the experiments.

Under the Theories, the students' findings are categorized in terms of one of Frazier's six theories as outlined in Chapter III (see Table 1). While the students voiced many ideas which could be called theories, those explanations which were held in common with the six existing theories are identified and named. The theories are shown in the sequence they were mentioned by students.

Following the categorizing of their explanations, each dyad's theories are charted (see Tables 2-4). These charts are used in three ways to: i) provide a graphical link with written material; ii) describe the students' findings; and iii) summarize the students' theories.

4.2 Vignette 1 - Steven and Michele

(see Appendix B for a complete transcript)

4.2.1 Assembled Cartesian Diver - Actions

The participants, Steven and Michele, described what they saw; water and an eye-dropper. The researcher asked them to move the eye-dropper. Michele turned the bottle in her hands and found that the eye-dropper would not move. She explained that the eye-dropper was being held by "some kind of force".

The researcher asked them if it was possible to get the eye-dropper to the bottom of the bottle. They thought that the eye-dropper was too light, and the only way to get the eye-dropper to the bottom was to invert the bottle. They inverted the bottle and realized as the eye-dropper floated to the surface, that they had exchanged the bottom of the bottle for the top. Steven proposed shaking the bottle until a whirlpool was formed. He believed that the whirlpool would cause the eye-dropper to spin to the bottom. The researcher acknowledged this great idea and prompted the participants to find a simpler way to get the eye-dropper to the bottom of the bottle.

The researcher noticed that Michele squeezed the bottle, with no effect on the eye-dropper, and encouraged her to squeeze harder. When Michele squeezed harder the eye-dropper sank to the bottom and then rose to the surface. The researcher asked why squeezing the bottle caused the eye-dropper to sink. Steven responded that if the sides of the bottle went in, it would cause less space in the middle and top of the bottle, and the pressure would force the eye-dropper to the bottom. He supported his idea by demonstrating that the water level at the top of the bottle rose as he squeezed the bottle.

The researcher asked whether the water did rise in the bottle. Further squeezing did not result in a consensus on whether the water level changed as the bottle was squeezed. However, the students concluded that the water level in the eye-dropper did rise when the bottle was squeezed. Steven came to the conclusion that as the water entered the eye-dropper it weighed down the eye-dropper causing it to sink.

4.2.2 Assembled Cartesian Diver - Theories

Steven and Michele used two theories to explain the Assembled Cartesian Diver. The first theory identified was the Pressure-Force Theory. Steven explained that if the sides of the bottle went in, it would cause less space in the middle and top of the bottle and the pressure would force the eye-dropper to the bottom. This theory was supported by observing the water level rising as the bottle was squeezed.

As the experimentation continued the participants were unsure as to whether the water in the bottle did rise. However, they noted that the water level in the eye-dropper rose when the bottle was squeezed. Steven was unable to explain this event, but said that as the water entered the eye-dropper it became heavier and so caused it to sink (Heaviness Theory).

4.2.3 Constructed Cartesian Diver - Actions

At this point the researcher asked the participants to produce a Constructed Cartesian Diver. Steven and Michele were given a 2-litre plastic pop bottle and a number of eye-droppers. At first they wondered how much water should be added to the bottle. They agreed to add the same amount of water found in the Assembled Cartesian Diver. The first eye-dropper placed in the bottle did not contain water. The eye-dropper floated and became stuck in a diagonal position. Steven and Michele could not explain this behaviour. Three additional eye-droppers containing some water where put into the bottle bringing the total to four. Upon squeezing, two of the eye-droppers sank to the bottom. A harder squeeze resulted in three of the four eye-droppers sinking to the bottom. The fact that one eye-dropper did not sink was attributed to the location of the squeeze. Squeezing on one side caused most of the eye-droppers to sink to the bottom. Squeezing on another side forced some of the other eye-droppers to the bottom.

Both participants squeezed the top of the bottle and the researcher asked for an explanation. They responded that all the eye-droppers were "squashed together" and squeezing the bottle at the top would "get them to move". As they squeezed, Steven and Michele noticed that one of the eye-droppers failed to return to the surface. Steven suggested that the eye-dropper was too full of water, and it stuck to the bottom the same way a glass sticks when all when all the air has been "sucked out". When Steven picked up the bottle and inverted it he noticed that the eye-dropper was not stuck to the bottle, but it was full of water. He also noticed that the eye-dropper that did not sink was full of air. Michele suggested removing the eye-dropper to ensure the other eye-droppers in the bottle would sink. Neither of the participants was able to successfully extract the floating eye-dropper. They continued squeezing the bottle and one of the eye-droppers remained at the water's surface. Steven observed that when the bottle was squeezed the water level rose and when released, the water went down, but the eye-dropper remained stuck in a diagonal position.

After a number of attempts, one of the eye-droppers was successfully removed and replaced. Without replacing the cap, the bottle was squeezed. The participants noticed that eye-droppers rose with the water level as the bottle was squeezed. Steven explained that with the lid off, the air pressure inside the bottle was released.

The floating eye-dropper was removed and re-inserted upside-down. Again the eye-dropper failed to sink when the bottle was squeezed. Steven commented that the eye-dropper "liked to stay by the air pressure" when the cap was on. The problematic eye-dropper was removed and filled with water. While filling the eye-droppers both participants thought there was something wrong with one eye-dropper as it was difficult to fill. The eye-dropper was finally filled to an acceptable level and returned to the bottle.

Once more the eye-dropper resting on the bottom became the centre of debate. Steven explained that the eye-dropper was completely full and it could not release the water because it lacked "air pressure".

4.2.4 Constructed Cartesian Diver - Theories

At this point the researcher introduced the Constructed Cartesian Diver. The first theory to be used by Steven and Michele evolved through the use of four eye-droppers in one bottle. All of the eye-droppers contained varying amounts of water. When the bottle was initially squeezed only two of the eye-droppers sank. A second harder squeeze caused three eye-droppers to sink to the bottom. The participants attributed this discrepancy to the squeezing location. The location of the squeeze (Pressure-Force) determined the number of eye-droppers that would sink to the bottom.

The students' second theory was the Air Theory. The Air Theory evolved over time. Steven first commented that one of the four eye-droppers was full of air, and the air prevented it from sinking. Further experimentation with the bottle cap removed led the participants to comment that the eye-droppers rose with the water level when the bottle was squeezed. Steven explained that with the cap off, the air inside the bottle was released.

The participants turned their attention to the eye-droppers and focused on the one resting on the bottom and the one that did not sink. They explained that the eye-dropper resting on the bottom could not release the water because it lacked sufficient air pressure. Steven and Michele stated that the floating eye-dropper "preferred to stay by the air pressure" when the cap was on.

4.2.5 Assembled Discrepant Cartesian Diver - Actions

At this point the researcher introduced the Assembled Discrepant Cartesian Diver. The participants described what they saw, water and two eye-droppers. One of the eye-droppers was "stuck" to the bottom, and the other remained at the top. They observed that the eye-dropper resting on the bottom had more water in it than the one resting at the surface. The researcher challenged the participants to get both of the eye-droppers to the bottom of the bottle and to remain there. They responded by squeezing the sides of the bottle resulting in both eye-droppers resting on the bottom. The researcher challenged the participants to get both of the eye-droppers to the top. Michele responded by squeezing the top edge of the bottle with no apparent affect on the eye-droppers. They explained that the eye-dropper did not rise to the surface because of a lack of "air pressure" in it. An absence of air at the "top of the bottle prevented the eye-dropper from rising". Steven suggested squeezing the edge of the bottle. The first attempt resulted in the eye-dropper resting on the bottom, rising slightly. The researcher asked the participants to be patient and try squeezing the edges again. Michele squeezed the bottle which did not change the position of the eye-droppers. Steven thought the eye-dropper's lack of movement was linked to air pressure.

Steven picked up the bottle and inverted it. He noticed that when he turned the bottle upside-down the eye-droppers exchanged positions. As the bottle was up-righted, one of the eye-droppers became lodged diagonally. Steven tapped the bottle, and the eye-dropper was successfully dislodged. Once again the bottle was inverted. Through the inverting and up-righting of the bottle both eye-droppers became inverted in the bottle and floated at the surface. The participants were told that the eye-dropper must float at the surface. Both of the eye-droppers were removed and re-inserted in their upright positions. The participants thought there might be too much water in the bottle. Some water was removed and the bottle squeezed. Once again the eye-droppers failed to float at the surface. The researcher asked the participants to find a way to get both of the eye-droppers to the surface by squeezing. Steven picked up, inverted, and squeezed the bottle. As the bottle was squeezed one of the eye-droppers expelled some air. The bottle was up-righted, and the once floating eye-dropper now rested on the bottom. Steven suggested filling the bottle with more water. After filling, the bottle was squeezed resulting in no observable movement of the eye-droppers. A close examination of the eye-dropper that once floated on the surface revealed that it was "full of something". The participants could not agree on whether it was full of water or air. Both participants wondered if the eye-dropper was broken.

The researcher pointed out that squeezing would work and encouraged the participants to continue squeezing. Steven squeezed the bottle very hard with no apparent change in the eye-droppers. The bottle was emptied and the bottle itself was closely examined. The participants examined the bottle looking for "anything peculiar inside". The bottle was found to have a concave bottom.

4.2.6 Assembled Discrepant Cartesian Diver - Theories

The bottle was filled and the participants were presented with an Assembled Discrepant Cartesian Diver. The presence of two eye-droppers in the bottle, one floating at the surface the other resting on the bottom, was similar to the ACD and so used the Air Theory. However, when the sides of the bottle were squeezed there was no apparent effect on the eye-dropper resting on the bottom. The participants explained that the sunken eye-dropper did not rise because it "lacked" air pressure. Also, there was an absence of air at the top of the bottle which prevented the eye-dropper from rising. Squeezing the edges of the bottle caused a slight upward movement of the eye-dropper resting on the bottom. The fact that it did not rise to the surface was attributed to the air pressure. To increase the air pressure in the bottle, they removed some of the water.

4.2.7 Constructed Discrepant Cartesian Diver - Actions

The researcher continued the challenge of getting both eye-droppers to the surface. Michele squeezed the side of the bottle which failed to cause the eye-dropper, resting on the bottom, to rise. She squeezed the edges of the bottle, and this produced a slight rise. Steven duplicated this action and successfully caused the eye-dropper to rise to the surface.

The researcher asked the participants to explain why the eye-dropper rose to the surface when the edges of the bottle were squeezed. Steven observed that the eye-dropper resting on the bottom was completely full of water and the other eye-dropper had a "bit of air space in it". Michele explained that pressure caused the water in the eye-dropper to come out. Steven added that the pressure came from squeezing. Further manipulations of the bottle resulted in the observation that when the sides of the bottle were pressed the eye-dropper sank, and as soon as the water level in the eye-dropper fell the eye-dropper rose to the surface. When the edge of the bottle was pressed the water level went down.

The researcher encouraged the participants to explain the eye-dropper's behaviour. Steven attributed the eye-dropper's behaviour to the "pressure". If pressure is applied below the eye-dropper the "pressure will push it up". Meanwhile, Michele thought "the eye-droppers go the way the water goes". She stated that in situations where the eye-dropper behaved in a contradictory manner the eye-dropper "goes the opposite way of the water". The researcher asked the participants if the water could go up when the cap was on. Both Steven and Michele answered no because there was not enough space at the top.

They experimented with the cap off the bottle and discovered that the water would rise when the bottle was squeezed. The cap was replaced and the participants squeezed the sides of the bottle. Both noticed the water level rose in the eye-dropper. When the edges of the bottle were squeezed both noticed that the water level inside the eye-dropper fell. The falling water level was thought to give the eye-dropper less weight, "water is going down so it's pushing the water inside the eye-dropper".

Michele summarized that weight was involved in the rising and falling of the eye-droppers. The researcher asked why the water went in and out of the eye-dropper. Steven replied that it was air pressure. Air pressure made the eye-dropper lighter, but when the water went in it made the dropper heavier. The participants filled the bottle so that the only air present was in the eye-droppers. Squeezing the bottle without the cap resulted in the floating eye-dropper rising and falling with the water surface. The eye-dropper resting on the bottom did not move. This behaviour was noticed by Steven, and he explained that the floating eye-dropper rose with the water level, and the eye-dropper resting on the bottom "has to be removed and all the air taken out". The researcher prompted them to squeeze the edges of the bottle. This resulted in both eye-droppers floating at the surface.

The participants asked the researcher to explain the behaviour of the Diver. The researcher asked them to remove the cap and squeeze the edges of the bottle. Steven and Michele took turns squeezing the edges of the bottle and then they were asked to fill the bottle and cap it. The participants found the bottle easier to squeeze. Steven removed the cap on the bottle and wondered why water came out. Michele explained that the water was "squished down" to the bottom as more water was added, and when the cap was removed that water came out. Steven explained that the "plastic" used in the bottle's construction stretched, and when the cap was removed the bottle returned to its original size.

The researcher asked the participants if a round (2 litre) plastic pop bottle could cause the eye-droppers to behave in the same manner as those found in the rectangular bottle. Steven thought that it might not be possible because the "rectangular" bottle was made of a "thicker plastic". The participants filled the pop bottle. The researcher asked them to squeeze the sides in order to add more water. The participants thought this was not possible because the pop bottle "did not have any sides". Steven explained that when the sides of the pop bottle were squeezed the sides went straight in, when the edges of the rectangular bottle were squeezed the bottle became wider. The researcher asked Steven and Michele to pour some of the water out of the pop bottle and squeeze the sides to make the bottle rectangular. While squeezing, two eye-droppers were added and the bottle capped. Both eye-droppers were floated. The researcher asked for the cap to be removed. As the cap was removed one of the eye-droppers sank and rested on the bottom. The sinking of the eye-dropper was attributed to the bottle not being completely filled when the sides of the cylindrical bottle was pressed together. The researcher asked if this explanation was similar to that of the rectangular bottle. The question went unanswered as the participants returned to the rectangular bottle.

Two empty eye-droppers were added to the rectangular bottle. Both floated and Steven explained that the bottle was filled to the top, and there was more air in the eye-droppers. A full bottle produced insufficient air pressure to force them to the bottom. To prove this Steven removed some of the water from the bottle and replaced the cap. A hard squeeze did not produce the desired results. The air pressure at the top of the bottle was identified as the reason.

The researcher asked the participants to summarize their findings. They claimed that when the sides of the bottle were squeezed there was pressure from the sides, and the "water has no where to go so it goes up into the eye-dropper". When the edges of the bottle were squeezed it put pressure on the cap, releasing the water in the eye-dropper.

4.2.8 Constructed Discrepant Cartesian Diver - Theories

Their first theory, based upon comparing the eye-dropper resting on the bottom to the eye-dropper floating at the surface, was the Pressure-Force Theory. "Pressure" was thought to cause the water in the eye-dropper to flow out. The Pressure-Force Theory led to the Heaviness Theory. The participants noticed that when the water level fell the sinking eye-dropper started to rise. Further encouragement by the researcher resulted in the participants diverging in their descriptions. Steven continued with the Pressure-Force Theory. "Pressure will push it up" if the bottle is squeezed below the eye-dropper. Meanwhile, Michele used the Pressure-Current Theory in her description as the eye-droppers were thought to "go the way the water goes". In situations when the eye-droppers behaved in a contradictory manner, Michele responded that the eye-dropper "goes the opposite way of the water".

Further experimentation and observation led Steven and Michele to agree that when the bottle was squeezed the water level inside the eye-dropper fell. The falling water level was thought to give the eye-dropper less weight (Heaviness Theory). Steven explained that air pressure "made the eye-dropper lighter" (Air Theory). He continued by commenting that when the water entered the eye-dropper "it made it heavier" (Heaviness Theory).

The Shape-of-the-Bottle Theory was used in their discussion about the differences in the round and rectangular bottles and their effect on the eye-droppers. Steven found that when the sides of the round bottle where squeezed the sides go straight in, while when the edges of the rectangular bottle were squeezed the bottle becomes bigger.

The aspects of the Air Theory were employed to explain discrepancies that occurred in the experimentation period. When two eye-droppers were added to the rectangular bottle both floated. A filled bottle was thought to produce insufficient air pressure to push the eye-droppers to the bottom.

Table 2.

Steven and Michele's Theories - All Events

Assembled Cartesian Diver

Pressure-Force Theory

Heaviness Theory

Constructed Cartesian Diver

Pressure-Force Theory

Air Theory

Assembled Discrepant Cartesian Diver

Air Theory

Constructed Discrepant Cartesian Diver

Pressure-Force Theory

Heaviness Theory

Pressure-Force Theory

Pressure-Current Theory

Air Theory

Heaviness Theory

Shape-of-the-Bottle Theory

Air Theory

4.3 Vignette 2 - Barbara and Jessica

4.3.1 Assembled Cartesian Diver - Actions

The participants, Barbara and Jessica, described what they saw; a liquid and an eye-dropper. They found it difficult to identify the liquid. They proposed drinking it because it looked like water but then rejected this course of action because of the potential danger. The participants inferred that the eye-dropper contained the same liquid as the bottle. They concluded that the liquids were the same because there were air bubbles on the inside of the bottle and on the eye-dropper. The eye-dropper was closely examined and observed to be partially full of a liquid within one inch of the top. They thought that there were two or three liquids in the eye-dropper. They described a method of placing a liquid of another type in the eye-dropper and adding it to the bottle. The participants believed this would work because they thought the only way to fill an eye-dropper was to squeeze the bulb. The researcher asked the participants to squeeze the bottle. As the bottle was squeezed the eye-dropper filled. The liquid was identified as water because it went up into the eye-dropper.

The researcher asked the participants to squeeze the bottle even harder which resulted in the eye-dropper sinking to the bottom. The participants noted that if one squeezed hard enough, the eye-dropper would sink to the bottom. They believed that the eye-dropper sank because "it could not fill up". They thought that the weight of the water in the eye-dropper caused it to sink and squeezing the bottle, "above or below the eye-dropper, forced the eye-dropper down". The researcher asked if they exerted the same force when they squeezed from the bottom and the top of the bottle. The participants thought it would be harder to squeeze from the top. They squeezed the bottle in different places, observed the results, and abandoned their earlier explanation. The "pressure" was used as the explanation for the eye-dropper's action. They thought that pressure originated from the sides and pushed the eye-dropper down. At this point Barbara and Jessica proposed to construct their own diver. They identified two variables, "shape and size of the bottle", as determinates of the eyedropper's behaviour.

4.3.2 Assembled Cartesian Diver - Theories

The students initially used the Heaviness Theory as they attributed the eye-dropper's sinking to the weight of the water in the eye-dropper. Following the Heaviness Theory they proposed the Pressure-Force Theory. They thought that squeezing anywhere on the bottle caused the eye-dropper to sink.

4.3.3 Constructed Cartesian Diver - Actions

Barbara and Jessica were given a range of bottles from which to choose. They selected a tall skinny bottle with a rectangular shape. As they filled the bottle they suggested that the water level should be the same as the Assembled Cartesian Diver. An eye-dropper without any water was selected, placed in the bottle, and the bottle was squeezed. They noted that the eye-dropper did not fill with water. A second eye-dropper containing some water was selected and placed in the bottle. They now found the bottle very hard to squeeze. The participants compared the height of the water in the eye-dropper with the height of the eye-dropper found in the Assembled Cartesian Diver. Jessica thought it was due to the "pressure of the water going up", "the water went up into the eye-dropper because it needed more room".

To confirm this explanation, the participants unscrewed the bottle cap and removed the eye-dropper and replaced the cap. Before squeezing the bottle, they thought it would be difficult to measure any changes in the bottle's water level. The researcher suggested removal of the eye-dropper in the Assembled Cartesian Diver. When the Assembled Cartesian Diver was squeezed, a slight change in the water level was observed. They concluded that the water level in the Assembled Cartesian Diver without an eye-dropper did not change when squeezed. When the Constructed Cartesian Diver containing an eye-dropper was squeezed, a change in the water level was observed. Barbara suggested that they squeeze the bottle with the cap removed. They predicted that the water would go up but only into the eye-dropper. When the experiment resulted in the water not going up into the eye-dropper the students concluded that the air inside the bottle blocked the water's movement. There was a smaller amount of air in the eye-dropper that enabled the water to flow into it. An additional explanation for the change in water level stated that an eye-dropper had an open end and the bottle was capped.

4.3.4 Constructed Cartesian Diver - Theories

The Pressure-Force Theory was used in the explanation of the eye-droppers' behaviour. The change in the eye-droppers' water level was attributed to the pressure. Further experimentation led them to believe that the air blocked the water's movement inside the eye-dropper. They concluded that the water was unable to get into the eye-dropper unless the air inside was reduced (Air Theory).

4.3.5 Assembled Discrepant Cartesian Diver - Actions

Barbara and Jessica described what they saw: one eye-dropper floating on the surface of the water and one resting on the bottom. The researcher asked them to predict what would happen when the bottle was squeezed. They predicted that one eye-dropper would rise, and the other would sink. When the bottle was squeezed the floating eye-dropper sank alongside the other eye-dropper. They explained that the eye-dropper did not rise to the surface because it contained more water than the floating eye-dropper. They squeezed the bottle again and noted that the water level in the eye-dropper at the bottom of the bottle changed when the bottle was squeezed. In contrast to the water level in the floating eye-dropper, they noted that the water level in the sunken eye-dropper did not reach the cap of the eye-dropper.

The researcher challenged the participants to get both eye-droppers to the surface by squeezing the bottle. They responded by squeezing the bottle in three different locations. The sunken eye-dropper became the focal point of further inquiry. They felt that it was harder to squeeze the water into the eye-dropper resting on the bottom than into the floating eye-dropper. The participants wondered how the eye-dropper was placed in the bottle, and if it were filled prior to or after placement. The participants proposed that when the eye-dropper was placed at the bottom of the bottle a "suction was formed as the bottle was filled with water". When the bottle was picked up and moved around, they realized that the eye-dropper was not stuck to the bottom. They then suggested that the sunken eye-dropper was placed in the bottle first, water was added, and then the floating eye-dropper was inserted. The researcher asked the participants to try this procedure and make their own Discrepant Cartesian Diver.

4.3.6 Assembled Discrepant Cartesian Diver - Theories

The participants used the Heaviness Theory as they compared the eye-dropper that sank with the eye-dropper that remained on the bottom. They found the water level in the eye-dropper which sank rose, while the water level in the other eye-dropper rose slightly.

4.3.7 Constructed Discrepant Cartesian Diver - Actions

Barbara and Jessica were given an empty bottle the same shape as the Assembled Discrepant Cartesian Diver and eye-droppers containing some water. They selected an eye-dropper that appeared to contain the same amount of water found in the eye-dropper resting on the bottom of the Assembled Discrepant Cartesian Diver. The eye-dropper was added to the bottle. While filling the Constructed Discrepant Cartesian Diver with water, they observed that the eye-dropper would not rest on the bottom. One of the participants thought that "things" floated in water, but "this eye-dropper did not float". The eye-dropper in the bottle was retrieved. The participants removed the cap and filled it with water as they thought it would make the eye-dropper heavier.

The researcher asked the participants to compare the eye-dropper that rested on the bottom with an empty one. They placed both eye-droppers in the rectangular bottle and added water. While filling the bottle the researcher asked if the shape of the bottle made a difference in the eye-dropper's behaviour. The participants thought the behaviour could be affected. To confirm this the eye-droppers were removed, emptied, filled with an amount of water and added to the bottle. Both eye-droppers floated on the surface. The bottle was squeezed, and both divers sank and rested on the bottom. When released, both divers rose to the surface. The participants concluded that squeezing the bottle at the same location as the Assembled Discrepant Cartesian Diver would produce similar results.

The researcher asked the participants what would happen if one of the eye-droppers were completely filled with water. They predicted that the eye-dropper would be heavier as water would be pushed up until the eye-dropper was full due to "the lack of air". One eye-dropper was filled with water and dropped into the bottle. It rested on the bottom. The participants attributed the behaviour of the eye-dropper to air. They determined that air must be present in the eye-dropper for it to float and absent for it to sink. The researcher asked the participants to get both eye-droppers to the surface by squeezing. Barbara proposed squeezing the bottle in a "special place". Squeezing the bottom of the rectangular bottle would exert pressure on the eye-dropper resting on the bottom causing it to surface. This explanation contradicted the earlier explanation that if the water went up into the eye-dropper, it would make it heavier and sink. Up until this point the participants squeezed the rectangular bottle on the flattened sides. One of the participants attempted to squeeze the bottle on the edges. This caused the resting eye-dropper to rise to the surface.

The participants summarized their findings; the eye-dropper's behaviour was related to where the bottle was squeezed. When the flat side of the rectangular bottle was squeezed, the water went up into the eye-dropper making it heavier and causing the floating diver to sink and rest on the bottom. Squeezing the edges of the rectangular bottle resulted in less water being present in the eye-dropper resting on the bottom allowing it to rise to the surface. They also explained that when one squeezed the edges of the bottle, the pressure caused the eye-dropper to surface. Releasing their grip caused the pressure to force the eye-dropper to rest on the bottom. The researcher asked the participants if the eye-droppers would behave in a similar manner in the round bottle. The participants responded that a "round bottle does not have two sides". Therefore, a rectangular shaped bottle was preferable for a discrepant diver. Squeezing any area on a rounded bottle caused the water to rise. A rectangular shaped bottle was different because all the pressure "went up". They summarized that the variables involved were the "water and the air". When the water level in a floating eye-dropper rose, the eye-dropper sank. When the water level in an eye-dropper resting on the bottom went down, the eye-dropper became lighter allowing it to rise to the surface. Barbara still questionned the shape of the bottle used in a Discrepant Cartesian Diver because when the rectangular bottle was squeezed, it became circular. A circular shape was important as it enabled the eye-droppers to float. They again summarized; the variables involved were the "pressure of the water, the shape of the bottle, and the amount of water in the eye-droppers".

At this point Barbara continued to think that they had not sufficiently figured out why it had to be a different side of the rectangular bottle. When the flat sides of the bottle were squeezed, "why did the eye-dropper sink and rest on the bottom"? When the edges were squeezed, "why did the eye-dropper rise to the surface"? Jessica explained that it was the pressure; "it just comes up". When the water entered the eye-dropper, it became heavier and sank. When the rectangular bottle was squeezed on the edges, the pressure of the water came up and "grabbed" the eye-dropper bringing it to the top. Barbara questioned this explanation. She thought that the pressure would be the same regardless of where the bottle was squeezed. Jessica responded to the challenge by explaining that it was "not possible to see" what took place due to the "water". The participants concluded that the shape of the bottle was not a factor in the sinking of the eye-droppers, but only a "special kind" of bottle caused the eye-droppers to rise to the surface. The participants summarized; the variables were the "size, pressure, water, air, shape, and the sides". At this point the interview was concluded and the participants were complimented on their explanations.

4.3.8 Constructed Discrepant Cartesian Diver - Theories

Barbara and Jessica examined ways to make an eye-dropper heavier and concluded that filling the cap of the eye-dropper with water would make it sink (Heaviness Theory). They commented that water would be pushed up into the eye-dropper due to a lack of air. They concluded that air must be present in the eye-dropper for it to float and absent for it to sink (Air Theory).

The participants were asked to get both eye-droppers to the surface by squeezing. Barbara proposed squeezing the bottom of the bottle. She thought that this would exert pressure on the eye-dropper and force it to the surface (Pressure-Force Theory). While trying to summarize the eye-droppers' behaviour in relation to the point of squeezing, Barbara and Jessica explained the eye-droppers' behaviour in relation to the amount of water in the eye-droppers. As the water filled the eye-dropper, the eye-dropper became heavier causing it to sink to the bottom (Heaviness Theory). While squeezing the edges of the bottle, water left the eye-dropper allowing it to become lighter and rising to the surface.

The Pressure-Force Theory was how the participants explained why the eye-dropper rose to the surface. By squeezing the edges of the bottle, the pressure caused the eye-dropper resting on the bottom to rise. By releasing the edges of the rectangular, the pressure caused the eye-dropper resting on the bottom to remain on the bottom. While squeezing the edges of the bottle, the participants were asked if the eye-dropper would behave in the same manner if the bottle were rounded. The Shape-of-the-Bottle became the focus of the discussion. A rounded bottle was said to have no sides, and a rounded bottle could only cause an eye-dropper to rise. A rectangular bottle was thought to be different because all the pressure "went up" (Pressure-Force Theory).

To explain the difference in the behaviour of the eye-droppers as they rose and sank in the rectangular bottle, Barbara and Jessica used the Heaviness Theory. They found that as the water level in the floating eye-dropper rose, the eye-dropper sank. When the water level in the eye-dropper resting on the bottom fell, the eye-dropper became lighter and started to rise. While examining the water level in the eye-droppers, Barbara re-examined the shape of the bottle and concluded that a circular shape was needed for the eye-droppers to float (Shape-of-the-Bottle Theory).

Barbara and Jessica were not finished proving and demonstrating their findings. Jessica continued to squeeze the rectangular bottle and explained that pressure of the water "came up and grabbed the eye-dropper bringing it to the surface" (Pressure-Force Theory). She reasoned that the water entered the eye-dropper and it became heavier (Heaviness Theory). Jessica again returned to the Pressure-Force Theory as she focused on the water grabbing the eye-dropper and bringing it to the surface.

Table 3.

Barbara and Jessica's Theories - All Events

Assembled Cartesian Diver

$\boxed{\text{Heaviness Theory}}$

$\boxed{\text{Pressure-Force Theory}}$

Constructed Cartesian Diver

$\boxed{\text{Pressure-Force Theory}}$

$\boxed{\text{Heaviness Theory}}$

Assembled Discrepant Cartesian Diver

$\boxed{\text{Air Theory}}$

Constructed Discrepant Cartesian Diver

$\boxed{\text{Heaviness Theory}}$

$\boxed{\text{Air Theory}}$

$\boxed{\text{Pressure-Force Theory}}$

$\boxed{\text{Heaviness Theory}}$

$\boxed{\text{Pressure-Force Theory}}$

$\boxed{\text{Shape-of-the-Bottle Theory}}$

$\boxed{\text{Pressure-Force Theory}}$

$\boxed{\text{Heaviness Theory}}$

Table 3.

Barbara and Jessica's Theories - All Events

Constructed Discrepant Cartesian Diver

Pressure-Force Theory
Heaviness Theory
Air Theory

4.4 Vignette 3 - Janet and Wendy

4.4.1 Assembled Cartesian Diver - Actions

The participants, Janet and Wendy, described what they saw; water and an eye-dropper. They reasoned that it was water because it was contained in a plastic pop bottle. The researcher asked the participants to get the eye-dropper to the bottom of the bottle. Janet proposed removing the water from the eye-dropper, "making it go down to the bottom". Wendy suggested putting more water in the eye-dropper "to make it heavy". Shaking and turning the bottle failed to move the eye-dropper and led the participants to believe the eye-dropper was "stuck".

The researcher asked the participants to predict what would happen if the bottle were squeezed. Janet thought the water would go up into the eye-dropper and nothing else would happen. A hard squeeze resulted in the eye-dropper sinking to the bottom. Wendy claimed the reason for the eye-dropper sinking to the bottom was pressure, "pressure from the water".

Squeezing the bottle was thought to make the "area" smaller. A smaller area would put pressure on the water. The researcher asked whether the water level in the bottle went up. Repeated squeezing resulted in the participants concluding that the water level did not change. They concluded that the air pushed the water down, preventing it from rising. Further inquiry by the participants enabled them to conclude that when the bottle was squeezed the air "pushes the water up" and when the bottle was released the air "pushes the water down".

The researcher asked Janet and Wendy to summarize their findings. Janet claimed that when the bottle was squeezed, water entered the eye-dropper. As the water filled the eye-dropper, it became heavier. When the squeezing stopped the water came out because the air was pushing down in the eye-dropper. The researcher asked the participants to construct a Cartesian Diver.

4.4.2 Assembled Cartesian Diver - Theories

After their success in causing the eye-dropper to sink, Wendy claimed the reason for the eye-dropper sinking to the bottom was the pressure (Pressure-Force Theory). The pressure came from squeezing the bottle which made the "area" smaller. The Air Theory was used as they tried to answer a question regarding a possible change in the water level. They concluded that when the bottle was squeezed the air pushed the water into the eye-droppers. Once the squeezing stopped the air pushed the water down.

In summary of their findings, Wendy claimed that as the water entered the eye-dropper, the eye-dropper became heavier. Once the squeezing stopped, the water left the eye-dropper because of the air pushing down (Heaviness Theory).

4.4.3 Constructed Cartesian Diver - Actions

Janet and Wendy were given a 2 litre plastic pop bottle and a number of eye-droppers. At first they filled the bottle to the lip. This was thought to be too much water and some was poured out. Both agreed that the level should be similar to the level in the Assembled Cartesian Diver. The first eye-dropper was filled with an amount of water and dropper into the bottle. Upon squeezing the eye-dropper did not sink to the bottom. Wendy thought the eye-dropper contained too much water. The eye-dropper was removed and some was expelled. Re-inserting the eye-dropper and both participants squeezing resulted in the eye-dropper sinking to the bottom. The researcher commented that both participants had to squeeze the bottle to make the eye-dropper sink. They said that the extra effort was needed because there was “more air”. The researcher asked the participants if they wanted to change the amount of air. Wendy added the water to the bottle claiming that this would “reduce some of the pressure”. Janet thought there was “more water in the eye-dropper”. Despite this view, water was added which enabled the diver to function with only one person squeezing.

To make it easier to squeeze, Wendy proposed adding more water to the bottle. Janet proposed filling the bottle to the lip, eliminating the “air pressure”, so making the bottle even easier to squeeze. Wendy confirmed this by filling the bottle and squeezing. Wendy proposed making it harder by putting more air into the eye-dropper. Adding air to the eye-dropper and squeezing the bottle confirmed this prediction. Janet proposed making the bottle easier to squeeze by adding more water to the eye-dropper. Janet predicted and confirmed that a water-filled eye-dropper would “sink down”.

The researcher asked them to summarize when was hardest and when was it easiest to make the eye-dropper sink. Wendy concluded that it was hardest with more air in the bottle and easiest with the whole bottle and the eye-dropper completely filled with water.

4.4.4 Constructed Cartesian Diver - Theories

While constructing their own Cartesian Diver, Janet and Wendy experimented with two variables, in the bottle and the eye-dropper. While they did not use any of the six theories, they did investigate the amount of air and water necessary to ensure that the bottle squeezed easily.

4.4.5 Assembled Discrepant Cartesian Diver - Actions

The participants described what they saw; one eye-dropper at the bottom, one at the surface. The eye-dropper resting on the bottom was thought to be filled with water. The eye-dropper resting at the surface was thought to be filled with some water. The researcher asked the participants to get the eye-droppers to the bottom. After completing the task, by squeezing the sides, the participants were asked to explain the sinking of the diver. Janet thought the air inside the bottle pushed down on the eye-dropper when squeezed. Wendy proposed that water was pushed into the eye-dropper making it "heavier".

The researcher asked the participants to get both eye-droppers to the top. Wendy squeezed the edges of the rectangular bottle and made both eye-droppers rise to the top. Janet explained that when you squeeze the edges of the bottle the water "gets out of the eye-dropper", "the air is pushing it out". The researcher commented that when the cylindrical bottle was squeezed the water entered the eye-dropper. Janet pointed out the eye-dropper resting on the bottom already contained water. Janet thought there may be some air in the eye-dropper so that "it can push the water out". The researcher remarked that squeezing was employed to get the eye-droppers to rise and sink. At this point the researcher asked the participants to construct a Discrepant Cartesian Diver.

4.4.6 Assembled Discrepant Cartesian Diver - Theories

Janet and Wendy proposed individual explanations for the way the eye-dropper behaved when the bottle was squeezed. Janet thought the air inside the bottle pushed down on the eye-dropper when the bottle was squeezed (Air Theory). Wendy proposed that the water was pushed into the eye-dropper, making the eye-dropper heavier (Heaviness Theory).

In explaining how the eye-dropper rose to the surface when the bottle was squeezed, Janet used the Air Theory as she believed the air pushed the water out of the eye-dropper.

4.4.7 Constructed Discrepant Cartesian Diver - Actions

The participants were asked to construct a Discrepant Cartesian Diver. They were given a number of eye-droppers and an empty bottle. They selected one eye-dropper containing some water. They thought the eye-dropper would float but this idea was recanted, and it was thought to sink. Wendy filled the bottle with water and Janet deposited the eye-dropper in the bottle. Janet predicted that the eye-dropper would sink. The eye-dropper floated. A second eye-dropper was filled with water and predicted to float in the water, when the bottle was squeezed. Wendy squeezed the edges of the bottle and remarked "it won't go when you squeeze it". The participants compared the water levels in the eye-droppers resting on the bottom in both bottles and found the eye-dropper in the Assembled Discrepant Cartesian Diver was "not totally filled with water". Janet and Wendy removed all the water from the Constructed Discrepant Cartesian Diver and extracted the eye-droppers. Wendy refilled the bottle and Janet ejected some water from the eye-dropper that had rested on the bottom. The eye-dropper was added to the bottle but instead of sinking it floated. A second eye-dropper was added to the bottle. This time the eye-dropper contained a greater amount of water. The eye-dropper sank and rested on the bottom. Now the cap was screwed back onto the bottle. Wendy squeezed the edges of the bottle and the first eye-dropper sank to the bottom.

The researcher asked them to explain why, when squeezed one way the eye-droppers go down and when squeezed the other way the eye-droppers rose. Janet explained that it was the opposite. When the edges of the rectangular bottle were squeezed the eye-droppers rose and when the sides were squeezed the eye-droppers sank. The participants noted that when the sides were squeezed the eye-dropper rose with the water level in the bottle. When the edges of the rectangular bottle were squeezed they commented that the eye-dropper fell with the water level in the bottle. Janet explained that the water level in the bottle and the eye-dropper fell because "there was more air coming in the bottle, it's pushing it down". Janet found that when the edges of the bottle were pushed "air is actually more in there", because there was more "space". The researcher asked the participants to expand upon the idea of more space. Wendy commented that the rectangular bottle changed shape when the edges were squeezed. Janet thought that the bottle was stretching, and when the sides were squeezed "the air would get smaller. Janet added that when the edges were squeezed the air inside the eye-dropper pushed the eye-dropper up. At the same time the water would be pushed out of the eye-dropper. Wendy thought the air from the bottle pushed the eye-dropper up. The researcher asked why the water would come out of the eye-dropper. Wendy claimed that the pressure pushed on the top of the eye-dropper. The air on top pushed the water out of the eye-dropper. It was also noted that when the edges of the bottle were squeezed the eye-dropper floating at the surface had less water. The participants concluded that when the edges of the bottle were squeezed the "pressure on the eye-dropper and water comes out".

The researcher asked the participants to summarize their findings. Janet commented on "air pressure". Janet continued by claiming that when there was more water in the eye-dropper it would sink. When the bottle was squeezed the water vacated and the eye-dropper became lighter. Wendy claimed that "there is more air in the eye-dropper". She added "if there is more water in the eye-dropper it kind of sinks down because there is no more air".

4.4.8 Constructed Discrepant Cartesian Diver - Theories

After a series of unsuccessful attempts, Janet and Wendy were successful in constructing an Discrepant Cartesian Diver. When prompted to explain the behaviour of the eye-droppers in the rectangular bottle, Janet suggested there was a relationship between the air and the water level, and that the position of the eye-dropper was linked to the water level in the bottle. Squeezing the edges of the rectangular bottle created more space which allowed for more air in the bottle. Wendy continued to use the Shape-of-the-Bottle Theory as she believed the bottle changed shape. Janet pursued her idea while including the Air Theory. She thought that as the edges were squeezed, the air inside the eye-dropper pushed it to the surface.

The Air Theory was used in the participants' explanation of the eye-droppers' behaviour. Pressure was thought to cause the air to push the water out of the eye-dropper consequently the eye-dropper would then have less water.

Janet and Wendy thought air caused the eye-droppers to rise and fall. In their final observation they said that when the water is ejected, the eye-dropper becomes lighter (Heaviness Theory).

Table 4.

Janet and Wendy's Theories - All Events

Assembled Cartesian Diver

Pressure-Force Theory

Air Theory

Heaviness Theory

Constructed Cartesian Diver

Assembled Discrepant Cartesian Diver

Air Theory

Heaviness Theory

Air Theory

Constructed Discrepant Cartesian Diver

Shape-of-the-Bottle Theory

Air Theory

Air Theory

Heaviness Theory

CHAPTER V

Discussion, Implications, and Recommendations

5.1 Introduction

The major finding in this study of three pairs of Grade 6/7 students is that the students' understanding was not static. The students' explanations changed as they moved through the stages of the study. In some instances the changes were minor, but when the students created their own discrepant diver, their actions changed and were more diverse as they drew upon their prior experiences with the diver. One might speculate that much of the change was related to the investigation of the variables involved in creating a working diver. However, the students' first-held theories appeared to influence their understanding as their initial explanations were echoed at the closure of each pair's investigation.

In this chapter three elements will be presented. The discussion will be conducted from two perspectives based on, i) events, and ii) each dyad. Implications for teaching derived from this study will also be discussed, and suggestions for further research, using the Cartesian Diver, will be presented.

5.2 Perspective 1 - Findings Based on Events

The students generated many theories as they worked with the Cartesian Divers. These theories are shown, by dyad and by event, in Table 5. The frequency of theories per event, common theories and theories not commonly shared will be discussed.

5.2.1 Frequency of Theories per Event

Each event prompted the dyads to generate their own theories. In the Assembled Cartesian Diver phase each dyad generated two to three theories; Janet and Wendy generated three theories. While constructing their own Cartesian Diver, each dyad used zero to two theories; Janet and Wendy did not generate any theories.

Experimentation with an Assembled Discrepant Cartesian Diver generated one to three theories per dyad. Janet and Wendy used three theories while the remaining dyads used only one theory.

When creating their own Constructed Discrepant Cartesian Diver the dyads generated the largest number of theories. Steven and Michele used nine theories to explain the diver. Barbara and Jessica used 11 theories to explain their diver's behaviour. Janet and Wendy used four theories.

Each dyad used a multiple of theories to explain the behaviour of the Cartesian Diver (all events). Steven and Michele used a total of 14; Barbara and Jessica used 16 theories; and Janet and Wendy 10 theories.

Table 5.

Comparison of Dyad's Theories

Events	Dyads		
	Steven and Michele	Barbara and Jessica	Janet and Wendy
ACD	Pressure-Force Theory Heaviness Theory	Heaviness Theory Pressure-Force Theory	Pressure-Force Theory Air Theory Heaviness Theory
CCD	Heaviness Theory Air Theory	Pressure-Force Theory Heaviness Theory	
ADCD	Air Theory	Air Theory	Air Theory Heaviness Theory Air Theory
CDCD	Pressure-Force Theory Heaviness Theory Pressure-Force Theory Pressure-Current Theory Heaviness Theory Air Theory Shape-of-the-Bottle Theory Air Theory Heaviness Theory	Heaviness Theory Air Theory Pressure-Force Theory Heaviness Theory Pressure-Force Theory Shape-of-the-Bottle Theory Pressure-Force Theory Heaviness Theory Pressure-Force Theory Heaviness Theory Air Theory	Shape-of-the-Bottle Theory Air Theory Air Theory Heaviness Theory

Note. ACD = Assembled Cartesian Diver; CCD = Constructed Cartesian Diver; ADCD = Assembled Discrepant Cartesian Diver; CDCD = Constructed Discrepant Cartesian Diver.

5.2.2 Commonly Held Theories

During the investigation the dyads produced theories for almost all the events. Janet and Wendy were an exception as they did not produce a theory in the Constructed Cartesian Diver.

When presented with an Assembled Cartesian Diver the dyads used two theories, the Pressure-Force Theory and the Heaviness Theory, to explain its behaviour. In the Constructed Cartesian Diver, the Pressure-Force Theory was used by two dyads to describe its behaviour. Janet and Wendy did not use the Pressure-Force Theory.

In their exploration of the Assembled Discrepant Cartesian Diver, the dyads used the Air Theory to explain its behaviour. The Constructed Discrepant Cartesian Diver brought about many diverse explanations. All the dyads used the Air Theory and Heaviness Theory, as in the previous events of the study. All three dyads used the new Shape-of-the-Bottle-Theory to explain the behaviour of the discrepant diver. Steven/ Michele and Barbara/Jessica repeatedly employed the Pressure-Force Theory to explain the diver's behaviour.

The most commonly held theories for the Assembled Cartesian Diver is the Pressure-Force Theory and the Heaviness Theory. There was no common theory for the Constructed Cartesian Diver as one group did not present a theory. The most commonly held theory for the Assembled Discrepant Cartesian Diver was the Air Theory. The dyads held three theories in common for the Constructed Discrepant Cartesian Diver. These were the Heaviness Theory, the Air Theory and the Shape-of-the-Bottle Theory.

5.2.3 Theories Not Commonly Shared

In the investigation of the Assembled Cartesian Diver, Janet and Wendy used the Air Theory to explain its behaviour. The other two dyads did not use this theory.

Janet and Wendy did not employ any theories to explain the diver's behaviour when creating their Constructed Cartesian Diver. Of the two remaining dyads, Barbara and Jessica used the Heaviness Theory in their Constructed Cartesian Diver, while Steven and Michele used the Air Theory.

While discussing an Assembled Cartesian Diver, Janet and Wendy used the Heaviness Theory to explain its behaviour. Steven and Michele were the only dyad to use the previously un-mentioned Pressure-Current Theory to explain the behaviour of their Constructed Discrepant Cartesian Diver.

5.3. Perspective II - Findings Based on Dyad

Each dyad generated a variety of theories as they worked with the Cartesian Divers. These theories have been categorized by usage and will now be examined using a different theoretical framework. Gunstone's work (1988) provides a useful categorization for examination of the theories from a constructivist perspective. Gunstone used four categories to summarize his findings. Gunstone suggests that students:

i) hold conceptions in common;

ii) can hold prior conceptions and scientific explanations simultaneously;

iii) prior conceptions are often unaffected by instruction; and

iv) prior conceptions are different from scientific explanations.

For the purpose of this study Gunstone's categories were modified to reflect a different research environment. The students were in a non-instructional setting, and actions and theories were used to explain the behaviour of the Cartesian Diver. The findings were thus summarized under the following headings:

i) students hold theories in common;

ii) students hold multiple theories at simultaneously;

iii) students' theories remain unaffected through experimentation; and

iv) students' theories are both similar and different from the accepted scientific theory.

Gunstone's categories have been modified to better reflect the outcomes of this study. There remain similarities between the two schemas with the present schema being used to examine the students' theories.

5.3.1 Students Hold Theories in Common

The study showed that the students held theories in common. Each dyad used the same four theories to explain the diver's behaviour. The Pressure-Force Theory was common to each dyad as they believed that pressure from squeezing the bottle caused "something to happen" to the water in both the eye-droppers and the bottle. All the pairs knew that pressure was an important component in the action of the eye-droppers, but none of them could define *pressure*.

The Heaviness Theory was also common to each dyad. They recognized that when water was added to an eye-dropper, the eye-dropper became heavier, and if enough water was added, the eye-dropper sank.

The Air Theory was used when the dyads discovered that air must be present for an eye-dropper to float and absent for an eye-dropper to sink. Air pressure was thought to push the water out of the eye-dropper.

All the dyads used the Shape-of-the-Bottle theory to explain the behaviour of the Constructed Discrepant Cartesian Diver. Their examination of the cylindrical bottle led them to conclude that squeezing at any point caused the water level to rise. Squeezing the edges of the rectangular bottle led them to think the water level fell.

One common finding amongst the dyads was the definition for floating and sinking. Each pair used similar terms to describe the state of the eye-dropper in the bottle. However, each participant had a different interpretation of the meaning of the words. For example, floating could mean an eye-dropper rising to the surface or resting on the bottom, sinking could mean an eye-dropper falling to the bottom or hovering beneath the surface.

5.3.2 Students Hold Multiple Theories Simultaneously

In the previous section, the students were shown to hold four theories in common. In addition to this finding, the study also found that three of the four theories were held at once.

Moving the diver to the bottom or the top of the bottle was accomplished by squeezing. One of the first theories used to explain this behaviour was the Pressure-Force Theory. The pressure from squeezing the bottle was thought to move the eye-dropper. Location of the squeeze was also thought to play a role. Squeezing at a point around the eye-dropper was believed to make the area of the bottle smaller and force the eye-dropper to move.

All dyads used the Heaviness Theory and the Air Theory to explain the behaviour of the Cartesian Divers. Student examination of the action inside the eye-droppers led them to use these two theories. Throughout experimentation each dyad identified the water and the air inside the eye-dropper as playing an important role in the diver's behaviour. Like the philosophical debate on whether a cup of water is half full or half empty, both played a role in the students' explanation of the diver's behaviour.

All three theories, while appearing to be separate, are interdependent.

5.3.3 Students' Theories Remain Unaffected through Experimentation

Based on the students' responses, it was evident that they had limited previous experience with the device called the Cartesian Diver or any similar apparatus. Consequently, this research provided an opportunity to chart student theories as they progressed through the events of the project. The study's first event, the Assembled Cartesian Diver, presented students with a unique challenge. The resulting theories can be viewed as a landmark for comparison with later theories. In the first event, all three pairs used both the Pressure-Force Theory and the Heaviness Theory. Janet and Wendy also included the Air Theory.

For Steven and Michele, experimentation did not change their theories. Initially, they used the Pressure-Force Theory to explain that squeezing the bottle's sides caused less space in the bottle, forcing the eye-dropper to the bottom. In the final event, involving the Constructed Discrepant Cartesian Diver, they used the Pressure-Force Theory to explain that squeezing the sides of the bottle pushed the eye-dropper up. The Heaviness Theory was used initially to explain that water entering the eye-dropper made it heavier, causing it to sink. This theory was repeated in the final event, the Constructed Discrepant Cartesian Diver, as the Heaviness Theory was used to explain that when water entered the eye-dropper it became heavier. However, Steven and Michele incorporated additional theories as they progressed through the phases of the experiment. For instance, experimentation with the bottle cap removed, led them to believe that air pressure was responsible for the eye-droppers' behaviour. Experimentation with one variable of the diver, air, led them to articulate the Air Theory.

Barbara and Jessica's initial theories remained almost unchanged as they progressed through the next three events of the study. In the first event, the Assembled Cartesian Diver, the Heaviness Theory was used to explain that the extra water in the eye-dropper increased its weight causing it to sink. The Pressure-Force Theory was used to explain that squeezing anywhere on the bottle caused the eye-dropper to sink.

In the final event, the Constructed Discrepant Cartesian Diver, Barbara and Jessica's theories reflected their earlier findings. The Heaviness Theory was still used to explain that extra water increased the eye-dropper's weight causing it to sink. While the Pressure-Force Theory was still used to explain that squeezing the bottle caused the eye-dropper to sink, the "force" of the pressure was now able to "grab" the eye-dropper and move it.

As they progressed through the events of the study Barbara and Jessica offered more theories to explain the diver's behaviour. For example, experimentation with the amount of air in the eye-dropper led them to conclude that water was unable to enter the eye-dropper unless the air inside it was reduced. Experimentation with air led them to initiate the Air Theory.

The dyad of Janet and Wendy used three theories in the first event of the study. Through the events these theories did change. Initially, the Pressure-Force Theory was used to explain that the pressure came from squeezing the sides which made the "area" of the bottle smaller. As the bottle was squeezed the air pushed the water into the eye-droppers, hence the Air Theory. The Heaviness Theory was used to explain that as the water filled the eye-dropper, it became heavier.

In the final event of the study, the Pressure-Force Theory was abandoned as an explanation for the diver's behaviour. The Heaviness Theory was still used to explain the eye-dropper becoming heavier as it gained water, and the Air Theory was used to explain the air pushing the water out, making the eye-dropper lighter.

5.3.4 Students' Theories are Both Similar and Different from the Accepted Scientific Theory

The study of the three pairs of students provided many instances in which the students' theories conflicted with the scientifically accepted theory. A survey of science texts by Barrett (1963), Cherrier (1978), Zubrowsky (1981), Van Cleave (1985), Ehrlich (1990), and the Exploratorium (1991) suggest the Heaviness Theory as an appropriate scientific explanation.

The Heaviness Theory, as described by the dyads, was similar to the accepted scientific theory. However, each dyad did not retain this one theory as their only explanation. As already reported, each dyad had many theories explaining the diver's behaviour of which the Heaviness Theory was but one.

Reflection on student theories suggests that a hierarchy can be found amongst them. The question is, if the Heaviness Theory is the accepted explanation for the diver's behaviour, can the components of this theory be identified in the other student theories? Theories lacking one component could be considered one step removed from the accepted scientific theory. Those lacking two components are two steps away and so on. For example when water is added to the eye-dropper, it becomes heavier (Heaviness Theory). For the water to enter the diver the air must compress. As the air compresses it loses its ability to float the eye-dropper (Air Theory). So one might argue the Air Theory represents one step removed from the accepted theory. Instead of looking at the water in the eye-dropper, the students are looking at the air!

The Pressure-Force Theory represents two steps removed from the accepted scientific theory. Heaviness Theory requires squeezing to force water into the eye-dropper. Without squeezing, the water cannot enter into the eye-dropper. Each dyad recognized the need for pressure as the Pressure-Force Theory was used as their first or second theory. The Pressure-Force Theory represents two steps removed from the accepted scientific theory as it disregards the weight of the water, the air's ability to float the eye-dropper and addresses moving the eye-dropper by force.

The Pressure-Current Theory represents three steps removed in the hierarchy. The Heaviness Theory requires the movement of water into the eye-dropper. When the students closely examined the water level in both the bottle and the eye-dropper, they mentioned that the water level rose and fell according to pressure applied to the bottle. Steven and Michele used the Pressure-Current Theory to explain that the eye-dropper moved in the direction opposite to the changing water level. The theory does not incorporate the weight of the water, the air's *ability* to float objects, and forcing the eye-dropper to move.

The Shape-of-the-Bottle Theory represents four steps removed from the accepted theory. The Heaviness Theory requires a bottle to be squeezed in order to force the water into the eye-dropper. Squeezing a cylindrical bottle causes a reduction in the volume. A rectangular bottle will increase in volume when the edges are squeezed. Each dyad recognized the importance of the shape of the bottle. The Shape-of-the-Bottle Theory was used to explain the discrepancy in the diver's behavior. The students recognized that a cylindrical bottle caused a diver to sink while a rectangular bottle caused a diver to rise. The Shape-of-the-Bottle Theory reflects four steps removed from the Heaviness Theory and accounts for only a change in volume of the bottle. This hierarchy of theories is presented in Table 6.

Table 6.

Hierarchy of Theories

	Theories				
Components	Heaviness	Air	Pressure Force	Pressure Current	Shape-of-the-Bottle
Weight	X				
Air	X	X			
Pressure	X	X	X		
Current	X	X	X	X	
Volume	X	X	X	X	X

Note. X represents a component found in each theory.

In general, each dyad was able to explain the behaviour of the Cartesian Diver. More explanations occurred as the students became familiar with the equipment and the variables that determine the diver's behaviour. While many explanations were scientific, they were context driven. Students could only explain what they saw. None of the dyads chose a *best* theory as they tried to develop one comprehensive theory. Their explanations were sufficient for the purpose of the moment in the context of the interaction between themselves and the researcher.

5.4 Implications for Teaching

This research focused on students' actions and explanations and provided insight into student thinking, the findings of this study could have valuable implications for teachers.

In this study, Frazier's's[1] category system was used as a framework to codify the students' explanations into a number of theories. The framework was valuable as it identifies important physical factors in the explanation of the Cartesian Diver's behaviour. Frazier's theories do not present a hierarchy of theories. He simply reports his findings. The limitation of this category system, and in general, all category systems, are the explanations that do not fit. Teachers may wish to create their own category system using Frazier's work as a template or create a new system which best serves them and their students.

[1] Frazier's theories reflect experimentation with a typical Cartesian Diver. The Shape-of-the-Bottle theory was added to the list to accommodate the Discrepant Cartesian Diver.

The encouragement of discussion throughout each dyad's investigation of the Cartesian Diver made explicit a number and variety of explanations. This style of investigation reflects similar approaches found among working scientists. While students may be able to work individually, it may be more beneficial for students to work co-operatively.

The study revealed that the students' explanations were context driven. They did not create a comprehensive or a *best fit* theory to account for the diver's behaviour. Unlike a scientist who strives to create one theory to explain a number of events, each dyad was content to explain the diver's behaviour within a particular context. The need for an overall theory is the goal of the scientist. Students do not conceive of such theories. They may not even see the need for such theories or even have any idea that theories can be created or exist. Recognition of this difference between scientists and children could change a teacher's approach to teaching science. Instead of encouraging one theory to explain a number of events, teachers could ask for multiple theories to explain a single event. The opportunity to draw, write, and present theories in dramatic representations may be explored.

In this study, the hands-on approach seemed appropriate as the students generated a number of explanations while investigating the Cartesian Diver. The order of the four events in the study meant that the students would investigate a working diver and then construct their own. The two events involving the construction of a diver generated the greatest number and variety of theories. Students may only be able to explain phenomena through creating and exploring products of their own construction. It is evident that experience and the development of familiarity with physical materials and the abstracting (theories) is important for students and for pedagogy.

Finally, the study involved a group of students. They did not receive a mark for their efforts or a prize. The motivation was derived from the context, not extrinsic rewards. As they worked they compared, constructed, described, designed, estimated, explored, hypothesized, identified, measured, observed, predicted, and suggested practising the proven skills so valued by educators.

5.5 Recommendations for Further Research

Several recommendations for further research can be suggested.

- Few other studies investigated the Cartesian Diver and none has compared and contrasted different grade levels, or adults and children. Comparing and contrasting grade levels or substituting adults for the children may provide valuable insights into the development of thinking skills and the role of specific knowledge, for example: buoyancy; displacement; and pressure.
- Commonalties amongst explanations was a focus of the study. It may be of value to look at the differences amongst student explanations and develop insight into the different ways events can be interpreted.
- This study examined a small number of students. A study involving a large number of students could be used to examine other issues; gender, culture, and socio-economic status as possible factors influencing student explanations.

- This study identified a hierarchy within Frazier's Theories. It may be of interest to examine this hierarchy in more detail.
- It has been suggested that experience with materials is an important factor in the facilitation of student theory development. This could be an empirical question.
- While the children were highly motivated in the study a suspicion exits that the presence of an adult during the interview may have effected the quality and the variety of the students' actions and explanations. A study involving students without the presence of an adult could be explored.

5.6 Summary

This case study focused on student explanations of the Cartesian Diver. The structure of the study reflected the case study literature reviewed in Chapter II. The literature, both historical and present day, on the Cartesian Diver contributed to the materials and experiments used in this study. Throughout the study a constructivists conceptual framework was used for developing the research questions, research methodology and the data analysis.

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APPENDIX A

Conventions of Transcription

Layout	Each new utterance starts on a new line and, if more than one line is required to complete the utterance, continuation lines are indented.
M:	Responses or actions made by Michele.
R:	Responses or actions made by the researcher.
S:	Responses or actions made by Steven.
-	Incomplete utterances or false starts are shown with a dash, e.g., "Well-er-"
.	Pauses are indicated with a period. In the case of long pauses, the number of periods corresponds to the number of seconds of pause. e.g., "Yes .. I do."
?!	These punctuation marks are used to mark utterances judged to have an interrogative or exclamatory intention.
CAPS	Capitals are used for words spoken with emphasis, e.g., "I really LOVE painting."
<>	Angle brackets are used to enclose words or phrases about which the transcriber felt uncertain.
*****	Passages that are impossible to transcribe are shown with asterisks, one for each word judged to have been spoken e.g., "I'll go ***."
_	When two utterances speak at once, the overlapping portions of their utterances are underlined.
(Gloss)	Parentheses are used to depict the actions of the participants and the results of their actions.
Italics	Italics are used to designate equipment through the experiments. Where it is judged necessary, included are the observations of the equipment.

APPENDIX B

Transcription of Steven and Michele

Assembled Cartesian Diver

R: Tell me what do you see?
S: Water
Water and um what do you call it?
A dropper thingy
M: Yah
R: It's an eye-dropper
This bottle will be designated the Assembled Cartesian Diver.
S: <eye-dropper>
M: And .... bubbles or is that just the bottle?
S: * * it's like frozen
R: What's frozen?
S: The bubbles * stuck
R: Okay we have water we have bubbles we have some . an eye-dropper in it
What else have we got?
M: I don't know <u>I can't see anything</u>
S: <u>I can't see anything</u>
R: Okay
I have a problem, can you move the eye-dropper?
M: * * *
R: Try it
(M picks up the Assembled Cartesian Diver and turns the bottle in her hands)
S: There's some kind of force that keeps it to the side
R: Wow!
Some kind of force
M: * *
(M puts down the Assembled Cartesian Diver)
M: Yah it does move
S: It moves a bit
R: Okay
Can you get it to the bottom?
M: Umm
S: Probably not because its light
Unless you tip it over

(M picks up the Assembled Cartesian Diver and turns it up side down and presents it to the Researcher as a solution to the problem)

R: Is that the bottom or the top now?
M: Oh that's the top

(M uprights the Assembled Cartesian Diver and returns it to the table)

M: U-humm
R: Try .. try anything
(M grabs the neck of the bottle)
M: It won't stay down though .. will it?
R: How come?
M: I don't know

(S picks up the Assembled Cartesian Diver and shakes it and returns to the table)

R: S shakes it up
S: Because it makes a whirl pool sometimes
R: What will a whirl pool do?
S: You know .. cause it spins down to the bottom
R: That's an excellent idea
But surely there must be an easier way
M: < Well>
S: Um probably ...
R: Try it S

(S takes hold of the cap on the Assembled Cartesian Diver)

S: Well ..... it might spill though
Take the eye-dropper out squirt all the water out and than turn it upside down see what that does
<Would that float?>
R: That would be a little tough to do wouldn't it?
S: Yes
R: Something very simple
M: Just because we don't know okay
R: That's frustrating isn't it?

(M picks up the Assembled Cartesian Diver and starts to manipulate the bottle by pressing on it)

M: I don't know
R: M you have a good idea
What were you trying to do there?
M: I don't know
R: What were you doing with your hands?
M: I'm squeezing it
R: Don't give up on that

(M squeezes the Assembled Cartesian Diver harder and eye-dropper #1 sinks and rests on the bottom)

M: Yah
R: Squeezing it worked

(M continues to squeeze the Assembled Cartesian Diver and the eye-dropper continues to fall and rise)

M: Yes!

R: S and you do it?

(S squeezes the Assembled Cartesian Diver and the eye-dropper sinks to the bottom)

R: Why did squeezing work and nothing else worked?

S: Umm

M: I don't know because of the pressure

S: Yep

The pressure of the water <next> if the sides go in the water will move more cause there is less space right here (pointing to the middle of the Assembled Cartesian Diver) and there's little space up here (pointing to the top of the Assembled Cartesian Diver)

R: How can we prove that?

S: Well you squeeze it and the water goes up a bit

(S squeezes the Assembled Cartesian Diver and the eye-dropper sinks to the bottom)

R: Did it?

S: Yes

M: No

S: A bit

Yah it goes up about ...

(M squeezes the Assembled Cartesian Diver very slowly and observes the changes in the water level)

M: It doesn't go up

R: Well something's happening it keeps going down

M: Yap

The water in the eye-dropper goes up (referring to the water level in eye-dropper #1)

R: Does it?

M: It does

S: It puts more weight into it

R: It does what S

S: It puts more weight into the eye-dropper and it goes down

R: Would you like to make one yourselves?

M: <u>Sure</u>

S: <u>Sure</u>

R: We have this nice bottle for you

Here's some water ... and S was right when he guessed it was water some people thought it was gasoline

S: Vinegar maybe

R: Pardon

S: It could have < been vinegar .. maybe >

R: It could have been

R: So if you want to do what you want
If want to duplicate it here are some eye-droppers or turkey basters
S and M are given a 2 litre plastic bottle, water and some eye-droppers. The bottle will be designated the Constructed Cartesian Diver.

M: How many are we supposed to put in? (referring to the amount of water to be put into the Constructed Cartesian Diver)

S: As much as it fills it up .... I guess

(M fills the Constructed Cartesian Diver with water)

M: < Is that filled? > (referring to the amount of water in the Constructed Cartesian Diver)

S: A bit more probably

M: I want to put these in .... okay?

(S picks up an eye-dropper and places it the Constructed Cartesian Diver)
The eye-dropper has no water in it and it floats diagonally at the surface.

R: And here's some if you want some water
A 1 litre container filled with water is made available.

S: It's like stuck right there (referring to the eye-dropper's position in the bottle)

(M adds an empty eye-dropper to the Constructed Cartesian Diver)
Unknowingly as the eye-dropper was placed in the Constructed Cartesian Diver the cap was squeezed and some of the air was replaced by water.

R: If you need to get the eye-droppers out ..

M: Can we put all these ..

(M adds a second empty eye-dropper to the Constructed Cartesian Diver)

R: It's up to you

S: Now put the cap on *

(M adds a third empty eye-dropper to the Constructed Cartesian Diver)
Now there are four eye-droppers in the Constructed Cartesian Diver.

R: Here you go here's the cap

(S puts the cap on and squeezes the Constructed Cartesian Diver)
Two of the four eye-droppers sink and rest on the bottom.

R: Wow!
That is truely remarkable

(M immediately squeezes the Constructed Cartesian Diver with no apparent effect)

M: < I'm not that strong >

R: Why does it not work for S and not for you?

(M squeezes the Constructed Cartesian Diver and both divers return to the bottom)

R: Oh it does work for you

M: The other two don't go down

(M again squeezes the Constructed Cartesian Diver and both divers return to the bottom)

S: Let's see

M: The other ones won't go down

S: Well let's see

< It doesn't >

(S retrieves the Constructed Cartesian Diver and squeezes hard, three eye-droppers sink to the bottom)

S: For some reason . when you squeeze on one side some of them most of them on this side go down

When you squeeze on the other side it looks like some of the others go down

R: Oh that's interesting

(M retrieves the Constructed Cartesian Diver and squeezes)

R: M I was curious why did you squeeze on the top?

M: I don't know

S: Cause it's maybe all squashed together right here (referring to the four eye-droppers floating at the surface)

(S squeezes the top of the Constructed Cartesian Diver)

(M duplicates D's motion)

R: So squeezing at the top will to loosen them up or get them to move?

(M continues to squeeze the Constructed Cartesian Diver)

One of the eye-droppers stops moving to the surface and rests on the bottom.

M: <u>How come that one stays?</u>

R: <u>How come that one stays?</u>

M and R are referring to the eye-dropper that is resting on the bottom.

R: Now we have one on the bottom!

How did that happen?

S: It's too full of water and than it got like maybe it had a bit of air stuck in it and it got like because sometimes if you like put a glass like right here and take all the air out of it it sticks

S uses hand motions to indicate where the glass would be placed on the mouth.

R: Oh really

So is it stuck to the bottom now?

S: I guess so

(M continues to squeeze the Constructed Cartesian Diver)

S: Wait .. see if I

R: I'm glad the lid's on nice and tight

(S picks up the Constructed Cartesian Diver and turns it upside down)

S: See and that one goes down there (referring to the eye-dropper moving towards the lowest point in the Constructed Cartesian Diver)

(S uprights the Constructed Cartesian Diver and squeezes)

S: Okay those went up

R: So what do you think?

(S closely examines the eye-dropper resting on the bottom)

S: How come that one is all full of water?

These ones only have a bit (referring to the eye-droppers floating at the surface)

R: So I'm not to sure how

(S squeezes the Constructed Cartesian Diver)

S: That one always seems to stay up there because it has air (referring the one of the eye-dropper that does not sink to the bottom)

M: How about we take it out and than and they will all go down?

R: Sure

(M removes the cap and extracts the one eye-dropper that does not sink)

R: We can leave the one on the bottom on the bottom
If you need more eye-droppers there are certainly more
You may want to try different ones
S tries to remove one of the floating eye-droppers but is unable to secure one with the tweezers.

M: Let's just try three

S: Yah

R: They're all supposed to the same but you never know

(M squeezes the Constructed Cartesian Diver)

S: Just a second . squeeze it . squeeze it all the water went up and then when she released the pressure the water went down but it was still stuck up here (referring to the top of the Constructed Cartesian Diver)

(M squeezes the Constructed Cartesian Diver at the top)

M: Its not going to happen

R: Why will it not go down?

S: <u>I don't know</u>

M: <u>I don't know</u>

(S tries to remove one of the eye-droppers)

M: Take the other one

S: This ones got * * * *
This ones got some kind of

(S removes one of the eye-droppers and closely examines it)

(M adds the eye-dropper first eye-dropper removed from the Constructed Cartesian Diver)

(M squeezes the Constructed Cartesian Diver without replacing the cap)
M jumps after squeezing the Constructed Cartesian Diver.

M: Whoops

R: What happened there

(M slowly squeezes the top of the Constructed Cartesian Diver)

M: They go up
The eye-droppers rise with the increased water level.

S: Oh because the um the lids not off and that releases all the air pressure stuck inside it

(M squeezes the bottle and water splashes out of the Constructed Cartesian Diver)

M: That was smart

S: There is something with this one (referring to the eye-dropper that was removed because it was thought have a problem)

M: Put a different one in

S: Yah

(M selects another eye-dropper and places it in the Constructed Cartesian Diver)

M: How the third always goes ...

S: Sideways for some reason?

(S replaces the cap on the Constructed Cartesian Diver)

S: Not enough room

(M squeezes the top of the Constructed Cartesian Diver)

S: There's a certain one that just seems to stick there
Let's try two < now > and squeeze it

(S removes one of the eye-droppers)

S: < I wanna try a * >

(M selects an eye-dropper and expels some air and places it in the Constructed Cartesian Diver)

The diver rests at the surface.

S: But .. we should take that one out or
(S removes the eye-dropper M placed in the Constructed Cartesian Diver)

M: This one doesn't fill up with water (referring to the eye-dropper that is resting in a diagonal position at the surface)

S: Which one?

M: The third . this one (referring to the eye-dropper that is resting in a diagonal position at the surface)

(S closely examines the eye-dropper removed)

M: Unless I just can't see it

S: Lets see

(S removes the eye-dropper that does not fill with water)

S drops the tweezers in the Constructed Cartesian Diver.

R: That's a first one S
That's all right it doesn't matter
It's okay S
It won't do any damage
That's truely a first S .. congratulations

S: Yah

M: It's upside down now (referring to the eye-dropper that is resting in a diagonal position at the surface)

R: Now that's interesting no one has ever tried that I wonder would work?

S: < I'm going to try it >

(S replaces the cap on the Constructed Cartesian Diver)

(M squeezes the Constructed Cartesian Diver)

M: Oh
I'm taking that one out

(M removes the eye-dropper that is resting in a diagonal upside down position at the surface)

S: It likes to stay .. that one sort of likes to stay by the air pressure when the cap lid is on

R: Likes to do

M: This one doesn't (referring to the eye-dropper just removed)

S: Try absorbing the water
(M places the eye-dropper in some water and expels some air)

S: It works
It works but it only goes past a certain point
You try it

(M places the eye-dropper in the Constructed Cartesian Diver

(M squeezes the Constructed Cartesian Diver)

All the eye-droppers sink to the bottom when the Constructed Cartesian Diver is squeezed.

R: Good stuff

S: That one stays down there (referring to the eye-dropper that rests on the bottom of the Constructed Cartesian Diver)

M: I am so smart

R: What . why does that one stay at the bottom do you think S?

S: Maybe because it's completely full and it can't release any and doesn't have any air pressure in it .. to do

R: Well you have done such a good job on that one we have another for you
This will bottle will be designated Constructed Discrepant Cartesian Diver.

R: Tell me what do you see?

S: Is it vinegar?

R: No its water

S: Its water

M: Two

S: Two ones stuck by the bottom the other by the top
But that one seems to have more water (referring to the eye-dropper resting on the bottom) than this one (referring to the eye-dropper floating at the surface)

(M picks up the Constructed Discrepant Cartesian Diver and inverst it)

M: They don't move
When the bottle was up-righted the divers jammed themselves between the edges.

R: Okay
Well this one is kind of a kind special one and it works best when its that way (referring to an upright position)
So I have a challenge
Oh S is doing it already
Try and get both of them on the bottom

(S picks up the Constructed Discrepant Cartesian Diver and starts to squeeze the sides)

S: And stay there?

R: And stay there

S: * * * < make go right up >

R: I think this one is getting old (referring to the gaining of water through condensation within the eye-dropper and the subsequent decline in response)

(S passes the Constructed Discrepant Cartesian Diver to M)

(M squeezes the Constructed Discrepant Cartesian Diver)

R: My other challenge is get both of them to the top

(M squeezes the top edge of the Constructed Discrepant Cartesian Diver)

R: Why are squeezing there M? (referring to the point where M is squeezing the Constructed Discrepant Cartesian Diver)

M: Umm ... because the bottle when you squeeze it at the bottom

S: It looks like there is no air pressure in it and it makes it harder to go down

M: There is no air
Is it filled up all the way to the top?

R: I don't know try it
Check it out

(M removes the cap from the Constructed Discrepant Cartesian Diver and checks the water level)

S: Yep pretty close

(M replaces the cap on the Constructed Discrepant Cartesian Diver)

R: Close enough?

S: Yah
Try squeezing it this way
See if that will work

(S squeezes the Constructed Discrepant Cartesian Diver on its edges)

M: It .. it almost

S: Went to the top

(M picks up the Constructed Discrepant Cartesian Diver and rotates it while closely observing the eye-droppers inside)

R: I think you had a good idea on squeezing it you just you may have to be a bit more patient

M: That one has a bigger hole than this one (referring to the eye-dropper resting on the bottom and one of the many extra eye-droppers)
The eye-dropper M is referring to was accidentally dropper prior to placement in the Constructed Discrepant Cartesian Diver.

R: That's because I dropped that one when I was filling it

(M squeezes the sides of the Constructed Discrepant Cartesian Diver)

(M moves hand to the top of the Constructed Discrepant Cartesian Diver while the other hand remains in the mid-section and squeezes)

S: Here lets see

(S squeezes the base of the Constructed Discrepant Cartesian Diver)

R: What's happening inside of the bottle?
S: This going down you squeeze it but it doesn't seem to stay down
(S removes the cap from the Constructed Discrepant Cartesian Diver)
(S extracts the eye-dropper floating at the surface)
(S removes all the water from the eye-dropper)
(S returns the eye-dropper to the Constructed Discrepant Cartesian Diver)
(S expels some air in the eye-dropper while it is immersed in the water)
(S replaces the cap on the Constructed Discrepant Cartesian Diver)
S: < I tried to get some air of that . I think that will work for some reason >
(M squeezes the sides of the Constructed Discrepant Cartesian Diver)
(M removes the cap on the Constructed Discrepant Cartesian Diver)
S: When you put it in than it will just .. here
(S uses the tweezers to extract the eye-dropper floating at the surface)
(M expels the water in the eye-dropper and returns it to the Constructed Discrepant Cartesian Diver)
R: Here some other tweezers
(M returns the cap to the Constructed Discrepant Cartesian Diver)
(M squeezes the Constructed Discrepant Cartesian Diver)
R: Oh lids not on tight enough
S: Here
(S and M tighten the cap on the on the Constructed Discrepant Cartesian Diver)
(M squeezes the Constructed Discrepant Cartesian Diver)
M: Now its even hard
S: For some reason its all air pressure
R: Can we get them both to the surface?
S: Let's see let's see I think .... that
(S picks up the Constructed Discrepant Cartesian Diver and inverts it)
(S squeezes the Constructed Discrepant Cartesian Diver)
S: Stay
R: Floats to the top?
(S puts the Constructed Discrepant Cartesian Diver down in the upright position)
(S picks up the Constructed Discrepant Cartesian Diver and inverts it)
S: When you turn it like this they both stay like that (referring to the position of the eye-droppers in the Constructed Discrepant Cartesian Diver) Sort of
M: Put it down
(S rests the Constructed Discrepant Cartesian Diver in an inverted position resting on the cap)
S: But this one goes like half .. way .... maybe it's stuck
The eye-dropper that rests on the bottom of the Constructed Discrepant Cartesian Diver has become stuck in the middle of the bottle.
(S taps the Constructed Discrepant Cartesian Diver)
S attempts to dislodge the stuck eye-dropper by tapping on the bottle.
M: They go on their sides
(M picks up the Constructed Discrepant Cartesian Diver)

(M inverts the Constructed Discrepant Cartesian Diver)
M: There they floating on the top
Both eye-droppers are inverted in the Constructed Discrepant Cartesian Diver and are floating at the surface.
M: Do you need the black thing on the top?
R: Yes
(M uprights the Constructed Discrepant Cartesian Diver)
M: We have to get this one up (referring to the eye-dropper resting on the bottom)
S: Oh I have an idea
(S removes the cap from the Constructed Discrepant Cartesian Diver)
S: Maybe if we flipped it over and put it in .. and crammed it in with the cap ... now try it
(S removes the eye-dropper resting at the surface)
(S inverts the eye-dropper)
(S inserts the inverted eye-dropper in the Constructed Discrepant Cartesian Diver)
(S replaces the cap on the Constructed Discrepant Cartesian Diver)
(M squeezes the Constructed Discrepant Cartesian Diver)
S: Now flip it over
(S grabs the Constructed Discrepant Cartesian Diver from M and inverts it)
The eye-droppers resume their positions.
S: * * * *
R: That's a very interesting idea S
We still have a bit of a problem
S: Maybe there is too much water in it
R: Well we can certainly take some water out
(M removes the cap on the Constructed Discrepant Cartesian Diver)
(M removes the eye-dropper floating at the surface)
(S removes some water from the bottle)
R: Oh too much water in the bottle . I see
S: Just dump some out
Just don't * the eye-dropper
(M pours some water out of the Constructed Discrepant Cartesian Diver)
(M adds the previously removed eye-dropper)
(S replaces the cap on the Constructed Discrepant Cartesian Diver)
(S squeezes the Constructed Discrepant Cartesian Diver)
(M squeezes the Constructed Discrepant Cartesian Diver)
R: This is a tough one
How do you get both of them to the surface .... to the top .... by squeezing
(S picks up the Constructed Discrepant Cartesian Diver and inverts it)
R: We will give you a hint you can squeeze it to the top
(S picks up the Constructed Discrepant Cartesian Diver and inverts it)
(S squeezes the Constructed Discrepant Cartesian Diver)

R: Oh S you just did a great job and now it won't work
Something just happened to one of them
S: It turned over
(M picks up the Constructed Discrepant Cartesian Diver and inverts it)
(M squeezes the inverted Constructed Discrepant Cartesian Diver)
S: They flip over when they go to the top
R: But what happens when you squeeze it?
M: They go down
R: Yes
What's happening in the eye-dropper when you squeeze it?
M: The water is * the air
S: See what happens if you let go
R: I see bubbles coming out
M: It's ... air bubbles
S: Try and flip it over and see what happens
(M uprights the Constructed Discrepant Cartesian Diver)
M: There they are both on the bottom
The previously floating eye-dropper has lost enough air to rest on the bottom.
S: Both are on the bottom
(M squeezes the Constructed Discrepant Cartesian Diver)
M: And now both on the top?
R: Yah both on the top now
(M squeezes the top of the Constructed Discrepant Cartesian Diver)
R: You did a great job guys
(S squeezes the bottom of the Constructed Discrepant Cartesian)
S: Try getting it to the top .. see what happens
M: No you just switched it over
(M rips the Constructed Discrepant Cartesian Diver from D's hands and inverts it)
S: Oh my god!
Maybe we need to fill it up with more water now
R: Try it
(M removes the cap on the Constructed Discrepant Cartesian Diver)
R: I think we have a bit of a problem
S: Just use the . oh are you going to dump it?
(S and M add water to the Constructed Discrepant Cartesian Diver using the eye-droppers)
R: If you want you can use the funnel and do it very carefully
S and M are given a funnel.
(M add an amount of water to the Constructed Discrepant Cartesian Diver)
(S tops up the water in the Constructed Discrepant Cartesian Diver)
M: It's at the top already
S: That's why I'm adding the water .. exactly even
M: There
There

S: Now try it

(M replaces the cap on the Constructed Discrepant Cartesian Diver)

(M squeezes the Constructed Discrepant Cartesian Diver)

No movement of the eye-droppers can be seen.

(M uprights the Constructed Discrepant Cartesian Diver)

(M squeezes the Constructed Discrepant Cartesian Diver)

No movement of the eye-droppers can be seen.

S: It seems to let all the water in when you squeeze it

The once floating eye-dropper has lost enough air to cause it to sink on the bottom.

S: Is that the water?

R: Is that the water?

S: Or is that the air?

That's water

(S picks up the Constructed Discrepant Cartesian Diver and shakes the bottle)

S: That's water .. looks like

That's water

That's .. water

M: Is this one like

S: Busted or something?

M: Does it work?

R: You tell me

S was along the right lines about squeezing it because squeezing it is the way

(S squeezes the Constructed Discrepant Cartesian Diver incredibly hard)

M: But where?

S: It's like .. let's see

(S removes the cap)

S: We have to try and get them to the top

(M removes some of the water from the Constructed Discrepant Cartesian Diver)

R: If you want you can pour the water out into one of these (referring to a 1 litre plastic beaker)

(M picks up the Constructed Discrepant Cartesian Diver)

(M starts to pour some of the water out of the Constructed Discrepant Cartesian Diver and spills it)

R: It's only water

S: Just dump it over

Just dump it out

The eye-droppers are going to get stuck watch

R: They'll come out

(S takes the Constructed Discrepant Cartesian Diver from M and finishes dumping the water out)

(S closely examines the inside of the empty Constructed Discrepant Cartesian Diver)

R: What do you see?

S: Just little .. little water left over
(M takes the Constructed Discrepant Cartesian Diver from S and closely examines the inside of the bottle)
M: The bottom is up
R: What are you looking for?
S: Just to see if there is anything .. anything peculiar inside of it
M: Is the bottom supposed to be up?
R: It's just a normal .. its a normal soap .. its a normal Murphy container
M: But some could be down
S: Okay now try filling it up with water
(S holds the Constructed Discrepant Cartesian Diver)
(M fills the Constructed Discrepant Cartesian Diver with water)
(M over-fills the Constructed Discrepant Cartesian Diver)
S: That's good
M: That was smart
S: Thankyou
R: It's only water
M: It will dry
S: Someday
(S uses an eye-dropper to add more water to the Constructed Discrepant Cartesian Diver)

S and M are given another Discrepant Cartesian Diver designated Assembled Discrepant Cartesian Diver .

(M picks up the Assembled Discrepant Cartesian Diver and squeezes)
M: This one is colder
It has more bubbles
R: Okay it still stands . how do you get both of them to the surface?
(M inverts the Assembled Discrepant Cartesian Diver)
R: Without tipping it upside down
M: Oh
(M squeezes the top edges of the Assembled Discrepant Cartesian Diver)
(S squeezes the bottom sides of the Assembled Discrepant Cartesian Diver)
R: If you squeeze it on that side it goes down
(S moves up the Assembled Discrepant Cartesian Diver and squeezes)
(M squeezes the edges of the Assembled Discrepant Cartesian Diver)
R: Oh it's starting to move
Maybe S can try it
(S squeezes the sides of the Assembled Discrepant Cartesian Diver)
S: It goes down but this one doesn't go up
(S turns the bottle around)
(S squeezes the sides of the Assembled Discrepant Cartesian Diver)
(R gently squeezes the edges of the Assembled Discrepant Cartesian Diver)

The diver resting on the bottom rises to the surface.

R: How did that happen?
(M squeezes in the same location)

The diver fails to rise to the surface.

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

The diver resting on the bottom rises to the surface.

R: You did it!

Try it M

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

The diver resting on the bottom rises to the surface.

R: There you go

S: Maybe there is too much water and not enough air to bring it to the top

R: Why does it go to the top when you squeeze it?

S: This one looks like it is full of water completely all the way to the top (referring to the eye-dropper resting on the bottom) and this one has a bit of air space in it (referring to the eye-dropper resting at the surface) so this one probably has ...

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: Why does it come to the top when you are doing what M is doing?

M: Some water comes out

R: Where's it go?

S: Into the bottle

R: What makes the water come out?

S: The um

M: Pressure

S: The pressure of the squeezing

R: But I thought pressure would put the water in

That is what you said earlier

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: This is unusual

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

M: This one when you press it down it goes up as soon as you let go the water goes down

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

M: But this one when you press water goes out

R: That is an excellent observation

What we have to do is explain why that's so

M: Press this way and it goes up

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: Tell me what you can do take the lid off

(M removes the cap from the Assembled Discrepant Cartesian Diver)

and press it on the sides

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: No the way you were doing it

S: This way?

R: And watch what happens to the water

S: It goes down

R: The water in the container

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

M: If you press it this way it goes up

R: Now can you explain that why the eye-droppers behave the way they do?

M: Because ..

S: The pressure

M: When there is more water . when the water goes up the um the eye-droppers go up

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

S: Well maybe because if you put more pressure here . more pressure here sometimes like the pressure up here will push this down

M: The eye-droppers go the way the water goes

S: If you push it up here it sort of like goes up with it because not enough space maybe right down here

R: Okay that's your theory all right
M you had another one

M: Umm the eye-droppers follow the way the water goes
But that doesn't work

(S replaces the cap on the Assembled Discrepant Cartesian Diver)

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

But if do it this way the eye-droppers go down
So it goes the opposite way of the water

R: Can the water go up when the cap is on?

M: What do you mean?
Can the water go up when the cap is on?

R: Inside the container
Can the water go up when the cap is on

M: <u>No</u>

S: <u>No</u>
Well there is not enough space . well a bit because there is a bit of space but

M: Yah

R: It can't come out though

S: Yah

R: Now we have a big puzzle

S: Let's see if we can fill it all the way to the top

(M removes the cap on the Assembled Discrepant Cartesian Diver)

M: As soon as you release the water goes down

S: Like the water comes up . it goes down

(M replaces the cap on the Assembled Discrepant Cartesian Diver)

M: Let's see if it goes up

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

S: See it fills up with water

R: It goes up into the eye-dropper
What happens when you squeeze it on the side again?

(M squeezes the edges of the Assembled Discrepant Cartesian Diver)
M: The water goes down in the eye-droppers
R: Right
M: And then they are less weight and then they go up
R: That makes good sense but why does it go down in the eye-dropper?
M: Because ..
S: The force is going up
M: The water is going down so it's pushing the water inside the eye-dropper
S: This when you press it like this there's um since it always well usually stays on the side when you twist it around it stays on the side and then when you press it on the side it goes up because I don't know really but it makes it go up if you squeeze it on the side but when you squeeze it here it goes down
(S squeezes the sides of the Assembled Discrepant Cartesian Diver)
(S squeezes the edges of the Assembled Discrepant Cartesian Diver)
R: What was your idea M?
M: The one on the top it goes down ... oh actually
R: What was that?
M: I was going to say the one on top goes down more than this one but it doesn't (referring to the eye-dropper resting on the bottom)
R: It's a puzzle isn't it?
Is there anything you can do to explain that?
Any more I should say you have done a lot of things
(M squeezes the sides of the Assembled Discrepant Cartesian Diver)
M: It goes up and than down
I don't know the weight when you press inwards the water from the bottom goes up into the eye-dropper and the eye-dropper gets weight and it goes down
(M squeezes the edges of the Assembled Discrepant Cartesian Diver)
M: But when you squeeze this way the water from this one goes down so it's pushing the water . no
R: Yes that last bit is very difficult
S: Well ...
M: Has anybody figured it out?
R: Yes we have
M: No but like the other people
R: It's very difficult . very difficult
You're doing a good job
M: I have no idea
R: Is there anything you can do to find out?
You are very close
(S removes the cap from the Assembled Discrepant Cartesian Diver)
M: Is it something to do with the weight?
R: Well certainly the reason the eye-droppers go up and down is got do with the weight
M: Yah I know

R: But why does the water go in and out?
S: Air pressure
R: What's that got to do with it?
Air pressure is a good idea
S: The air-pressure in the eye-droppers . the air pressure makes it lighter but when the water goes in it makes it heavier or is it the other way around
R: I can agree with that
S: Try um
(S squeezes the sides of the Assembled Discrepant Cartesian Diver without the cap on it)
Some of the water comes out of the Assembled Discrepant Cartesian Diver.
(M squeezes the sides of the Assembled Discrepant Cartesian Diver without the cap on it)
M: When the um ... cap is off . well I can't really test it
(S squeezes the sides of the Assembled Discrepant Cartesian Diver without the cap on it)
S: < When the cap is off . if you push it up >
M: < If you push it up the water line >
S: The water goes up and this come with it because that's * * * (referring to the eye-dropper at the surface)
(S squeezes the edges of the Assembled Discrepant Cartesian Diver without the cap on it)
R: When you push it that way
S: When you squeeze it this way
M: But they don't move the bottom doesn't move when the cap is off
(S squeezes the sides of the Assembled Discrepant Cartesian Diver without the cap on it)
R: Fill it right up to the top with water that is what you were going to do one time
(M tops up the Assembled Discrepant Cartesian Diver with water)
(S and M top up the rest of the Assembled Discrepant Cartesian Diver using eye-droppers)
(S replaces the cap on the Assembled Discrepant Cartesian Diver)
R: There is no air at all in the container
S: No
R: There's air in the eye-droppers
(S squeezes the sides of the Assembled Discrepant Cartesian Diver without the cap on it)
(S squeezes the edges of the Assembled Discrepant Cartesian Diver without the cap on it)
R: What happens?
S: It goes up but for some reason this one kind of somehow you have to get it to the top and try and take it out and get all the air out of it (referring to the eye-dropper resting on the bottom)

(M removes the cap on the Assembled Discrepant Cartesian Diver)
(M replaces the cap on the Assembled Discrepant Cartesian Diver)
M: See when you put the cap on water comes out there's
R: Press it in the middle there does it go down?
(M squeezes the sides of the Assembled Discrepant Cartesian)
R: Press it on the side
(M squeezes the edges of the Assembled Discrepant Cartesian Diver)
R: So now you've got them up and down
(S removes the cap on the Assembled Discrepant Cartesian Diver)
(S replaces the cap on the Assembled Discrepant Cartesian Diver but does not tighten it)
S: There try it now
It will probably explode
R: Water will come out
(M squeezes the sides of the Assembled Discrepant Cartesian and holds it)
Some of the water comes out.
(S tightens the cap on the Assembled Discrepant Cartesian Diver)
R: Oh I see what you're doing
S: Try squeezing the side up here
(S squeezes the edges of the Assembled Discrepant Cartesian Diver)
R: It works well doesn't it?
S: Yes
M: I have no idea
R: No I can understand that it's a real problem
S: It's confusing
R: Are you puzzled too? (referring to S)
S: Yah
R: But you really understand very clearly how the eye-droppers go up and down you explained that beautifully
But umm what would you like us to do?
M: Tell us
R: Really?
R: < Tell us > something to do
Take the take the top off
(M removes the cap on the Assembled Discrepant Cartesian Diver)
R: Squeeze it on the side
(S squeezes the edges of the Assembled Discrepant Cartesian Diver and holds it)
Hold it like that
Now M you fill it up with water to the very top
(M adds some water to the Assembled Discrepant Cartesian Diver)
S: It's gonna go flying
R: Now put the top on
(M replaces the cap on the Assembled Discrepant Cartesian Diver)
M: It gonna stay in
R: Put it on nice and tight

M: It's gonna be like a pop bottle
R: Is it?
S: It's gonna go spissssh
(S squeezes the edges of the Assembled Discrepant Cartesian Diver and holds it)
R: What's happening?
M: I don't know
They're going down (referring to both eye-droppers resting on the bottom)
(S inverts the Assembled Discrepant Cartesian Diver)
R: Now what would happen
Turning it upside down is not going to * *
(S uprights the Assembled Discrepant Cartesian Diver)
(M squeezes the edges of the Assembled Discrepant Cartesian Diver)
M: It's easier to
S: Now it's staying at the top (referring on of the eye-dropper rising and floating at the surface)
R: Do they both go up to the top?
S: No only that one and then it went back down
M: It's easier to press on the sides now
R: Yah
S: Here lets see can I try something
(S grabs the Assembled Discrepant Cartesian Diver)
(S squeezes the edges of the Assembled Discrepant Cartesian Diver)
R: One won't coma up at all
S: Well this one it goes up right away and than comes straight down
R: Right so you haven't got one at the top anymore?
M: But how come see this one has a little bit of air but this one doesn't
S: Oh I think
(S removes the cap on the Assembled Discrepant Cartesian Diver)
As S removes the cap water comes out of the Assembled Discrepant Cartesian Diver.
R: Well how . why did the water come out?
S: Because it was full
M: He squeezed it
S: It was full
R: How how can it be full and not * * last time?
How can a bottle be full and than you take the lid off and more comes out?
M: Because it was squished in
And it let .. squished all the water down to the bottom and then put more water in and let go and they go out so it's like it has too much water in it
R: How can you over fill a bottle?
S: But well because it's only plastic and I guess it can stretch out a bit and expand
R: Ah okay
(M squeezes the edges of the Assembled Discrepant Cartesian Diver)

S: Try squeezing it like this

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

R: If we did that with these bottles could we do the same? (referring to the 2 litre pop bottles)

S: Probably no because this is a thicker plastic than that

R: Oh I think these are pretty well the same thickness
You could see if it could work
You can use a smaller one it maybe easier to work with (referring to a 1 litre pop bottle)
We are trying to help you understand what is going on here but we may not be successful
Adults are not always successful in helping people to understand things
The 1 litre pop bottle will be designated Alternative Constructed Discrepant Cartesian Diver.

(S fills up the Alternative Constructed Discrepant Cartesian Diver)

S: That's almost right there (referring to the water level in the bottle)

R: Now can you squeeze the bottle?

S: With the lid on or off it?

R: Off it to add more water

M: You see it has no sides!

R: It has no what?

M: It has no sides

R: What difference does that make?

S: It's round

M: You can't push it down
If can't .. it won't go down

S: If it's round maybe like

M: Cause this one the sides

R: What difference does that make?

M: It's a four sided thing and this is a circle

R: We could call it oval couldn't we

S: See if you squeeze it like this usually these sides go straight in (referring to the Alternative Constructed Discrepant Cartesian Diver) than like otherwise with this one when you squeeze it these sides come in (referring to the Assembled Discrepant Cartesian Diver) and this is a wider bottle in (referring to the Alternative Constructed Discrepant Cartesian Diver)

R: I have an idea we'll pour some water out in (referring to the Alternative Constructed Discrepant Cartesian Diver) now make this bottle the same shape as the other bottle in (referring to the Assembled Discrepant Cartesian Diver) hold it and we'll have S fill it up

(M holds the Alternative Constructed Discrepant Cartesian Diver)

(S fills the Alternative Constructed Discrepant Cartesian Diver)

R: So its the same shape now right

M: Yah

R: Okay now we have the same shape

S: Drop the eye-droppers in?
R: You can do that if you want
(S adds an eye-droppers to the Alternative Constructed Discrepant Cartesian Diver)
(S adds a second eye-droppers to the Alternative Constructed Discrepant Cartesian Diver)
(S replaces the cap on the Alternative Constructed Discrepant Cartesian Diver)
S: They're both at the top
S: Let go and see what the tension is
(M lets the Alternative Constructed Discrepant Cartesian Diver go)
Nothing happens.
R: But what would happen if you took the cap off?
(S removes the cap on the Constructed Discrepant Cartesian Diver)
The bottle expands to its regular shape.
M: It goes down
S: It goes down because it wasn't really filled up to the top it was filled up when it was pressed together
M: That bottle is weird
R: Is it?
S: No I don't know
R: Or are we doing the same thing?
S: Doing the same thing .. except .. well we try and let go and filled this with water (referring to the Constructed Discrepant Cartesian Diver)
(S tops the water in the Constructed Discrepant Cartesian Diver)
(S replaces the on the Constructed Discrepant Cartesian Diver)
(S shakes the Constructed Discrepant Cartesian Diver)
S: Now try it . here
(M squeezes the Constructed Discrepant Cartesian Diver)
M: The one that goes to the bottom has a lot more air
S: I have an idea and I would like to use this bottle (referring to the Assembled Discrepant Cartesian Diver)
(S fills tops off the Assembled Discrepant Cartesian Diver)
(S adds an empty eye-dropper to the Assembled Discrepant Cartesian Diver)
(S adds a second empty eye-dropper to the Assembled Discrepant Cartesian Diver)
(S replaces the cap on the Assembled Discrepant Cartesian Diver)
S: They're stuck both of them are at the top (referring to both of the eye-droppers are resting at the surface)
R: Can you get both of them on the bottom
S: No because it's all filled up to the top and there's more air in them
Look well you can tell cause when you squeeze it not much air can go into it not much water can go into it because there is so much air
M: I've no idea
R: M
Ready to give up?

M: Yes very

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

S: There's not enough air pressure .. in it .. to put them to the bottom
See now watch if I dump a bit of this out . it might . be going it

(S dumps some of the water out of the Assembled Discrepant Cartesian Diver)

(S replaces the cap on the Assembled Discrepant Cartesian Diver)

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: I have never seen somebody squeeze the bottle so hard
Why is the bottle squished in?

M: Cause there is a lot of air in it so it's easier to *

S: For some reason the air pressure up here has a factor in it (referring to the air pocket at the top of the Assembled Discrepant Cartesian Diver)

R: Do you agree M

M: I guess I don't know

R: You've explored some very very difficult ideas here
I never seen anybody find them so many difficult problems I congratulate both of you
What would happen if

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

R: Oh it went back to normal

S: Because I tried to push it this way
See it's weird because if I push it this way (referring to squeezing the sides of the Assembled Discrepant Cartesian Diver) it doesn't push in it doesn't stay like that but if I push it this way it stays (referring to squeezing the edges of the Assembled Discrepant Cartesian Diver)

R: For a little while

S: For some reason

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

S: Water hardly goes up

R: When you push on it sideways

(S squeezes the edges of the Assembled Discrepant Cartesian Diver)

M: But .... when you push it this way the water goes and it doesn't come down

R: It doesn't come down?
You mean

M: Well after a while

R: Are you talking in the bottle or the eye-droppers?

M: Yah the bottle

R: It didn't go down?

M: No

S: < When I unscrew it all the go sqiiish >

(S removes the cap on the Assembled Discrepant Cartesian Diver)

R: Oh the opposite happened

S: Well because the air was tightly secured

(S replaces the cap on the Assembled Discrepant Cartesian Diver)

S: Try it a again M

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

S: Now I will release it now and squeeze

(S removes the cap on the Assembled Discrepant Cartesian Diver)

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

(S replaces the cap on the Assembled Discrepant Cartesian Diver)

S: Okay let go now . see what happens

(M releases the sides of the Assembled Discrepant Cartesian Diver)

R: Why's it different this time?

M: Cause there's less air in the bottle

R: Where did the air go?

M: Out

S: Out

R: Ah ha when you released it

(M squeezes the sides of the Assembled Discrepant Cartesian Diver)

R: So if you released the cap what would happen?

S: The air would come in

(M removes the cap on the Assembled Discrepant Cartesian Diver)

(M replaces the cap on the Assembled Discrepant Cartesian Diver)

M: It would go down

S: The air would come out

R: I think they've explored this as far as they want to go
Do you want us to try and give you an explanation?
When you squeeze it that way (referring to the sides of the Assembled Discrepant Cartesian Diver) the water goes up
Why does the water go up?

S: Because the pressure from the sides

M: The water has no where to go so it goes up

R: When I squeeze it this way (referring to the edges of the Assembled Discrepant Cartesian Diver)

M: You're making it wider

S: These ones have sides and those ones are just round if you squeeze round ones they make more sides

R: Watch the eye-dropper very carefully
Watch what happens to the water in the eye-dropper when I squeeze

S: Oh I see now!
The pressure releases the water and than like if you squeeze this (referring to the edges of the Assembled Discrepant Cartesian Diver)than its putting pressure on that (referring to the cap on the eye-dropper)it squeezes it out

R: Its a very difficult thing to think you way through and I think you've done a superb job
Thankyou both very very much