African Journal of Research in SMT Education, Volume 14 (3) 2010, pp. 21–34

The concept of spatial scale in astronomy addressed by an informal learning environment

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Abstract

This study describes how a group of grade 7 and 8 students in South Africa engaged with the notion of spatial scale in the Universe before, during and after a visit to an astronomy science centre. A limited amount of research has been conducted on this concept worldwide. Using a combination of concept maps, observations and interviews, results indicate that, despite contrary suggestions in the literature, students aged 13- to 15-years are able to improve their conceptions of size and distance from naïve and conflicting knowledge to a more scientific understanding after their visit. The findings also demonstrate, using a human constructivist framework, that students showed both weak and strong restructuring of knowledge. Experiences with size and distance also appeared to be important in the students' affective domain. The paper argues that a combination of related, themed experiences related to spatial scale can account for the improvement, and recommends that these and even more innovative activities should be explicitly promoted at science centres and in out-of-classroom activities.

Keywords: informal learning, astronomy, size distance, spatial scale, human constructivism

Introduction

As a result of its recent introduction in Curriculum 2005 as *Planet Earth and Beyond*, the learning of basic astronomy is a topical issue within South African education system. Many science teachers at grades 7 to 9 have expressed difficulty in tackling an area of the curriculum which was previously assigned to the geography syllabus. This paper reports on a study which used the notion of 'big ideas' to define key concepts in basic astronomy (Lelliott, 2007). The notion of 'big ideas' comes from the American Association for the Advancement of Science's (AAAS) Project 2061 which developed 'topics of importance' for literacy in science, mathematics and technology. The Project 2061 developers map out different aspects of science with the intention of providing a series of strand maps which educators such as teachers and curriculum developers can use to locate the benchmarks for science literacy within the curriculum. Instead of the term ‘theme’ or ‘topic’ the AAAS has started informally using the term big idea (American Association for the Advancement of Science, 2005), a notion which I found useful to identify key concepts for my study.

Within the strand of *Planet Earth and Beyond* there are several big ideas in astronomy which the curriculum addresses, including those of gravity, the day/night cycle, the Moon phases, the Solar System and stars. One big idea which is crucial to the understanding of astronomy (and can be related to most other aspects of science) is the notion of spatial scale. Spatial scale is a concept used for discussing the relative area, volume, size or distance of entities. It is used in this article to refer to variables of size and distance at the scale of planets, the Solar System, and beyond. The immense sizes of heavenly bodies as well as the enormous distances involved in any discussion of space are crucial to the understanding of the other big ideas, and yet there has been little research in this area. The South African National Curriculum Statement does not make specific reference to concepts of size and distance, but they appear in its ‘unifying statement’ for the knowledge strand Planet Earth and Beyond which states “Our planet is a small part of a vast solar system in an immense galaxy” (Department of Education, 2002, p. 69). In the school classroom aspects of scale are some of the most difficult concepts to get across to learners due to the enormous scale of the universe (Sadler, 1998) and visiting a planetarium or science centre might be expected to provide opportunities for demonstration of scale not available to the classroom teacher.

This paper forms part of a larger study (Lelliott, 2007) whose main purpose was to determine the extent to which students learnt in the process of a visit to either the Johannesburg Planetarium (8 students) or the visitors’ centre of Hartebeesthoek Radio Astronomy Observatory, known as HartRAO, (26 students) in Gauteng, South Africa. Using data collected prior to and after the visit, the paper demonstrates that students had a greater appreciation of the concepts of size and distance after their visit despite the relatively brief duration of the experience.

Literature Review

Notions of spatial scale have been examined recently by a research group based in the USA (see for example Jones, Taylor, Minogue, Broadwell, Wiebe & Carter, 2007; Jones, Tretter, Taylor & Oppewal, 2008). They found that subjects were able to relate better to the human scale, they were more accurate with large scale than with small scale and that relative size was easier to conceptualise than exact size. While there have been numerous studies of astronomy concepts such as Earth shape and gravity (e.g. Roald & Mikalsen, 2000; Sharp & Sharp, 2007; Vosniadou & Brewer, 1992), and the Earth-Sun-Moon system (e.g. Barnett & Morran, 2002; Baxter, 1989; Liu, 2005), there have been few studies involving the concepts of size and distance. Sharp (1996) is relatively optimistic that children of primary school age are capable of grasping “complex and abstract information” about basic astronomy, and that “comparisons involving relative size, distance, age and time were … useful and familiar to children” (p. 707 and 709). Conversely, Sadler (1998) suggests that “comprehension of vast astronomical scales appears to remain beyond the reach of students even after taking an Earth science course [or] astronomy course in high school” (p. 283), while Bakas and Mikropoulos (2003) considered “that the comprehension of such large distances is meaningless and cannot be easily understood by students of 13-14 years of age". A related concept to size and distance is student understanding of geologic time, where the scale involved is also very large and difficult to appreciate. Dodick and Orion's study of grade 7-12 students in Israel, suggested that they can begin to appreciate geologic time around Grades 7 and 8 (Dodick and Orion, 2003). This grade range is similar to that of my own study (age 12 to 14), and my results shown below suggest that students *are* capable of a greater understanding of the concept of spatial scale within the solar system and universe as a result of interactions during their science centre visit.

In their 1992 study of British primary school teachers' knowledge of astronomical phenomena, Summers and Mant (1995) concluded that few had an accurate knowledge of scale of the Earth-Sun system, whereas 85% knew that the Moon is smaller than the Earth. A recent study of university students concluded that misconceptions of astronomical distances are considerable, and educational interventions to target them should be part of science courses (Miller and Brewer, in press). Sadler's quantitative survey of 1250 grade 8-12 students in the USA contained a single question on the distance between the Sun and the closest star, which the majority of students were not able to answer accurately (Sadler, 1998). Trumper used Sadler's question and two additional ones based on the scale of the Earth and the Sun in his studies (Trumper, 2001a, 2001b). He concluded that this topic was one of the weakest areas of high school students' knowledge, with only 20-25% answering these questions correctly. More recently Bakas and Mikropoulos (2003) determined that while 64% of their sample of 11- to 13-year-old Greek students knew the real size of the Earth and the Sun, only 16% of the same students were able to correctly identify the relative distance of the Earth from the Sun using a model. Agan (2004) showed that high school students were able to speak of 'great distances between stars', but only the undergraduate students could relate the distances to a scale model. In a quasi-experimental study Sharp and Kuerbis (2006) found that while the majority of the treatment group of 31 9- to 11-year-olds, who experienced a 20-hour astronomy intervention, improved their knowledge of relative sizes of planets, very few were able to express a scientific understanding of relative distances between planets. This suggests that distance may be a more difficult concept to appreciate.

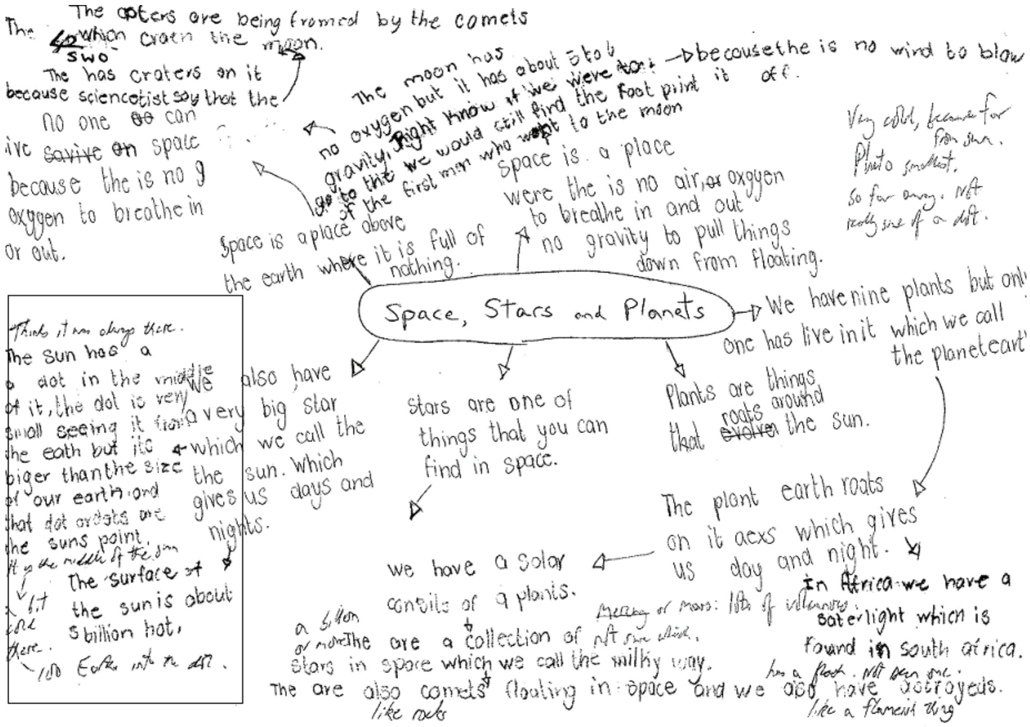
Four of the eight peer-reviewed studies cited above used multiple choice- or true/false-style questions. Lelliott & Rollnick (in press) suggest that such limited data collection techniques may limit the extent to which the participants can express their understanding of the concept of spatial scale. Instead, the use of models and interviews are more appropriate investigative methods for determining learning in basic astronomy.

My study was conducted within the theoretical framework of human constructivist learning (Anderson, Lucas & Ginns, 2003; Mintzes, Wandersee & Novak, 1997) and conceptual change theory related to informal learning (Alsop & Watts, 1997; Tyson, Venville, Harrison & Treagust 1997). Human constructivism (HC) attempts to explain how people acquire scientific concepts by a combination of gradual accretion of knowledge as well as significant knowledge restructuring. By combining HC with the Alsop and Watts model, students' prior knowledge of concepts is considered important as a foundation for their subsequent learning, and the affective nature of the learning experience is considered as part of their overall interaction.

Methodology and data collection

The study was qualitative, examining 34 grade 7 and 8 students from four schools in Gauteng, South Africa. The four schools formed part of a larger convenience sample of seven schools, with 170 students visiting. The 34 students were selected when they had completed a personal meaning map (PMM, see below) on the basis of their prior knowledge about astronomy (from high to low), their beliefs (particularly those with strong beliefs), their gender (the same proportion as the overall ratio of girls to boys) and their race (representation across all population groups). None of the students had received any specific instruction from their teacher regarding spatial scale. Prior to their visit to an astronomy science centre each student constructed a personal meaning map (a variant of concept mapping used in informal learning institutions, see Adelman, Falk & James, 2000; Falk, 2003). This PMM formed the basis for an unstructured interview with the researcher, based on what had been drawn in the map. For example, Figure 1 shows a PMM drawn by Neo. In the rectangular section, Neo has written about sunspots. The interviewer picked up on that and asked:

> Just looking at what you drew, …. dots on the sun. Now is that dot on the sun there sometimes or is it always there?



Space, Stars and Planets

The opters are being fromed by the comets which craen the moon.

The ~~so~~ swo The has craters on it because sciencotist say that the

no one ~~co~~ can ive ~~savive~~ ~~on~~ space because the is no oxygen to breathe in or out.

The moon has no oxygen but it has about 5 to 6 gravity. Right know if we were to go to the moon we would still find the foot print of the first man who wept to the moon → becouse the is no wind to blow it off.

Space is a place above the earth where it is full of nothing.

Space is a place were the is no air, ~~or~~ oxgyen to breathe in and out no gravity to pull things down from floating.

Very cold, because far from sun. Pluto smallest. So far away. Not really sure of a draft.

We have nine plants but only one has live in it which we call the planet earth

Plants are things that ~~evolven~~ roats around the sun.

The plant earth roats on it aexs which gives us day and night.

In Africa we have a saterlight which is found in south africa.

Stars are one of things that you can find in space.

We also have a very big star which we call the sun. Which gives us days and nights.

we have a solar consits of 9 plants.

Mercury or Mars: lots of volcanoes.

a billion or more The are a collection of Not sure which. stars in space which we call the milky way.

The are also comets like rocks floating in space and we also have astroyeds. has a flash. Not seen one. like a flaming thing

Think it was always there.

The sun has a dot in the middle of it, the dot is very small seeing it from the eath but its biger than the size of our earth and that dot ordats are the suns point.

It is the middle of the sun

The surface of the sun is about 5 billion hot.

Is it one there.

100 Earths into the dot.

Figure 1: Example of a Personal Meaning Map

During the visit to the science centre, extensive field notes were taken regarding the nature of the experience and the behaviour of students. The personal meaning map and unstructured interview were repeated with each student 1 to 16 days after the visit (mode = 6), to determine what they had experienced in the cognitive and affective domains. In addition to questions which emerged from the unstructured interview based on the PMM, the following additional structured interview questions relating to size and distance were asked both prior to and after the visit:

> The sun and the moon look the same size in our sky. Are they? Why do you say that? [Which is really bigger?] Why do they look the same size?
>
> Stars at night look like pinpricks of light. Why? What are they?
>
> In the fastest space ship we could build, how long would it take to reach the closest star outside our solar system? [Guess?]

The data were transcribed and then analysed using the qualitative data analysis software ATLAS.ti. These and other questions formed part of an interview schedule which was scrutinised for content validity by several science education experts and piloted with two classes of grade 7 students.

In order to understand how the students related to the concept of spatial scale, it is important to understand the nature of the interventions at both study sites. Each student participated in a single visit either the planetarium or HartRAO. The visit to the planetarium lasted about one hour, and students were seated in the auditorium viewing a 'show'. The presenter (a professional astronomer) conducted a live audio-visual show using a star projector and video equipment to project images on the dome of the building. During the presentation she explained why the Sun appears so much bigger than other stars even though it is an ordinary star, as a result of the immense distance the stars are away. She then visually demonstrated just how far it is from the Sun to the next nearest star (Alpha Centauri) by comparing the distance across the solar system with the distance between the two stars. By using relatively simple division arithmetic projected on the planetarium dome she showed that it would take about 4000 years to reach Alpha Centauri, travelling at speeds twenty-times faster than our current spacecraft. The presentation also included visual demonstrations of the relative sizes of the planets, the distance of the Moon from the Earth in relation to their sizes and movements of the stars across the sky.

The visit to HartRAO lasted for up to three hours, where the students participated in numerous activities. The ones relevant to spatial scale included 'taking the solar system for a walk' using a scale model of the solar system, reduced four billion times – under instruction by the educator students paced out distances between the Sun and the first six planets. In an explanation of the Sun in relation to stars, the educator used an analogy of close and distant trees to explain why the Sun looks so much larger than the stars. A live projection of sunspots led to a discussion of the size of the dark patches on the Sun in relation to the size of the Earth, while Moon models were used to demonstrate an explanation of the phases.

From a pedagogical viewpoint, it is interesting to note that the presentations at both sites relied on mainly on models and analogies to demonstrate the immense sizes and distances involved in even basic astronomical concepts. In addition to the presentations and activities described above, both sites referred to size and distance in other discussions when students asked questions.

Results

This study is about learning, and it is important to clarify what I regard as the difference between knowledge and understanding. Tennyson's framework of declarative knowledge ("knowledge that"), procedural knowledge ("knowledge how") and contextual knowledge ("knowledge why, when and where") is a useful basis for classifying types of knowledge involved in learning (Tennyson & Rasch, 1988; Wellington, 1990). Most scholars would agree that the most valuable form of knowledge is contextual where a learner is able to fully explain why something occurs.

For example, contextual knowledge of spatial scale in the Earth-Moon system would involve not just that the Earth is larger than the Moon (declarative) or that their relative sizes result in an orbital relationship (procedural), but that their size is related to their origin, and their orbits are due to their relative masses, a concept which moves beyond spatial scale. In this example, I am using contextual knowledge in the same sense as understanding, where a true understanding of relationships in the Earth-Moon system is synonymous with contextual knowledge. In this paper, I will use the term 'knowledge' to refer to Tennyson's declarative and procedural knowledge and 'understanding' to refer to an ability to explain fully a phenomenon at the contextual level.

In the study, I defined the concept of spatial scale as a single big idea: a composite estimation of a student's knowledge of the size of the Sun, stars, the Moon and other heavenly bodies as well as his or her understanding of distance within the solar system and beyond. Using data from the PMM, the PMM interviews and the structured interview questions listed above, I developed hierarchical categories of student knowledge (3 highest and 1 lowest). The categories and criteria for assigning students' views to a category are self-explanatory and are shown in Table 1. Each student was placed into a category for the knowledge of spatial scale they demonstrated during their PMM and interviews, both prior to and after the visit to the study site. For example Ntobeko was placed at level 1 prior to the visit; she regarded the Sun as being "big" and the stars "so small", but was unable to clarify further. She considered the sun and the moon as being the same size. After the visit she was classified at level 2; although she now could explain that the sun is bigger than the moon, and that the moon is closer to Earth (hence they look the same size), she still believed that the sun is the biggest star, and that other stars are small (football-sized). Students at knowledge level 3 are described below, in greater detail.

Table 1: Criteria for classifying students according to knowledge of astronomical sizes and distances.

Spatial scale definition	**Knowledge Level 1**	**Knowledge Level 2**	**Knowledge Level 3**
Knowledge of spatial scale.	Confused and conflicting knowledge regarding spatial scale.	Some correct ideas regarding spatial scale. Some incorrect ideas and misconceptions.	Basic scientific understanding of spatial scale in the solar system and beyond, with fewer misconceptions.
Knowledge of relative sizes of Sun and Moon	Does not know relative sizes of sun & moon, thinks moon is larger than sun, or thinks they are the same size. Distance may not have been expressed.	Relative size of sun and moon is correct, but student does not understand relative distance of sun and moon correctly, or cannot explain the difference in size.	Student has scientifically correct conceptions of the relative size and distance of the sun and moon from the Earth.

Students' knowledge and understanding of the concepts of size and distance in the solar system (and for some students the universe as well) improved considerably over the period between the pre-visit and post-visit interviews (Figure 2). Students at the lowest level, with confused and conflicting ideas about spatial scale decreased from 15% to 6%; only 2 students remained at knowledge level 1, and they both showed the least change in all the astronomy concepts across the study. Students with an apparent scientific knowledge at level 2 decreased while level 3 students increased from 21% to 53%.

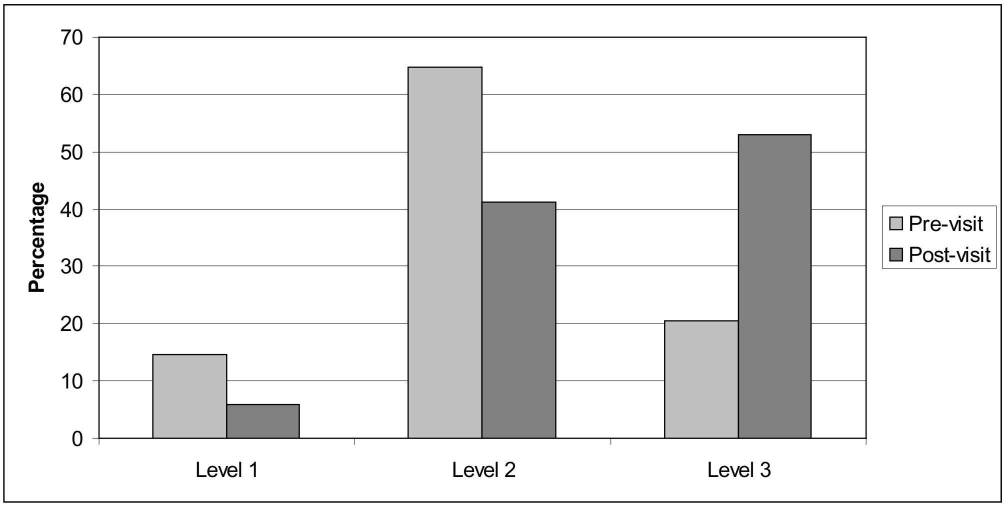


Figure 2: Students' conceptions of spatial scale (n=34)

The specific question about the Sun/Moon size (see methodology section above) was asked to determine whether students could not only relate scale and size in the sky, but give reasons for why objects look similar or different in size. If students can explain why the moon and the sun look the same size in the sky, then they understand more about scale within the solar system. The question only determined the relative size of the Sun and the Moon, not the extent of the Sun's vastness. The results are shown in Figure 3.

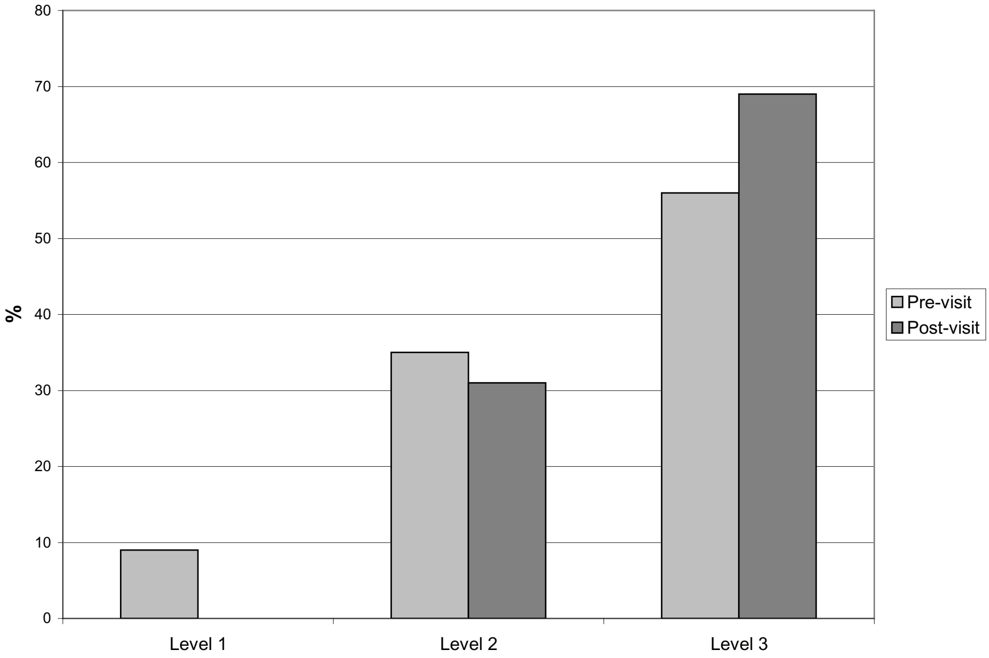


Figure 3: Students' knowledge of the size of the Sun and Moon (n=34 pre-visit, n=29 post-visit)

Prior to the visit, just over half the students (19 students, 56%) had a scientifically correct concept of the relative size of the Sun in relation to the Moon (level 3), and could also explain that their apparent similarity in size is due to the fact that the Moon is closer to the Earth than the Sun. Before going on the visit, 12 students (35%) did know that the Sun is larger than the Moon, but could not explain why they looked the same size in the sky in terms of their relative distances from the Earth (level 2). Taking these two categories together, the vast majority of students (91%) did know that the Sun is larger than the Moon, and only 3 students thought that the Moon is larger than the Sun or that the 2 objects are the same size. After the visit the percentage of students in category 3 (scientific conception) increased to 69%, and all students could describe the Sun as being larger than the Moon. The percentage of students in category 2 decreased slightly after the visit, and no students remained at knowledge level 1.

For a more fine-grained analysis of how individual students changed their conceptions of spatial scale we can examine the cases of two students and use a human constructivist theoretical lens to determine how they learnt during their visit. Prior to the visit, Brenda, a 13-year-old girl whose first language is SePedi, knew that the Sun is bigger than the Moon, but was unable to explain why they look similar in size in the sky, and similarly, although she understood that stars are much bigger 'up close' than they appear in the sky, her idea was that are about "as big as this room" in size. She also, like numerous other students in the study, thought of the Sun as the biggest star: "but the sun is one big, big star. Bigger than all of the other stars". On this basis she was classified as being at knowledge level 2. After the visit, her appreciation of size and distance in the solar system was substantially greater. She referred to the size of the Earth in relation to the Sun as being 'amazing': "I told them about the Earth. Like it's about 3 and 24 zeros and like the sun eh 320 times bigger than the Earth, it's very, very big. I couldn't believe it". Although Brenda did not quite remember the mass of the Earth correctly, and referred to it as 6×10^{21} kg in her personal meaning map, and "3 and 24 zeros" in her interview, her conception of the relative size of the Earth and Sun was quite different from her pre-visit conception. Similarly, Brenda appeared to have modified her understanding of distance: she remembered correctly that the Earth is 1.3 light seconds from the Moon and 8 light minutes from the Sun; facts which were referred to during the HartRAO visit. When questioned about this she demonstrated a limited understanding of the concept of light seconds and minutes, but appeared to have the basic understanding that they are units of distance used in space. On her PMM she had written that the Earth is 1.3 light seconds from the Moon, and the Earth is 8 light minutes away from the Sun. I asked her about this in the following exchange:

> Interviewer: If you say the sun is 8 light minutes from the Earth. What does that mean?
>
> Brenda: A light minute is equal to 300 000 seconds per minute I'm not sure. Ja.
>
> Interviewer: So what does a light minute mean? What do you actually mean by that?
>
> Brenda: The distance between the sun and light because we do not use kilometres and metres in space. Ja. We use light years and light minutes and light seconds in space.

Brenda was therefore categorised as being at knowledge level 3 after her visit. From a human constructivist viewpoint, I suggest that these changes in her understanding of spatial scale are examples of 'differentiation' and 'superordinate learning'. Brenda now has a significantly differentiated understanding of size and distance. Differentiation in human constructivist terms involves an overarching concept in the learner's mind which becomes modified or changed as a result of the addition of new (subsumed) concepts. She has also acquired a completely new concept of distance being measured in light units (superordinate learning). This new concept includes (or subsumes) concepts of light and time (years, minutes and seconds) which Brenda was previously familiar with. Although I am not convinced that Brenda could explain *how* her new understanding of light units is a measure of distance, I consider that she showed substantial knowledge restructuring. She linked the new concept of light units to the familiar concepts of distance, light and units of time. Only three other students referred to the concept of light units as a result of the visit.

The second student, Sipho, a 13-year-old boy with Zulu as his first language, also showed changes in his knowledge and appreciation of spatial scale, but not to the degree shown by Brenda. Prior to the visit he was classified at knowledge level 2 on the basis of his PMM and the interviews. For example he stated in his PMM that distances between Earth and stars are measured using a 'timeline'. In the interview he clarified the timeline to be a measuring unit appropriate for the distance to a star, as kilometres "can't reach that level". However, he confused distance with speed, and was not able to explain how to do the measurement. He also regarded stars as being about the same size as the Earth. He also referred to the Sun as "the most biggest star in the universe which can provide us with heat", while he had an appreciation of the relative sizes of the Sun and the Moon as being due to distance as follows:

> Interviewer: Okay. So why do they look the same size?
>
> Sipho: Because of the … They are far away.

Interviewer: Which one's furthest away?

Sipho: The furthest is the sun.

After the visit, he was able to extend this understanding to the Sun in relation to the stars

> "The sun looks more bigger because it is the nearest star so the other stars look very, they are so far so they look you think that they are small, but they are not. Some of them are even more bigger than the sun".

He was classified at knowledge level 3 after the visit, but in Sipho's case, weak knowledge restructuring has taken place; he appears to have extended the small size = greater distance concept which he understood within the Earth-Sun-Moon system to the relationship between the Sun and other stars.

Finally, viewing data using an affective lens from revised conceptual change theory (Alsop & Watts, 1997) I examine examples of how students' experiences at the science centre appeared to be important to them. Categories of affective learning included enjoyable, wondrous, germane (personally relevant) or salient. In answer to the interview questions, "What was particularly interesting or surprising for you during the visit?" and "What things did you most enjoy about the visit?" the following quotations are examples of students who referred to aspects of spatial scale.

Thembi (on her personal meaning map): It will take you six months to get to Mars and another six months to get back, but the world goes near Mars every two years, meaning staying away from Earth for … three years. [this student also expressed her dream to be the first black woman in space, and had been to see Mark Shuttleworth in Johannesburg].

Paul : I enjoyed … when I was shrunk to 4 million times smaller [this was the taking the solar system for a walk activity]

Tumo: The asteroids. They said that their distances is from here to Cape Town.

Interviewer: You mean that's the size of an asteroid?

Tumo: Ja. …….The sun they say that in some years to come the sun will go hundred times more bigger and it will dry out some planets which will destroy any planets, in fact our solar system, it will destroy our solar system and reduce it's own size back again.

Nnaniki: And one thing I asked myself because they say the bigger the planet the much more the moons, but I'm surprised that earth is bigger than Mars right, but Mars has two moons and earth has only one. So I've been trying to figure that out I can't seem to…

Neo: In some few years to come the sun is going to get bigger and bigger and bigger and bigger and suddenly it will come to a small dwarf and so there will be no sun anymore.

Like the earlier example of Brenda ("I couldn't believe it"), in each of these transcripts there are aspects of wonder – Thembi regarding the distance to Mars, Tumo expresses incredulity at the size of asteroids and both Tumo and Neo are awed by the future of the Sun. Paul enjoyed the scaled-down solar system, while Nnaniki was fascinated by size of planet in relatin to the number of moons. In recent years, increasing attention has been given to the role of the affective domain in learning, both within science education (Alsop & Watts, 1997, 2003), and in museums (Allen, 2002; Dierking, 2005). Alsop and Watts (1997) suggest that unpalatable experiences can hinder cognitive learning, while germane and salient experiences promote such learning. In my study, all five of the students quoted above learnt substantial new 'facts' about astronomy, but only Nnaniki (and Brenda above) showed any substantial knowledge restructuring. There were numerous other examples in the study (across diverse topics such as planets, stars, rockets and aliens) where students' enjoyment or wonder motivated them to talk to people after the visit, about what they had experienced. Further research in this aspect of science learning would seem to be valuable.

Discussion and Implications

While students may take away many impressions from a visit to an astronomy science centre, most astronomers would agree that an understanding of astronomical size and distance is crucial. Recent research suggests that an understanding of scale is of great importance in the modern world due to the ability of science and technology to reach into the largest and smallest fields of study (Jones et al. 2007). From a conceptual viewpoint therefore, it is crucial that all students have an understanding of the concept of scale in astronomy. Both the study sites incorporated the concept of spatial scale into several aspects of their work, with the calculation of the distance to the nearest star (outside the solar system) at the planetarium and the pacing out of the distances between the solar system planets (at HartRAO) being the most prominent. My findings show that students' appreciation of aspects of spatial scale changed quite substantially from the pre- to the post-visit. Prior to the visit 80% were at knowledge levels 1 and 2, while after the visit 53% were at level 3, suggesting that the sites were able to effect not just an increase in knowledge (such as the relative sizes of the Earth, Sun and Moon) but a deeper understanding of the scale of the solar system. Further, there was evidence of different levels of knowledge acquisition by students, some of whom learnt new facts fairly superficially (for example Sipho), and others such as Brenda who appear to have restructured knowledge more substantially. Finally, my findings indicate that affective learning is important for students visiting a science centre, and suggest that the relationship between affect and cognition might be an avenue for further research.

As discussed in the literature review, there are different views whether children of age 12 to 15 years are capable of comprehending the enormous scales involved in astronomy. Given my findings, albeit from a small qualitative study, that students are able to improve their understanding of the concepts of size and distance after a visit I would agree with Sharp's findings that for students of this age group it *is* appropriate to cover this concept (Sharp, 1996; Sharp & Kuerbis, 2006). Sadler (1998) disputed this, but provided limited evidence in his paper as support, and examination of the test he conducted has proved difficult, as it was never made widely available (Hufnagel, 2002). On the basis of their pre-intervention study, Bakas and Mikropoulos (2003) supported Sadler's notion, yet never incorporated the concept of spatial scale into their virtual reality intervention to test their premise.

It appears that the types of intervention which provide opportunities for learning about spatial scale are also important. From Sharp's description of his quasi-experimental study (Sharp & Kuerbis, 2006), while his students appeared to work with relative size in several lessons, their opportunity to experience relative distances was more limited (planetary movements with sizes and distances to scale acted out in the playground). Like other concepts in my larger study (Lelliott, 2007), the approach by the study sites to provide a *variety of experiences related to size and distance* is likely to be the most appropriate way of building students' knowledge and understanding of the concept of spatial scale. Allen (2007) has noted that such 'thematic coherence' is a challenge to achieve in museums, but is likely to be an important way of promoting conceptual change. In science centres mediation is provided by a combination of the exhibits, activities and the educators. By explicitly linking different experiences related to the concepts of size and distance science centres can assist students to restructure their own knowledge and partake in meaningful learning. In the planetarium and at HartRAO the activities experienced by students (described in the methodology section above) appeared to relate directly to students' improved understanding. At the planetarium, the calculation of the time it would take to reach the nearest star was referred to by seven of the eight students who visited. At HartRAO, at least one the activities (the solar system scale model, the discussion of the Sun's relationship to the stars, the demonstration of sunspots and the model of Moon phases) was referred to in most of the students' interviews, indicating they influenced their thinking. Since both study sites dealt with the various aspects of spatial scale as described above, it is likely that the visit itself was mainly responsible for the change in knowledge, and was successful in doing so. The study suggests that astronomy-related science centres are effective sites to get this type of knowledge and understanding across to students.

The activities experienced by the students are ideas that could be used by teachers in their schools, and not solely at science centres. In order to teach several astronomy topics in the National Curriculum Statement, the concept of spatial scale needs to be demonstrated. Star movements (as seen from Earth), the relationships between the Earth, the Sun and the Moon resulting in such phenomena as the Moon phases, eclipses and the seasons all need to invoke the enormous distances across the solar system and beyond. Ideas for demonstrating spatial scale can be found at the Powers of Ten website (www.powersof10.com/) and a web page of the Solar System that is to scale (http://www.phrenopolis.com/perspective/solarsystem/index.html). An initiative underway at the Museum of Science and Industry in Chicago is to email visitors when the space ship they 'launched' is half way to Mars (approximately six months after their visit to the museum), which again could be adapted to the school environment. What is apparent is that innovative ideas such as these are the best ways of getting across the concept of astronomical distance, not only to school students but to all potential lifelong learners.

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