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An exploration of common student misconceptions in science

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This study formed the basis of an assignment for a teacher-training course. The objectives of the study were to define three scientific concepts and identify for each some of the misconceptions that students commonly have. Six students, representing three distinct age groups were interviewed, using a predetermined set of questions and activities for each concept. Student responses were recorded and evaluated in an attempt to understand what misconceptions were held by the students, how they acquired them. The study showed that the level of misconceptions varied between concepts. There appeared to be some patterns in the level and type of misconceptions between the three age groups, suggesting that a more rigorous study in this area would be of value.

Science, misconceptions, teacher training, students

INTRODUCTION

Concepts can be considered as ideas, objects or events that help us understand the world around us (Eggen and Kauchak, 2004). Misconceptions, on the other hand can be described as ideas that provide an incorrect understanding of such ideas, objects or events that are constructed based on a person's experience (Martin *et al*., 2002) including such things as preconceived notions, non-scientific beliefs, naïve theories, mixed conceptions or conceptual misunderstandings (Hanuscin, n.d..). Piaget suggests that children search for meaning as they interact with the world around them (see Eggen and Kauchak, 2004, p.281) and use such experiences to test and modify existing schemas. There are many possible sources for the development of misconceptions. First, not all experiences lead to correct conclusions or result in students seeing all possible outcomes. Second, when parents or other family members are confronted with questions from their children, rather that admitting to not knowing the answer, it is common for them to give an incorrect one (Alagumalai, pers. comm*.).* Other sources of misconceptions include resource materials, the media and teachers (http://www.jhargis.com/misconex.htm). The main issue is that all of the above sources are considered to be 'trustworthy', leading to ready acceptance by students of what they are being taught (http://www.jhargis.com/misconex.htm).

Misconceptions themselves can be related to such things as misunderstanding factual information or being given conflicting information from credible sources such as parents and teachers (http://www.jhargis.com/misconex.htm); Hanuscin, n.d.). The big issues are that once a misconception has been formed, it is extremely difficult to change (Eggen and Kauchak, 2004) and that possessing misconceptions can have serious impacts on learning (Hanuscin, n.d.).

Students come into the classroom with prerequisite knowledge (existing schemas) and as they progress through their education these schemas are progressively (or sequentially) built upon

(Alagumalai, pers. comm.). In order to teach science effectively, it is vital to ensure that existing schemas are sound and to modify any misconceptions that will compromise them, following the logic that misconceptions themselves can be considered to be sequential and therefore lead to ever increasing issues with learning as students continue to build their knowledge on current understandings (Hanuscin, n.d.; Alagumalai, pers. comm.). There are many strategies available to help teachers modify misconceptions (http://www.jhargis.com/misconex.htm), but before this can be achieved, the teacher needs to have strategies for identifying exactly what misconceptions a student may have.

This study was undertaken as an assignment in a Junior Science Methodology course as part of a Graduate Teacher training program. As such it was more of a learning exercise rather than a true research project. The objectives of the study were to define three scientific concepts and identify for each some of the misconceptions that students commonly have. Six students of different ages were interviewed, using a predetermined set of questions and activities for each concept and their responses recorded, in an attempt to discover what the students' misconceptions were, how they acquired them and whether the exercises, combined with discussion, helped to modify any such misconceptions. Three examples of science concepts and their associated misconceptions are given in Table 1.

Table 1. Three examples of science concepts and their associated misconceptions

Scientific Concepts	Associated Misconceptions
Whether something sinks or floats depends on a combination of its density, buoyancy, and effect on surface tension.	Things float if they are light and sink if they are heavy.
Clouds contain very small particles of water or ice that are held up in the air by the lifting action of air currents, wind and convection. These particles can become bigger through condensation and when they become too heavy to be held up in the air they fall to the earth as rain, hail or snow.	Clouds contain water that leaks out as rain.
An animal is a multicellular organism that is capable of independent movement.	An animal is a land mammal other than a human being. Insects, birds and fish are not animals.

METHODOLOGY

Subjects

Six students, ranging between 6 and 15 years old were interviewed, to test both the misconceptions themselves, and whether they changed with the age of the students (Table 2). The students could be roughly split into three age groups: a) 6 to 7 years old, b) 10 years old and c) 14 to 15 years old.

Table 2. Age demographic of students interviewed

Student	Age
1	6
2	7
3	10
4	10
5	14
6	15

Approach

Three different approaches were used for the interviews. For Misconception 1, students tested the question using practical activities. For Misconception 2, students had to give verbal responses. For Misconception 3, a questionnaire was used (adapted from Dawson, 1997), in which, having been asked the question, students ticked off their answers on a worksheet. The aim of using three different approaches was to make the interviews: a) more fun for the students, b) more informative for the interviewers, and c) allow a range styles for presenting results. In all cases, probing and clarifying questions were used in an attempt to identify the bases for the students' responses.

Student interviews: The student interviews were divided into four parts.

1. Students were asked a question or series of questions.
2. Students were asked to answer or test the question(s).
3. Students' answers or discoveries were discussed with the interviewer.
4. Students were asked to answer further, or test discoveries again.

The approaches for the student interviews were as follows.

Misconception 1: Things float if they are light and sink if they are heavy.

1. Why do some things float and some things sink?
2. Feel these two items. (Metal and plastic spoons of the same size). Which is heavier? Will they float or sink? Why? Test this to see whether you were right. Why was it so?
3. What about these two items? (Small metal pin/drawing pin and large plastic spatula/chopstick) Will they float or sink? Why? Test this to see whether you were right. Why was it so?
4. What about these two items? (Metal lid and plastic animal). Will they float or sink? Why? Test this to see whether you were right. Why was it so?
5. What about these two items? (Two plastic animals of the same size) Will they float or sink? Why? Test this to see whether you were right. Why was it so?
6. Discuss.

Misconception 2: Clouds contain water that leaks out as rain.

1. What is a cloud?
2. What makes up a cloud and how does it form?
3. How does rain get out of clouds?
4. What happens to the cloud when it rains?
5. Discuss.

Misconception 3: Birds, fish and insects are not animals.

1. What is an animal?
2. Look at the worksheet and tick whether you think each thing listed is an animal, plant or something else.
3. How did you decide on these answers?
4. Discuss.
5. Would you change any of your answers?

RESULTS

Misconception 1: Things float if they are light and sink if they are heavy

Why do some things float and some things sink? In response to the initial question of why some things float and some things sink, four out of six of the students initially explained sinking and floating in terms of weight. However, most had some understanding that shape or other factors could influence this, but found it difficult to describe. The eldest student (age 15) had a clear and accurate understanding while the youngest (age 6) had some vague notions of water and air pressure deciding what would sink or float. Details of student responses to testing whether various items would sink or float in Experiments 1-4 are given in Table 3.

Table 3. Student Responses to Misconception 1: Things float if they are light and sink if they are heavy

Experiment	Item	Prediction	Reason	Result
Student 1 - Age 6 years				
1	Plastic Spoon	float	because it is plastic	float
	Metal Spoon	sink	heavy	sink
2	Plastic Toy	sink	because it is made of rough plastic	float
	Drawing Pin	float	because it is boat shaped	sink
3	Plastic Chopstick	sink		sink
	Metal lid	float (but only if you put it in gently)		float
4	Plastic animal	float	because they are the same plastic as before	float
	Plastic animal	float	because they are the same plastic as before	sink
Student 2 - Age 7 years				
1	Plastic Spoon	float	light	float
	Metal Spoon	sink	heavy	sink
2	Plastic spatula	float	light	float
	Metal pin	sink	heavy, made of metal	sink
3	Plastic animal	sink	heavy	sink
	Metal lid	float	lid is like a boat	float
4	Plastic animal	sink	because of shape (cf experiment 3)	float
	Plastic animal	sink	because of shape (cf experiment 3)	sink
Student 3 - Age 10 years				
1	Plastic Spoon	float	light	float
	Metal Spoon	sink	heavy	sink
2	Plastic spatula	don't know	don't know	float
	Metal pin	sink	heavier than spatula	sink
3	Plastic animal	sink	heavier than lid	sink
	Metal lid	float	don't know	float
4	Plastic animal	float	slightly lighter	float
	Plastic animal	sink	slightly heavier	sink
Student 4 - Age 10 years				
1	Plastic Spoon	float	light	float
	Metal Spoon	sink	heavy	sink
2	Plastic Toy	float	just know from the past	float
	Drawing Pin	sink	just know from the past	sink
3	Chopstick	sink	used them before	sink
	Metal lid	float	because of its shape	float
4	Plastic animal	sink	practically hollow	float
	Plastic animal	sink	not hollow, different shape	sink
Student 6 - age 15 years				
1	Plastic Spoon	float	light, doesn't break surface tension	float
	Metal Spoon	don't know	metal broke surface tension	sink
2	Plastic spatula	don't know	surface tension	float
	Metal pin	float	surface tension	sink
3	Plastic animal	float	less dense than metal	sink
	Metal lid	sink	more dense than plastic	float
4	Plastic animal	sink	because plastic animal sank in Experiment 3	float
	Plastic animal	sink	because plastic animal sank in Experiment 3	sink

Experiment 1: Heavy metal and light plastic. A plastic and a metal spoon of same size and shape but markedly different weights were tested. Three out of five students (there was one missing response for this section) predicted that on the basis of weight alone the metal spoon would sink. The youngest student made the same decision but on the basis of the materials the spoons were made of. While the eldest wouldn't commit to whether the metal spoon would sink or float as he couldn't predict its ability to break surface tension.

Experiment 2: Light metal and heavy plastic. A plastic spatula (Sue)/toy (Fiona) and a metal pin (Sue)/drawing pin (Fiona) of markedly different shape, size and weight were tested. Despite the large weight difference, two of the students thought that the pin was heavier (less than 1g) than the spatula (15g). The eldest child (age 15 years) felt that the pin would not break surface tension and would therefore float. One student thought that the drawing pin would float because it was boat shaped and that the toy would sink as the plastic was rough. Two of the children quickly recognised that their first explanation had been incorrect as testing showed that the drawing pin, although lighter sank, while the toy floated. The others in general continued to insist that they were right even after observing results to the contrary). For example, even after careful weighing, one student (age 10 years) still maintained that the pin was heavier than the spatula.

Experiment 3: Metal and plastic of differing surface areas (plastic lighter than metal but smaller surface area). Some of the students predicted that the plastic would float (one justified this on the basis that it was less dense). Two students thought the plastic toy would sink because it was heavy. Most of the students thought the lid would float. Various reasons were given but many related, eventually, to the shape of the lid, the youngest (age 6 years) acknowledging that the lid needed to be placed carefully for this to occur. The eldest child (age 15 years), despite having used surface tension as his argument throughout the interview, did not recognise that here was actually a case for demonstrating surface tension and actually expected the lid to sink, which he attributed in this case to its density.

Experiment 4: Two plastic toys of approximately the same weight and shape. Three of the five students (there was one missing response for this section) based their answers on the experience of the plastic toy used in Experiment 3 and thus predicted that both would sink. Two students were correct in their conclusions although it was hard to see how they determined the differences.

Misconception 2: Clouds contain water that leaks out as rain

What is a cloud? All four younger student described clouds in terms of their visual appearance on a fine day. The 7 year old described clouds as ‘steam-like’, analogous to the steam generated in the bathroom after showering. The eldest student (age 15 years) described clouds as water vapour floating above the dew point, while the 14 year old described them as water mixed with air that stays together.

What is a cloud made of and how do they form? Three of the students said that clouds were made of water or water vapour. Two said they were made of gas (undefined) and one that they were made of undefined crystals. In terms of how they form, two students (ages 10 and 14 years) stated that they had no idea and left it at that. Three children (ages 7, 10 and 15 years) talked about evaporation of water, two of them (ages 7 and 15 years) additionally defined the ocean as the source of the water. The youngest (age 6 years) described clouds as coming from the sky.

How does the rain get out of a cloud? Three of the students (ages 7, 10 and 15 years) had a general concept of water (or clouds) getting heavier until it rained. Three did, however, have strong misconceptions:

Age 6: “Clouds melt”

Age 10: “Clouds bump together and the rain gets squeezed out”

Age 15: “Too much evaporation gets into the clouds until they fill up and burst open and drain out. Like too much water in a balloon that then bursts.”

What happens to a cloud when it rains? Before describing the answers to this question it has to be acknowledged that it was not a good question as there is no clear answer. We originally designed the question to direct the students to the idea that clouds are made of water, not just contain it. Most of the students felt that the cloud would go away or at least diminish in size as it rained. The youngest (age 6 years) thought that clouds get bigger when it is raining (which is admittedly true in one sense).

Misconception 3: An animal is a land mammal other than a human being, and birds, fish and insects are not animals

An animal is a land mammal other than a human being. Four of the students had no general misconceptions about what an animal is and classified them correctly in the survey. The other two (ages 7 and 10 years) initially felt that humans were not animals but corrected that idea following some discussion. The 6 year-old correctly classified all of the animals but also included trees in this category. He had been taught the definition of an animal at school just three weeks prior and had decided that trees also fitted into that criteria, based on the idea that animals were alive, ate and could grow. During discussions, it did however, become apparent that despite getting the responses correct, student descriptions of defining features for being an animal included such things as having a heart, a brain, eating meat and having a digestive system, thus showing some degree of misconception.

Birds, fish and insects are not animals. Only one student had a misconception in classifying birds, fish and insects as animals. Despite an initial reluctance to participate in the classification exercise, she eventually classified all animals correctly except for insects, which she intimated were not animals as she had been taught that at school. She had been recently studying insects and learning the definition of an insect, and felt therefore that this separated them from animals.

DISCUSSION

Student Misconceptions

This study was a preliminary investigation. However, a number of observations suggested various patterns that would be worth following up. The first thing we observed was that, in general, the level of student misconceptions about the scientific concepts we posed was lower than we had expected. We also found that the youngest students often had roughly correct conceptions that appeared to be intuitive or experiential, but that these could be easily confused by what they had been subsequently taught as observed in older students. We saw a number of examples where an initially sound (and often simple) concept became confused after additional information was added through teaching (such as when learning specifically about insects led to acquisition of the misconception that they now had to be classified separately to other animals). It is commonly suggested that parents, teachers and the media all influence the development of misconceptions in science (http://www.jhargis.com/misconex.htm). In the same way that learning in science can be considered to be a sequential process, so can the development of misconceptions, so that once a misconception has been acquired it may be carried on and built upon further. As such it is imperative that teachers need to be very careful to introduce new topics in such a way as to prevent students from developing misconceptions that did not exist before as new but related concepts are introduced, namely, to integrate new knowledge into older understandings in such a way that links are maintained and correct concepts are maintained.

How did students learn or discover their responses, including their misconceptions? During the interviews it was not always easy to determine how students had acquired their ideas. It is difficult to generalise based on age with such a small sample size but we did see some patterns. With the younger students (ages 6 and 7 years) answers were mainly intuitive, based on direct experience and observation and there was evidence of learning from experience and observation during the interview process itself, namely, if a plastic animal sank in one experiment, it followed logically that the same would happen in the following experiment, even though that was not necessarily the case. The 10-year-old students were often reluctant to discuss what they knew, let alone how they had learnt it, while the older students (ages 14 and 15 years) appeared to be trying to combine their intuitive knowledge with that which they had been actively taught. This often seemed to confuse them, for example, the oldest student was fixated on surface area but could not pick the one experiment where it was actually relevant.

Influence of the interview process. Both of the 10 year old students found the interview process highly threatening. Their fear of failure compounded any confusion they may have felt about the concepts introduced. Looking for trick questions prevented clear honest answers, or in some cases any answer at all. In contrast, both of the younger (age 6 and 7 years) students were highly enthusiastic and enjoyed the process. The two older students (age 14 and 15 years) were both very matter-of-fact in their answers, often thinking through questions before answering.

How do you modify a student's science misconceptions? It is frequently discussed that it can be very difficult to change the way an individual perceives something (Guesne and Tiberghien, 1985). As stated previously, although observing within our sample of students that the level of misconceptions were not always as high as we had predicted, we did find that some of the students, particularly the older ones were very resistant to modifying ones that we did identify. The older students tended to give fairly definite answers, and even when they were challenged and given evidence that they were incorrect, we encountered a great deal of resistance to modifying their existing schema. For example, even in the face of evidence that a metal pin weighed less than 1g and a plastic spatula weighed 15g continued to insist that the pin would sink because it was heavier than the spatula.

So how do you modify an existing schema that is incorrect or modify a misconception? This seems to be a very difficult question to answer despite a great deal of effort and no easy answers can be found in the literature. This study has highlighted some potential patterns in terms of both the ability and willingness to learn of students in different age groups. Our experience was that the younger students had a true and open desire to learn and as such were openly receptive to, and enthusiastic about new knowledge but as students got older there were many mediating factors including fear of failure and entrenched misconceptions that made it difficult for them to either engage in the learning process or accept that they may be wrong. It would be very interesting to take this study further with a larger number of students and test the findings of this study.

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