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Floating and Sinking:

Everyday Science in Middle School

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ABSTRACT

Why do corks always float, lead sinkers sink but clothes pegs both float and sink? This inquiry unit explored these questions and is suitable for upper primary and lower secondary students. The unit comprised sequenced activities culminating in the students making and explaining a working Cartesian Diver. The learning aim was to develop a causal explanation for floating in which students understood floating in terms of balanced forces. The research aim was to document student understandings of balanced forces. Data came from classroom observations and a discourse analysis of the Cartesian Diver activity. The unit explored prior knowledge of floating and sinking, introduced new phenomena demonstrating balanced/unbalanced forces and emphasised 'working scientifically. The study found that a range of alternative conceptions survived alongside a set of scientifically acceptable explanations in different students. This indicates the presence of multiple subjectivities, deep-seated informal alternative discourses and some formal scientific discourses. Students can develop relational explanations for abstract phenomena but need time and guidance.

INTRODUCTION

In 1999 a new science curriculum was introduced in Queensland aimed at developing students' conceptual understandings (Queensland Schools Curriculum Council, (QSCC), 1999) and 'working scientifically' (inquiry science). 'Working scientifically' sets out to engage students in constructing and refining their understandings in science by investigating, understanding and communicating phenomena and science concepts (QSCC, 1999, pp. 32-34). Zipf and Harrison (2002) found that teacher-centred approaches often close down the inquiry process whereas constructivist approaches are more student-centred and promote inquiry (Tobin & Tippins, 1993). Hackling and Fairbrother (1996) argue that open-ended investigations that devolve as many decisions as possible to the students promotes scientific thinking. The new science curriculum is therefore based on constructivist learning theories that establishes prior knowledge and uses this as a foundation for new knowledge.

Our understanding of constructivism holds that the teacher facilitates student understanding through frequent discussions, teacher set and open-ended investigations, demonstrations, argumentation, reflective thinking and research projects. In this framework, the teacher becomes a critical component of curriculum reform (Zipf & Harrison, 2002) because the model of scientific inquiry modeled by the teacher influences the image of science constructed by the students. Constructivist teachers do not believe that 'anything goes'; rather, the teacher manages the learning by devolving what the students can do, on their own, to them. The teacher intervenes with 'need to know' information, questions and analogies

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whenever student learning stalls. Such teachers scaffold learning rather than control or dominate learning. Thus, teachers need robust PCK.

A crisis in science teaching and learning

The quality and quantity of science being taught across Australia in primary and secondary schools is concerning (Goodrum, Hackling, & Rennie, 2000). Key questions ask, how do students develop effective understandings of science concepts, what misconceptions inhibit learning and what strategies promote conceptual change? Driver, Squires, Rushworth and Wood-Robinson (1994) state that students develop ideas about natural phenomena before they are taught science in school. Similarly Osborne and Freyberg (1985b) suggest that students do not always have scientific views but do have ideas about science. Horwood (1988) suggests that science education should assist the student to make sense of her/his world and it is important that students are able to both describe and explain the phenomena they encounter. McDermott (1993) raises the point however, that the difference between what is taught in school and what is learnt is often greater than most teachers realise. We suggest that the basic groundwork for making connections and understandings about science has not been established during those early years in the school system because science is often avoided or taught inappropriately as part of other key learning areas (KLAs) such as English (Appleton & Asoko, 1996; Goodrum et al., 2000). The gap, then, between primary science and secondary level science is potentially magnified. Consequently, science at the senior level is avoided by increasing numbers of students, creating a nation of school leavers bereft of science literacy (Goodrum et al., 2000).

The project and rationale

Our project seeks strategies that enhance students' conceptual learning using cycles of reflective explanations. In part of this project teachers from a rural Queensland primary and secondary school, along with researchers at Central Queensland University (CQU) committed to a professional learning partnership (Harrison & Nichols, 2002). A unit plan focussing on floating and sinking was developed using a practical 'hands on' approach and was taught to five Year-9 classes.

Floating and Sinking

People are curious about Floating and Sinking and most believe that small objects float and large objects sink. Children playing with toys in baths, puddles and ponds know that some toys, leaves, sticks and milk cartons float in water. Children also believe that soft objects float and hard ones sink and often claim that all floating objects have air in them somewhere. Research shows that people hold curious ideas about floating and sinking as highlighted by Driver and her colleagues who wrote that:

> When [7-14 year olds] considered objects which floated with a sizeable proportion above the surface, most children described them as 'floating'. When only a small portion of the object was above the surface, however, some students took a different view: they thought that it was partly floating and partly sinking. Others said that it was starting to sink and would eventually go down. Some pupils, considering objects that appeared to be on top of the water, thought that the objects were not floating because they were held up by the water's skin. Many children thought that objects that were completely submerged but freely suspended such as fish and submarines were not floating … When pupils were asked for one reason why some things floated, the most frequent suggestion was that they floated because they were light. [Few] children qualified their answer by saying 'light for their size.' (Driver et al., 1994, pp. 102-103)

Floating and sinking is a common area of science study often used to develop understandings of balanced forces. Heywood and Parker (2001) believe that students rarely think of floating

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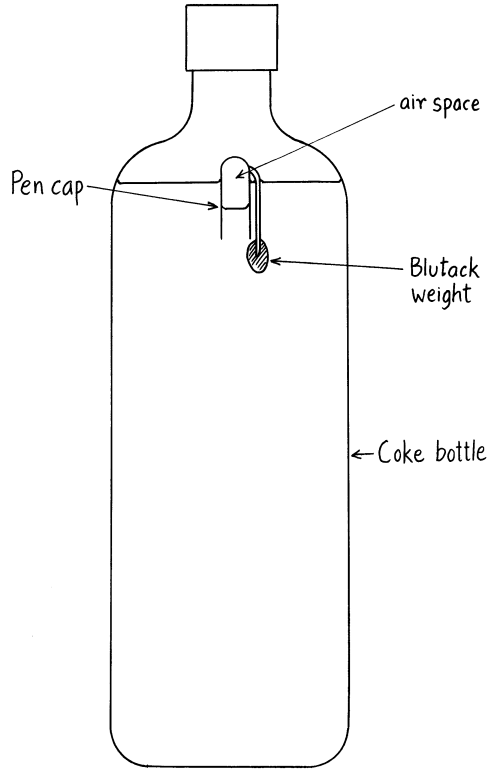
and sinking as forces in action. A common misconception is that weight is a reason why something floats or sinks. Galili (2001, p. 1073) sees weight as a concept that combines a long history, ubiquitous use and considerable theoretical complexity. Indeed, there are subtle differences between the phrases 'weight IS the gravitational force' and 'weight is DUE TO the gravitational force' and Galili suggests "that in current physics textbooks this distinction is not seen, which is why weight is often perceived as a primary quality of an object, or in Galileo's view, a one-way downward pull becomes a common misconception among many students. We may therefore expect difficulties, misunderstandings and incomplete conceptions when teaching floating and sinking.

Floating and Sinking Unit

The 'Floating and Sinking' unit plan was designed to have students work towards a scientific explanation of floating and sinking in terms of balanced and unbalanced forces. The school's science schedule comprised one 30 minute and 2 x 70 minute periods per week. This unit plan consisted of seven sequential lessons designed specifically to build on the knowledge established in the previous lesson and was implemented over a period of three weeks. At the end of this time students were asked to complete an assessment item that involved two parts: one, a practical activity, where each student constructed a Cartesian Diver during class time and two: a written activity, where each student provided a description and explanation of the Cartesian Diver, which was completed at home. Figure 1 shows the worksheet activity.

This paper presents findings from an analysis of the student assessment worksheets indicating their understandings and explanations of floating and sinking. We have divided the remainder of this paper into three sections; in the first section the methodology associated with our data collection and analysis is outlined. The second section presents the results of the study and the third section discusses implications associated with these results in the context of the current literature.

Figure 1: Activity sheet for making a Cartesian Diver



Make a Cartesian diver using a plastic Coke bottle, a Bic pen cap and some plasticine. When you squeeze the bottle, the diver should dive and when you

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stop squeezing the bottle, the diver should rise. You should be able to make it go up and down. Can you make it stop halfway?

Students are asked to research, plan, make, and demonstrate a working Cartesian diver. The criteria are simple: **does it work** (diver goes up and down), students **describe how** it works, and students **explain why** it works.

Students need to make it work and provide either a written or verbal explanation of what is happening. For full marks, they need to talk about balanced forces and how these forces change as the diver ascends and descends.

METHODOLOGY

The research involved five classes of Year 9 students at a rural High School in Queensland. A constructivist methodology was sustained through the data collection, interpretation and reporting, following the theoretical model proposed by Guba and Lincoln (1989). Data collection for this study included participant observation during the classroom activities (Meeriam, 1998), plus the collection of the written worksheets. The worksheets were marked by the students' science teacher, then photocopies of the worksheets were made in order to carry out a discourse and content analysis (Moore, 2003; Rowan, 2001; Wetherell, Taylor, & Yates, 2001). These worksheets were analysed for descriptions of, and explanations concerning the Cartesian Diver. By way of establishing the context we now present observations of the assessment activity as it occurred in two year 9 classes, with teachers Wendy and Graham.

Wendy's class

The assessment began as a practical activity where students were asked to make a working Cartesian Diver (see figure 1). The students were asked to bring a plastic Coke bottle and a Bic pen cap; plasticine was provided. Wendy began with a general discussion around some of the terms that her class had used in the preceding activities in relation to the concepts of floating and sinking. She then described the Cartesian Diver and went over the syllabus outcomes (Energy & Change 5.1) expected for this assessment (QSCC, 1999, p. 22). She told how to seal the Bic cap so no air would escape and how to adjust the amount of plasticine on the bottom of the cap to adjust its weight in order for the pen cap to just float in the water in the Coke bottle. Wendy also asked the students "what do we mean by balanced"; "what is a force?" and reinforced with the students that "as long as you can answer those questions in your own words you will be right". All the students were able to construct a Cartesian Diver and make it work. Part of the assessment included being able to make the Diver ascend, descend and to stop in the middle of the bottle. As the class wrote up their worksheets Wendy walked around discussing the process with the students as they asked questions. She encouraged her students to talk about what they had done and what they had seen. She then asked them to explain what they thought was happening with the Cartesian Diver and to use some of the science terms that they had become familiar with during the past 2-3 weeks as they had worked through the activities.

Graham's class

Graham began in a similar way to Wendy. He revised the terms weight and mass to ensure that his students could use these concepts when they came to write up their explanations of the activity. He spent time going over the work sheet and the students showed great enthusiasm for the activity. Consequently this lesson was successful and all his students made a working Cartesian Diver. Graham moved around his class asking questions and getting students to tell him what they thought was happening when the bottle was squeezed and when the pressure was released. Varying sized bottles added interest and discussion, especially

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when the students were asked to apply pressure to the sides of their bottles. Most of the students got their Divers to momentarily stop halfway, but for some, this part of the activity was difficult. We suggest that this was a powerful learning moment when the students then focused on why some bottles worked and others did not work. Having the Diver stop halfway involved careful balancing of the upward and downward forces and alerted students to the dynamic nature of interacting forces.

RESULTS

First, we present simple quantitative data demonstrating the wide range of responses in the worksheets. This quantitative data is not meant to indicate any statistical significance, but indicates the broad range of expression among this cohort of students, as determined by the textual analysis of the structural content of their written worksheet. This is clearly shown in the number of pages that each student handed in as part of their assessment. Table 1 shows that most students handed in between half to 1 page of written work, focused on their description and/or explanation of what was happening during the Cartesian Diver activity. We include the indicators (Table 2) that were developed and used by the teachers to grade the assessment item in relation to the desired outcomes for this segment of the curriculum. It was the teachers' role to consider whether the students had met the outcomes for this unit, and through this kind of measurement, decide whether the students had understood the concepts being covered in the unit.

Second, we present the qualitative data for the worksheet responses used by the students, to show their understanding of the phenomena experienced in the Diver activity. These are divided into four categories; these are good explanations, description only, misconceptions and confusions. The four categories were then coded according to specific types of explanations using an analytical framework originally developed by Dagher and Cossman (1992). The explanations were then analysed for specific discourses associated with scientifically acceptable conceptual understandings and alternative understandings.

Section 1: Quantitative data

We received 107 assignments from which two worksheets were discounted because of illegible data. Table 1 summarises the assignment lengths.

Table 1: Number of pages written by students (N=107)

< half page	half page	1 page	1.5 – 2 pages	> 2 pages
12 students	60 students	31 students	4 students	0 students

The curriculum statement and outcomes for Energy and Change, against which the assignments were assessed, are as follows (QSCC, 1999)

> *Level 5 Statement*
>
> Students understand that everyday situations can be analysed in terms of the motion of objects and energy transfer. They understand that ideas of energy transfer and transformation can be used to explain common phenomena and the ways of obtaining and using energy.
>
> *Core learning outcome (CLO) 5.1*
>
> Students analyse situations where various forces (including balanced and unbalanced forces) act on objects.
>
> *Level 6 Statement*
>
> Students understand the relationships between laws of motion and energy and everyday experiences. They use these laws to explain energy transfers in the manipulation of forces, and to explore and express ideas about future energy use.
>
> *Core learning outcome 6.1*

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Students use scientific ideas of motion (including action and reaction) to explain everyday experiences.

Indicators achieved towards CLO 5.1 and 6.1 as marked by the science teachers:

Have you:

A) Made a working Cartesian Diver?

B) Correctly described what makes it rise and what makes it sink?

C) Successfully identified forces involved in floating and sinking?

D) Adequately explained why it rises and sinks?

E) Related balanced forces to floating and sinking?

F) Accurately explained whether the diver did or didn't stop halfway?

Table 2: Indicators achieved by students as marked by the science teachers. (N= 105)

Indicator A	Indicator B	Indicator C	Indicator D	Indicator E	Indicator F
105 (100%)	85 (80%)	55 (51%)	56 (52%)	52 (48%)	45 (42%)
	(borderline 2)	(borderline 5)	(borderline 5)	(borderline 4)	(borderline 4)

Of the 105 assessment criteria sheets examined and marked, 100% achieved indicator A, 79.4% achieved indicator B (two students borderline). Borderline achievement was indicated on the criteria marking sheets as a tick that crossed the line between the boxes labelled 'yes/no'. 51.4% achieved Indicator C (5 borderline). Indicator D was achieved by 52.3% (5 borderline); 48.5%) achieved indicator E (4 more borderline). Indicator F was achieved by 45 students (42%) with 4 students presented as borderline achievement. When each paper was examined only 14 students (13%) achieved outcome Energy & Change 5.1 (must demonstrate A) B) C) and E)) while 28 students (26.1%) achieved all of A) to F) thus progressing towards Energy & Change 6.1.

Section 2: Qualitative data

These worksheets were then coded into the following categories:

1) Good explanation — this was defined as a use of appropriate/acceptable terms and concepts in relation to the Cartesian Diver; for example 'mass stays the same but weight changes'. (Note: when we refer to 'good' we are using this term in a post-structural sense; in other words we are using 'good' as a constructed notion, rather than 'good' in the sense of being technically correct.)

2) Description — the student simply described what happened in this activity.

3) Misconception — defined as an incorrect use of terms or concepts such as 'mass changes' or 'floats because of air'.

4) Confusions — worksheets where meanings of terms or concepts, plus the overall narrative used in the response were not adequately explained and/or meaning was muddled.

Table 3 data show that only one student in five provided an adequate explanation and another quarter were just descriptions. Half the students did not adequately explain or describe floating and sinking.

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Table 3: Number of assessments by category (N= 105)

Category	Number	Percentage
Good explanations	21	19.6%
Descriptions	29	27.1%
Misconceptions	50	46.7%
Confusions	5	4.6%

Each category was further coded following Dagher and Cossman's (1992) analytical framework. Dagher and Cossman explored the nature of explanations used by science teachers in junior high school classrooms. Using the constant comparative method, Dagher and Cossman generated ten types of teacher explanation. The types of explanations are listed below and our analysis of each worksheet uses these definitions:

- *Analogical:* A story that parallels the unfamiliar phenomenon, e.g., "it can float because it's like a submarine".
- *Anthropomorphic:* Attributing human characteristics to a phenomenon, e.g., "she floats because she is lighter".
- *Functional:* Explained as a consequence of function (natural), e.g., "It floats because of the air in it".
- *Genetic:* Uses a sequence of events (what, not why) and resembles description by stating "what happens, not why it happens", e.g., "it floated on top of the water".
- *Mechanical:* A relationship because of physical (shape/design) properties (pressure), e.g., "it floats because of its shape".
- *Metaphysical:* Where a supernatural agent is identified as a cause of the phenomena, e.g., "God made it float".
- *Practical (how to):* Instructions of how to perform physical or mental operations, e.g., "to float you need to do …" this was regarded as description rather than explanation.
- *Rational:* A clearly identifiable scientific statement or story where scientific evidence is given for a claim, e.g., "a boat floats because the upthrust from the water equals the weight".
- *Tautological:* This is a circular story, e.g., "it floats because it is made to float
- *Teleological:* It has to or needs to happen as part of the phenomena, e.g., "boats float because we need them to float".

Category one: 'Good' explanations

We applied these categories to the written explanations used by the students and Table 4 shows the types of explanation used by the students whose worksheets were categorised as 'good' explanations.

Table 4: Types of 'good' explanations (N = 21)

Analogical	Anthropomorphic	Functional	Genetic	Mechanical
0	0	6	1	2
Metaphysical	Practical	Rational	Tautological	Teleological
0	0	12	0	0

Note: Many 'good' explanations contain factual errors and misconceptions. 'Good' does not mean that all the statements are scientifically correct; rather, it means that the explanation is well structured and contains a causal explanation using balanced forces. The errors inherent in the 'good' explanations highlight the difficulties students have when reasoning with multiple pieces of information and the complexity of a 'good' explanation.

'Good' explanations followed a specific pattern and were likely to be rational, functional or mechanical. An example of a 'good' **functional** explanation can be seen in the following response:

> When pressure (force) is applied to the bottle the air becomes more compact or compressed. The air becomes compressed rather than the water because water doesn't compact. Therefore the air space in the pen cap also compresses. This then allows more water into the lid, which increases the downward force (from equal with the upthrust). It then supersedes the buoyancy or upthrust and the lid sinks. When the pressure is released the air expands again and the force of the buoyancy causes the lid to rise again. When floating the forces of gravity and buoyancy are both equal but when the cap is ascending or descending the forces are different. (St 46)

Here, the student infers that water entering the pen cap increases the downward force (weight) which then becomes more than the upthrust and *causes* the pen cap to sink. This explanation can be read as though the sinking of the pen cap is a function of the water entering the cap. Functional explanations are similar to those categorised as mechanical however the difference lies in reference to changing the shape or design of the container. Next, in a 'good' **mechanical** explanation the movement of the Diver is related to the application of pressure on the bottle:

> The Cartesian Diver should go up and down when you apply pressure. You have to apply a lot of pressure to get the Diver to go down because the upthrust and the pressure are very strong and the pen cap was balanced. When you wanted it to float on the middle you need only medium pressure. When we wanted it to rise to the top of the water's surface we did not apply any force on the bottle. The related forces are gravity and the increased water pressure in the bottle. (St 26)

The mechanical explanation reasons that the Cartesian Diver moves as a consequence of the changing shape of the bottle as the bottle is squeezed. A strong connection is made between the rise and sinking of the Cartesian Diver and the amount of pressure or squeezing on the bottle. This student explains how applying pressure alters the relationship between forces of gravity and upthrust. The causal differences between the 'good' functional and the 'good' mechanical explanations lie in the way the students talk about the relationship of air, water and pressure. In other words, there is a lack of talking about amounts of water and air and hence, by inference, weight changes.

Twelve responses could be categorised as 'good' **rational** explanations – scientifically acceptable discourses where scientific concepts were used to explain what was happening. In constructing such a story, the student uses scientific terms in reasoned way:

> When the Diver is floating, all the forces which include gravity, buoyancy and the forces acting from either side are equal causing an equilibrium therefore the diver must float. But when you add pressure to either side of the Diver the force from either side is greater than before and the air is contracted into an even smaller space, so the water has more room to fill in adding to the weight of the diver so it must sink lower in the water. (St 61).

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This implies that the student sees the movement of the Diver as the result of the change between the forces acting within the system of the bottle. The student explains why the movement occurs; consequently, the explanation can be seen as the result or product of a process of reasoning communicated by the student in a written form. Three 'good explanations' used analogies within the explanations, for example:

> With the lid [of the bottle] on, when the bottle is squeezed quite hard, the pen lid sinks because the air inside it compresses. When the air compresses, the water fills the left over space, which makes the pen lid have more weight making the gravity increase. This makes the pen lid sink. … The Cartesian Diver works the same way as a submarine. The air that is stored in submarines is liquid oxygen. This is more compressed than regular air so it takes up less space and therefore has more space to allow for the water needed to increase the weight of the submarine. It will then sink because the gravity acting upon it is greater than the buoyancy. (St 44)

Here the student likens the Cartesian Diver to the way a submarine works; referring to the action of descending and ascending submarines to show the way in which the pen cap is able to be raised or lowered within the bottle by applying pressure to the outside of the container. The student continues the explanation referring to how the presence of water will add weight to the submarine. Using the analogy of a submarine, the student uses a 'known' phenomenon (the movement of the submarine) as an explanation of a previously unknown phenomena (the Cartesian Diver).

It was surprising that only twenty-one of the 105 papers could be categorised as using good explanations considering the amount of time spent discussing the activity both before, during and after the actual practical application between the students, teacher and the two researchers who took part in each practical session. This Diver activity took place during a '70 minute' teaching period where there was a reasonable amount of time spent, by each student in talking with the teachers and with the two researchers present. In each of the classes the students enjoyed the activity and were very enthusiastic about showing their successful divers to both the teacher and the two researchers. Table 5 lists the categories of explanations other than 'good' explanations.

Table 5: Categories of alternative explanations (N= 84)

Category	Number
Description	29 (27.1%)
Misconceptions	50 (46.7%)
Confusions	5 (4.6%)

Category two: Description

While 19.6% of the student papers were 'good', 27.1% were classified as purely descriptive. Here the students merely re-told what had happened during the activity as shown in the following example:

> The way it worked was by the amount of pressure that was put on the bottle to make the pen lid sink. As I squeezed the top of the bottle the diver sunk to the bottom and rose again. This was because the bluetac that was on the end of the lid, wasn't too heavy that it sunk straight away, but wasn't too light that it floated horizontally. (St 78)

The student describes squeezing the bottle so that the Diver sinks and rises and refers to the amount of bluetac on the pen lid. Although there is some reference to the notion that the pen lid has weight due to the amount of bluetac there is less of an emphasis on this as altering the

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relationships between the forces acting within the closed system of the Cartesian Diver. While these worksheets include a apparent theme of a relationship between squeezing the bottle and thus applying pressure, there was no explicit explanation of the relationship between forces involved with the floating and sinking aspects of the Cartesian Diver.

Within the category of 'descriptions' four common discourses could be identified. These themes related to

- Squeezing the bottle
- Pressure on the bottle
- Upthrust and
- The rising water level.

These four discourses identified key ideas contained in the written statements indicating the different understandings of the students as to the reasons why/how the Diver worked. What this shows is that the students who used descriptions rather than explanations were highly aware of what was happening within the bottles but did not have the language or the concepts to work through a reasoned explanation and merely saw the assessment as a record of the activity that they had done. This points to is the need to design specific teaching interventions to address this shortcoming.

Category three: Misconceptions

The largest group of alternative explanations were categorised as misconceptions. These papers made up 46.7% of the worksheets analysed. The same analytical framework was applied to this category of worksheets in order to evaluate if the misconceptions contained any patterns of specific types of explanations. We found that the majority of misconceptions were in explanations that could be coded as functional, while the remainder were coded as analogical, genetic, and mechanical, with only two rational and one teleological explanation. We also found that these misconceptions contained discourses that included air, forces, pressure, mass/weight, volume, and increased water levels. We present the types of explanations found in the 'misconceptions' category (listed in Table 6) first, and then, discuss the patterns emerging from these misconceptions.

Table 6: Types of explanations found within the misconception category (N = 50)

Analogical	Anthropomorphic	Functional	Genetic	Mechanical
3	0	30	5	9
Metaphysical	Practical	Rational	Tautological	Teleological
0	0	2	0	1

Of the 50 misconceptions, three worksheets referred to submarines. While we have loosely categorised these three explanations as analogical, it is more of a comparison than an analogy, as seen in the following example. The student begins by discussing what happens when the bottle is squeezed and how the Cartesian Diver can be made to stop halfway in the bottle. The student then goes on to say:

> This acts like a submarine because when submarines let water into a special compartment so they sink to the bottom easier, then when they have to rise they pump the water out so they can float to the surface. (St 51)

This 'explanation' may also be anthropomorphic in the way in which the student refers to the submarine doing the pumping of the water (Tamir & Zohar, 1991). This is seen particularly with the phrase "they pump the water out so they can float to the surface". Submarines were

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commonly compared as a reference point to explain why the Diver was able to float and sink, however the students did not go pass the notion of description when explaining how submarines or the Divers actually worked. Five worksheets were categorised as genetic explanations where these types of explanations focused more of the sequence of events rather than how the movement of the Cartesian Diver occurred. This is clearly seen in the following statements:

> When the bottle is squeezed the air pressure expands out and the cap sinks (St16).
>
> The pressure of the air makes it go up and down, the harder you push the bottle in the most likely it is to sink to the bottom (St 31).

Genetic explanations focus on the sequence of events that occurred during the activities rather than providing an underlying reason for the movement of the Diver. Students using this type of explanation predominantly saw air as causing the movement of the Diver. While this resembles functional explanations, the difference lies in the way the students used the role of 'air' in causing the sequence of events. We wondered whether the students who answered this way did so because they were being idle or they did not know. This needs to be considered because it highlights the role of motivation in the classroom activities. Nine of the 50 worksheets were categorised as mechanical explanations where the physical shape or design was a key focus as is indicated in this statement:

> By squeezing the sides of the bottle the water pressure increases and causes the lid to descend deeper in the water. (St 24).

This student infers that squeezing changes the shape of the bottle and causes the Cartesian Diver to descend. A mechanical explanation, this response refers more to the properties of the container than the forces that the student sees as acting on the Diver. Misconceptions can occur easily when students are writing about how they 'see' something happened, rather than writing down a reasoned or logical step-by-step explanation. While rational explanations are more likely to be associated with 'good' explanations, rational explanations containing misconceptions were found in these worksheets. The misconceptions relate more to the wrong conclusion rather than errors in the process of working out how the Diver works, as highlighted in the following example:

> When the bottle is squeezed the water pressure increases and compresses the air in the pen lid, causing there to be more water in the pen lid than air, causing it to sink because it's less buoyant. (St 58)

In this segment the student appears to have reasoned that the pressure caused by squeezing the bottle compresses the air in the lid, however, rather than focusing on the increased amount of water altering the weight of the Diver, the student has concluded that the lack of air in the cap has caused the Diver to sink (Driver et al., 1994).

Most misconceptions were found in the group categorised as functional explanations. Functional explanations were defined earlier as a phenomenon explained as a consequence of function (natural) where explanations such as 'It floats because of the air' were used. From this definition most of the misconceptions were related to the way that these students perceived the role or presence of air in causing floating or sinking. For example a common misconception was that:

> The force of the compressed air pushes the Diver down (St 77; St 47; St 36; St 82).

Functional explanations are shown in Table 8. Most misconceptions coded as functional explanations related to how many students understood the function of air in explaining floating and sinking. Most of the students who used a functional explanation explained the actions of the Cartesian Diver as a consequence of the presence of air either in the cap or in

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the bottle. From this it can be argued that functional explanations that focused on air were more likely to contain misconceptions (Driver et al., 1994). Other dominant discourses found within functional explanations that had been categorised as misconceptions were related to forces, mass/weight and pressure (see Table 7).

Table 7: Dominant discourses found within functional explanations in the misconception category (N=50)

Theme	Number of Worksheets
Air	23
Pressure	9
Forces	6
Mass/weight	8
Volume	1
Increased water	3

There were three main discourses relating to air, the first concerns air that forces the Diver down to the bottom of the bottle as seen in this excerpt:

> The Cartesian Diver works because when pressure is forced onto the bottle it caused the water level in the bottle to rise. This then, made the air in the top of the bottle become compressed in the small space remaining in the top of the bottle. This then drove pressure onto the Cartesian Diver and made it descend. (St 23).

In this example the student suggests that the air in the top of the bottle rather than the lid 'made' the Diver to sink. What is significant here is the way language is used; 'forces' is used as a verb rather than a noun. So the air is then given human actions — so the air then, has free will to initiate the actions that happen. A similar discourse concerns air leaving the Diver:

> The reason that the pen cap sank was because I squeezed the bottle, which meant the air was released out of the cap, and when I stopped squeezing the bottle all the air come back in (St 25).

This student perceives the air as being squeezed out of the cap as the bottle is squeezed. There is no indication as to where this air goes, just as there is no indication of how the air 'comes back'; it reappears magically. Another common discourse was that air pressure above the pen lid causes the Diver to sink or, alternatively, the water puts pressure on the lid as shown in these statements:

> When the Cartesian Diver was placed inside the bottle it had a large air space inside and stayed afloat as the air was trying to escape the lid, plus there was more upthrust than gravity acting here. But when the bottle was squeezed the weight of the Cartesian Diver increased, as the water is putting pressure on the pen lid which makes it heavier and the gravity force is stronger than the upthrust, in result it tends to sink. (St 56)

> The pressure above the water increases and pushes the pen lid down (St 63)

In both of these statement there appears to be a perception that 'whatever' is above the pen cap, when the bottle is squeezed, this 'whatever' in turn, pushes from the top down onto the cap, causing the pen cap to sink. The last common misconception concerns mass and weight. In the worksheets these two terms were often either seen as the same or are confused with one another as demonstrated in the following statement:

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> The Cartesian Diver works because of pressure and gravity. It is also because when something is put into water it loses all its mass and depends on a pressure or a force of some kind to make it descend deeper into the water (St 66).

Here, 'mass' has been confused with 'weight' and mass is seen as something that changes in relation to the depth of water in which the object is placed. Two other confusions relate to volume and the changing water level. Again this may be seen as both confusion among terms and a misconception, for example:

> The lid rose when the bottle was released because the air inside the lid helped it to float to the surface. When the bottle is squeezed the water level rises around and inside the pen reducing the volume of the water and making the pen lid heavier (St 92).

Although the student states a misconception regarding the role of air in the pen lid, "the air helps the lid to float", there is some confusion about what is actually being reduced when the bottle is squeezed and how this is connected with making the pen lid heavier.

Category four: Confusion

Five written explanations were classified as confused and this represented a very small group among the 107 worksheets. This indicates that most of the students were capable of some reasoned response: the question then becomes, what teaching and learning inquiry experiences enhance their explanations? (see discussion section). While there was confusion among the scientific terms used in the worksheets concerning mass and weight, density and balanced forces (St 59; St 85) there was also confusion about the relationship between air, pressure and forces as seen in the following excerpt:

> When you squeeze the bottle, the air bubble inside the lid has no effect and releases the air leaving little air inside making it more dense, that also effects the floating and sinking. When the pressure is released it leaves less pressure making it easier for the air to take effect. (St 97).

While this statement could be interpreted that the student 'knows' what is happening the vocabulary available to this student does not enable the explanation to be seen as reasonable or that the student 'understands' the phenomena in a scientifically acceptable conceptual model. What this indicates is that most of the students were capable of a reasoned response, but that teaching and learning experiences that could enhance the explanations of this group need to be enhanced. Exploration of this analysis and what it means for the conceptual understandings of the students is covered in the following discussion section of the paper where we discuss these results and associated implications/recommendations in the context of literature concerning student understandings of classroom activities.

DISCUSSION and CONCLUSIONS

Scientific Language and Explanation

McDermott (1993) suggests that the reasoning used by students reveals a great deal about their understandings of the scientific concepts being discussed. This was evident in the worksheet discourses. Close examination of the worksheet discourses revealed some 'good explanations' (19.6%) of the forces involved with floating and sinking but a large percentage of worksheets still contained misconceptions (46.7%). This group deserves our pedagogical attention. The misconceptions followed specific patterns in the explanations put forward. While this high number of misconceptions may be interpreted as the students lacking understanding of the concepts explored in the unit plan, it also indicates that many students may lack the 'scientific language' (Bell & Freyberg, 1985) and a means of communicating a reasoned written explanation. Bell and Freyberg (1985) differentiate metaphoric and scientific

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meaning with metaphoric meaning using everyday language. This can be seen in statements like "gravity pulls the lid down" where students rationalise an action from the way they see it unfold in front of them.

With this in mind it is important that teachers and students identify the kind of understanding/meaning/language that both are using. Bell and Freyberg (1985) suggest that students are more likely to work with the metaphoric meaning while the teacher works from the scientific meaning. It is therefore important for the teacher and the students to understand the difference between these meanings and to negotiate which 'language' is being used. In this instance, a strategy that develops common or shared conceptual vocabulary is important.

Osborne and Freyberg (1985a, p. 5) suggest that children develop their own ideas about science that are often significantly different to those used by scientists and that "many children find it difficult to understand the ideas put forward in science lessons". However this lack of understanding is not necessarily due to 'poor' teaching but rather is influenced by the children's own view of the world. Like Osborne and Freyberg (1985a), we found that children's views of the world are highly contextualised and multiple. This is demonstrated in statements such as "the now compressed air is not enough to keep the weight of the cap afloat so it sank". This illustrates an everyday understanding of motion, rather a relational concept involving forces. A strategy that may help here is the practice of expressing step-by-step reasoned arguments. Students need time and practice (repetition) in being able to work through their thoughts orally or on paper.

Heywood and Parker (2001, p. 1180) extend the notion of everyday understandings when they assert that the force concept is problematic to teach because the Newtonian view of force and motion involves the development of an abstract conception that often is at odds with the everyday experiences of the students. To us, this highlights the presence of multiple subjectivities and competing discourses between students and within each student. Misconceptions can be seen, then, as informal discourses held about formal science concepts and may explain why, for some students, these informal beliefs are hard to change.

Consequently, teaching strategies that explore prior knowledge are essential to ascertain the kinds of images and 'talk' that children use when constructing their ideas about science and how 'things' work. Another critical element is time; more time is needed for teachers to develop the ideas and understandings that children have, and to work towards a shared understanding of what specific concepts mean using scientific terminology.

Weaknesses in Explanations

The incomplete conceptions demonstrated by a majority of students and the presence of errors and misconceptions in most of the student explanations accords with Galili's (2001) predictions of difficulties in teaching floating as a balanced force interaction. Less that 20% of students came close to producing a force-based explanation that is relational and interactive. We should not be discouraged because most of the other students, to varying degrees, produced descriptions that could, given time and discussion, develop into scientific explanations. This was the Year-9 class' first experience of this type of teaching, learning and explaining.

Available textbooks are relatively silent on discussion concerning balanced forces, especially related to floating and sinking. The degree to which errors and misconceptions in textbooks on the subject of forces influenced the teachers' and students' prior knowledge also is unclear (Harrison, 2001, Zipf & Harrison, 2002). This is a subject for further research.

Knowledge and Reasoning

McDermott (1993) suggests that even when scientific statements are correct, the reasoning is not and this was highlighted in many of the worksheets. For example:

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> When the Cartesian Diver was placed inside the bottle it had a large air space inside and stayed afloat as the air was trying to escape the lid, plus there was more upthrust than gravity acting here. But when the bottle was squeezed the weight of the Cartesian Diver increased, as the water is putting pressure on the pen lid which makes it heavier and the gravity force is stronger than the upthrust, in result it tends to sink (St 56)

While the student knows that pressure and gravity are involved with floating and sinking on further examination of the explanation, it is evident that pressure and gravity are just words being used rather than part of a reasoned explanation of why the Diver works. This clearly shows that this student may not have scientifically acceptable views about the science involved but he/she does have ideas about how the Cartesian Diver worked (Osborne & Freyberg, 1985b). These ideas need to be worked through, perhaps using bridging analogies (Clement, 1993), concept substitution and problem solving skills (Harrison, Grayson, & Treagust, 1999). With some explanations the problem was the use of terms such as gravity, mass, weight and pressure; however, there often was no direct link made between the interrelationship of these concepts. As McDermott (1993, p. 153) states "this indiscriminate use of language reflects the fragmentary nature of their [students'] understandings of the particular topic". DiSessa (1988) calls this phenomena 'knowledge in pieces'. Students do not have logical organised theoretical statements rather they have bits of scientific information. The role of future research is to devise, trial and refine ways to help student explain rather than describe and to learn how to construct relational explanations.

What this may mean is that while many students could identify and name scientific concepts they were often unsure of the correct relationship between these concepts in terms of floating and sinking. Clearly demonstrated then, in this study, was the difference in many of the students' abilities to write reasoned, logical good explanations with a scientifically acceptable conclusion and their ability to talk through some of the actions of the Cartesian Diver in the classroom. The aim of the new Queensland Science Curriculum (QSCC1999) is to promote "working scientifically" where students are encouraged to communicate what they are seeing, doing and experiencing. While Horwood (1988) declares students should be able to both describe and explain phenomena, it is equally important, as McDermott (1993) points out, for students to be able to have practice in problem-solving qualitative problems and in explaining their reasoning. Thus, in a constructivist epistemology of "working scientifically", a floating and sinking inquiry unit seems capable of promoting the active engagement in thinking and doing science that can develop relational explanations.

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