Awakening students' minds to Einstein, Gravity and the Solar System

A study of outreach centre effectiveness

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School of Physics

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Declaration

This thesis contains published work and/or work prepared for publication, some of which has been co-authored. The bibliographical details of the work and where it appears in the thesis are outlined below.

The following two papers were co-authored by the student and supervisors, with the following percentage contributions:

- Conceptualization: Student 80%, Supervisors 20%
- Data collection and analysis: Student 100%
- Writing first draft: Student 100%
- Editing and preparation of final submission: Student 80%, Supervisors 20%

Chapter 3

Chapter 4

The following paper was co-authored by the student, supervisors and other authors, with the following percentage contributions:

- Conceptualization: Student 20%, Others 80%
- Data collection and analysis: Student 20%, Others 80%
- Writing first draft: Student 20%, Others 80%
- Editing and preparation of final submission: Student 20%, Others 80%

Chapter 5

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This thesis has been formatted according to the guidelines of the American Psychological Association (APA) (6th edition), with Australian English spelling. Tables have been formatted on an individual basis to enhance readability.
Abstract

Science education in Australia is facing many challenges, particularly relating to student achievement and student attitudes. Science outreach centres present an opportunity to address these concerns, and have a responsibility to be key drivers of innovation within science education. The purpose of this research was to investigate the impact and effectiveness of educational programmes delivered through the Gravity Discovery Centre (GDC), a science outreach centre north of Perth in Western Australia. In particular, conceptual understanding of relevant physics concepts were examined. Student experiences related to their participation in science education outreach activities are described in this thesis.

Astronomy was considered to be interesting and engaging for more students compared with other science-based subjects, and for this reason, the GDC was considered an ideal context to investigate how students learn complex physics concepts by experientially engaging in a personal educational process in a science centre. Three case studies involving school groups of 11-15 year old students and their excursions to the GDC present different methodologies that explore student knowledge and the benefits of visits to a science outreach centre. The case studies describe students exploring aspects of Einstein's theory of general relativity; participating in a solar system walk in an Australian bush setting; and conducting experiments from the top of a 45-metre high tower to observe the effects of gravity.

Concepts related to Einsteinian physics are usually not taught until students are in university. The first case study explored the impact of an enrichment programme on aspects of Einsteinian physics related to space, time and gravity, on Year 6 children’s understanding of, and attitudes towards this topic. The research design was an exploratory case study of one class of 26 students who participated in six in-class lessons as well as an excursion to the GDC. Mixed methods of data collection included a pre/post-instruction questionnaire, classroom observations and an interview with the physics professor who conducted the programme. The results indicated a statistically significant improvement in children’s conceptual understanding on the pre/post questionnaire with a small effect size.

The second case study focussed on the Solar System Walk activity at the GDC and how it enabled the participating Year 7 to 9 students to better comprehend concepts about the
size and scale of the solar system. The results from this case study revealed that: prior knowledge is important; time spent at the GDC impacts student learning; and the kinaesthetic nature of the activity may support learning by indigenous students and those from low socio-economic schools. The findings also suggest that age is not a barrier to learning about the solar system; and that learning is closely dependent on opportunities, exposure, learning environment and teaching expertise.

The third case study focused on an exhibit called the Leaning Tower of Gingin, where students were exposed to learning about gravity through experiments. The pre- and post-excursion worksheets and the activities at the GDC were designed to enable the students to be explicit about their ideas about gravity. Through discussions with their teacher, other students and GDC staff, they could develop more scientific explanations for their observations about gravity.

Finally, the findings from each of the case studies are brought together through the development and presentation of a Model of Student Outreach Centre Engagement. The Falk and Dierking (2000) Contextual Model of Learning was used as a basis for development of the new model, which relates specifically to student learning within the school system and with exposure to outreach centre experiences. The model shows the interaction between students' prior knowledge, school curriculum, teachers and the outreach centre, in the development of students' interest, knowledge and perceptions of science.
Acknowledgements

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Marina Pitts
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Chapter 1: Introduction and Context

Introduction
This first chapter introduces the doctoral research presented in this thesis about engaging school students in science at the Gravity Discovery Centre (GDC), located near Gingin, 80 km north of the capital city of Perth in Western Australia. The research involved an in-depth investigation of three educational programmes delivered at the GDC in enhancing school-aged students’ interest in and understanding of science. The first programme focused on Einstein’s theory of general relativity and included an excursion to the GDC. The second programme involved students learning about the size and scale of the solar system by participating in a GDC exhibit called the Solar Walk. The third and final programme involved students learning about gravity by designing and conducting gravity experiments by dropping objects from a 45 metre tower at the GDC.

This chapter begins with a brief introduction to the educational context of the research at the GDC followed by an explanation of the three propositions that established the rationale for conducting the research. Following the research rationale, the research purpose is outlined and the research questions presented. The next section of the chapter includes an outline of the theoretical, curricular and methodological contexts of the research and the chapter then concludes with a description of the structure and a summary of the content of each of the subsequent chapters of the thesis.

Educational Context: The Gravity Discovery Centre (GDC)
The Gravity Discovery Centre (GDC) is an independent non-profit facility originally established to provide public education to complement the Australian International Gravitational Observatory (AIGO) Research Centre at a location 80km north of Perth, Western Australia. The GDC is a learning centre that focuses on modern physics, astronomy and biodiversity. In parallel with the development of the buildings and exhibitions, the GDC staff collaborated with a group of committed volunteer teachers to develop educational programmes linked to exhibits. Stage 1 of the GDC was opened in 2003 and Stage 2 in 2008. It is located beside the AIGO Research Facility where research personnel conduct experiments related to the search for gravitational waves. Albert Einstein first proposed gravitational waves in 1916, as part of his Theory of General Relativity. They can be thought of as ripples in space and time created by violent cosmic
events such as the collision of black holes. In February 2016, the first direct observation of gravitational waves was announced (https://www.ligo.caltech.edu/news/ligo20160211).

The GDC provides school students with access to science learning facilities related to astronomy and physics; the disciplinary areas of interest for this educational research. The facilities at the GDC include a scale model of the solar system, the Gingin Observatory, the robotic Zadko telescope, a 20 metre pendulum tower and the Leaning Tower of Gingin, a 45 metre steel tower where students can conduct free fall experiments. More detailed information about the GDC can be found at the Centre’s website (http://gravitycentre.com.au) and a description is provided in a paper that introduces the broader research context in which this doctoral study was conducted (Venville et al., 2012). Later chapters in this thesis also provide descriptions of the GDC science education exhibits and related educational programmes of relevance to this research in more detail.

**Research Rationale**

This section of the chapter presents a set of three logical and interconnected propositions that formed the rationale for this doctoral research on science education outreach activities at the GDC. The first proposition that underpins the research is that science education in Australia is facing a number of challenges that need to be addressed. The second proposition is that informal education science centres, such as the GDC, provide an important educational context for developing high quality, innovative and creative science education programmes that challenge the status quo. The third proposition underpinning the research is that astronomy is an ideal science discipline in which to conduct research on engaging students to learn science. Each of these three components of the research rationale is further elaborated and situated in the research literature in the following sections.

**Proposition 1: Science Education in Australia is Facing Challenges**

Science and technology are key factors contributing to the economic growth and social prosperity of both advanced and developing nations, including Australia (Office of the Chief Scientist, 2014). Moreover:

science, technology, engineering and mathematics (STEM) education has a vital role to play in developing flexibility and resilience in the new Information Age, providing young people with the knowledge and skills that are valuable in life and
work and routes to careers in economically important sectors, innovation and manufacturing. (The Royal Society, 2014, p. 17)

Unfortunately, there is a worldwide trend of declining student enrolments in science, technology, engineering and mathematics related subjects (e.g. The Royal Society, 2014; Tytler & Osborne, 2012). Within Australia this phenomenon has been referred to as a crisis (Tytler, 2007; 2014) because it has resulted in a chain of problems starting with the decreasing numbers of students selecting physics, chemistry and higher mathematics as senior school subjects. This has led to low enrolments in advanced tertiary courses in the same subjects, which in turn, has caused a shortage of postgraduate research students and science teachers (Universities Australia, 2012). Evidence has accumulated to demonstrate that schools and universities are not producing enough scientists to sustain the scientific and economic development of Australia (Kennedy, Lyons & Quinn, 2014).

There are several phenomena contributing to declining enrolments in science subjects, including poor student attitudes towards science. When scientific literacy was the major domain for examination in the Organisation for Economic Cooperation and Development (OECD)’s 2006 Programme for International Student Assessment (PISA), an assessment of students’ attitudes towards science was undertaken. The results showed that 15-year old Australian students had very low interest in learning science. Of the 57 countries that participated, Australia was ranked 54th for students’ general interest in learning science (Thomson & De Bortoli, 2008). Moreover, on an index for motivation to learn science, or take up a science career, 15-year-old Australian students’ mean was below that of the OECD average (Thomson & De Bortoli, 2008). Students were more likely to feel disengaged from science and to achieve poorly in science and mathematics due to regional and remote geographic location of their school, lower socio-economic status, or because they identified as Indigenous Australians (Thomson & De Bortoli, 2008; Thomson, De Bortoli & Buckley, 2013). “We are locked into a cycle of disengagement that fails our teachers and students today” (Office of the Chief Scientist, 2014, p. 21).

Evidence indicates that the quality of teaching is a significant determinant of students’ attitudes toward school science and a major factor in students continuing with science education past the age of 16 years (Osborne, Simon, & Collins, 2003). Research has suggested that the reasons students ‘switch off’ science are complex but include a number of factors such as poor teaching, content matter that is not stimulating, and perceived lack
of relevance to the real world and to the lives of students (Haynes, 2008). Another commonly cited reason for students losing interest in science during their high school years is that science subjects are perceived as being more conceptually challenging and more difficult to score high grades (Haynes, 2008; Venville, Oliver, Longnecker, & Rennie, 2010). In England and Wales (Haynes, 2008) and in Australia (Venville et al., 2010), it has been reported that schools often discourage potential underachievers from attempting STEM (Science, Technology, Engineering and Mathematics) subjects because it may affect the school’s position in publicly published league tables.

In addition to poor attitudes towards science, falling achievement of Australian school students in science relative to other countries is well documented in the latest results from the PISA (Thomson et al., 2013). Moreover, Year 8 science scores in the Trends in International Mathematics and Science Study (TIMSS: conducted by the International Association for the Evaluation of Educational Achievement) were not significantly different to the TIMSS 1995 results (Thomson et al., 2011). The results showed that eight per cent of Australian Year 8 students did not reach the minimum international science benchmarks (Thomson et al., 2011). This result, combined with significant improvements by other countries, has moved Australia down in the TIMSS rankings. “The performance of Australian school students in science and mathematics literacy is now lower than important international peers” (Office of the Chief Scientist, 2014, p. 21).

The proposition that there are challenges facing science education in Australia, in particular, student achievement in science, was the primary issue underpinning the research reported in this thesis.

**Proposition 2: A Critical Role for Science Centres is Fostering Science Educational Innovation**

Internationally, science centres are recognised as valuable, informal or out-of-school, science education contexts. The Office of the Chief Scientist (2014, p. 20) in Australia distinguishes between formal and informal education:

Formal education refers to learning through educational institutions with structured and direct instruction, such as schools, universities and through other accredited training programmes. Informal education refers to learning through indirect means
such as on-the-job training; through community centres such as museums, libraries and technology centres; and through the media.

Over the past 25 years, the number of science centres in the world has increased from 400 to more than 3000 (Koivu & Myllykoski, 2015). This growth of about 100 new science centres per year demonstrates an extraordinary investment in informal science learning by government and industry. “Science centres have attracted public investment because they demonstrate how science and curiosity are an essential part and ingredient of humanity and of our well-being” (Koivu & Myllykoski, 2015, para. 4).

Out-of-school learning can take place in a range of settings including camps, homes, museums, outreach centres, parks and public spaces, zoos and science centres like the GDC. Typically, out-of-school learning takes place outside of the formal curriculum, is non-compulsory and is not formally assessed, and while capable of reinforcing formal learning, this is not its main purpose (Dillon, 2015; Rennie, 2007). Excursions can inspire, stimulate interest in, encourage positive attitudes towards and lead to a more thorough understanding of science. Moreover, out-of-school learning can be unstructured, unguided and led by the interests of the individual students, with learning taking place without them realising (Dillon, 2015; Rennie, 2007).

Learning experiences outside the classroom are often the most memorable, helping young people to make sense of the world around them and integrate new experiences and understandings into all aspects of their formal and informal learning. By realising that learning does not only happen within the classroom, young people start on the journey of lifelong learning. When students learn outside the classroom, they:

- are exposed to new experiences;
- learn in different ways, more often related to their preferred way of learning;
- are motivated to learn more and feel positive about learning;
- become self-confident, developing self-esteem and self-awareness;
- work collaboratively fostering decision making and team work; and,
- improve communication skills with peers and adults.

(Council for Learning Outside the Classroom, http://www.lotc.org.uk)

Despite these well-known advantages of out-of-school learning, Koivu and Myllykoski (2015) argue that the rapidly changing environment this century has resulted in countless
pressures on science centres to rethink their role and reposition themselves. Some of the pressures on science centres include competition from digital media for people’s time and the novelty factor. Moreover, the traditional interactive exhibit is under threat because audiences are moving on from just ‘doing’ or ‘tinkering’ and want to be involved in experimenting, making things, collecting data, testing and simulation. Koivu and Myllykoski (2015) assert that science centres “need to go beyond public expectations and introduce novelties that inspire audiences – by surprise” (para. 16). They need to become enablers and platforms for talent and expertise, nurture creativity and actively create a culture of experimentation.

An example of continuing international investment in informal science education is an initiative launched in 2014 by the Wellcome Trust, a global charitable foundation based in the UK (http://www.wellcome.ac.uk/Funding/Public-engagement/Funding-schemes/Science-Learning/index.htm). Science Learning Plus Two, will provide £9 million of funding to explore how informal learning activities, such as visits to museums or science centres, playing games and watching dramas or documentaries, have the potential to make a positive impact on young people's engagement with science. The Wellcome Trust initiative supports research into the processes by which learning happens outside the classroom, exploring the most effective practices and building the evidence base in this area. The Wellcome Trust philosophy, outlined on their website, embraces innovation, risk taking, acting swiftly and long term ambition.

In December 2015, the Australian Prime Minister, Malcolm Turnbull, announced a 1.1 billion dollar investment in innovation to direct the future of Australia towards a knowledge economy through an “ideas boom” (Australian Government, 2015). The package includes a $48 million investment in a science, technology, engineering, mathematics (STEM) literacy program, $14 million to encourage girls in the STEM sector, and $51 million to encourage digital literacy. Support will be provided to expand community engagement initiatives, including Inspiring Australia and citizen science initiatives.

Consistent with these new initiatives in the UK and Australia, the second proposition underpinning the research presented in this doctoral thesis is that science centres have a responsibility to be key drivers of science education innovation. Science centres, including the GDC, have an obligation to continue to justify public investment and to make sure they
do not stagnate while the world around them changes. It is critical that science centres are actively involved in research on science education. An opportunity exists for science centres to become innovators in the education space where educational norms are questioned and cutting edge curriculum and pedagogies are developed and evaluated.

Science centres are not subject to the curricular restrictions that are imposed on schools and teachers. As such they have greater freedom in the provision of science programmes and activities for students that are new, exciting and engaging. If science centres are to remain relevant, it is crucial that they provide cutting-edge exhibits and experiences that excite and motivate students. At this stage, there are few studies specifically investigating school curricula linked with student learning at science centres and this remains a topic for further investigation. The discussion sections of chapters 3, 4 and 5 outline the positive and negative factors related to learning in the informal setting of a science outreach centre, specifically the Gravity Discovery Centre.

**Proposition 3: Astronomy is an Ideal Discipline for Conducting Research on Engaging Students to Learn Science**

Australia is world renowned in astronomy. To maintain our edge and to ensure we have the levels of expertise to support projects such as the International Square Kilometre Array (http://www.ska.gov.au) and the Australian International Gravitational Observatory (http://www.gravity.uwa.edu.au), more scientists and a scientifically, digitally and mathematically literate workforce is required now and in the future (Office of the Chief Scientist, 2014).

The literature supports the idea that astronomy is an effective sub-discipline of science for interesting students in science and mathematics careers, helping them to develop a deeper understanding of the nature of science and promoting the use of information technology (Rosen et al., 2010). A key finding of the 2010 Relevance of Science Education (ROSE) Report, an international research project that examined important factors in the learning of science and technology, as perceived by learners, was that despite boys' and girls’ interest in science being context dependent (boys enjoy technical and mechanical contexts while girls prefer health, aesthetic and social contexts), both girls and boys found astronomy to be an appealing subject (Sjøberg & Schreiner, 2010).
In addition, contemporary students are no longer satisfied with the basics of Newtonian physics (Blair, 2012). Curricula now include subjects such as computer science, informatics, engineering and artificial intelligence. Where in the past it was thought that the mathematics involved in general relativity was too complex for high school students to comprehend, current subjects stimulate their interest and understandings of concepts related to general relativity. A barrier to implementation of general relativity into the curriculum is that teachers were rarely taught this content during their own schooling or teacher training.

Another factor is that the mass media, including television documentaries and comedies, is possibly impacting on students’ interests in and understandings of astronomy and physics and has been speculated as fuelling renewed interest and greater enrolments in physics (Townsend, 2011). For example, the 2014 Warner Brothers Entertainment Inc. movie Interstellar promoted discussion on the Internet about the accuracy of scientific concepts featured in the movie such as solar powered drones, black holes, wormholes, the effect of gravity in space, gravitational slingshots and extra dimensional space (see: http://www.buzzfeed.com/astrokatie/things-that-happen-in-interstellar-ranked-by-science#.jitONNARR for an example of the public discussion of these scientific concepts). Professor Kip Thorne, the science advisor and executive producer of Interstellar published a book called The Science of Interstellar (Thorne, 2014) where he explains what is known by scientists today about the phenomena in the movie and how the movie takes these ideas beyond what is known. Thorne interprets the movie, like an art critic or viewer interprets a painting. In the Preface of the book, Thorne reflects on engaging youth in science:

As a child and later as a teenager, I was motivated to become a scientist by reading science fiction by Isaac Asimov, Robert Heinlein, and others, and popular science books by Asimov and physicist George Garnow. To them I owe so much. I’ve long wanted to repay that debt by passing their message on to the next generation; by enticing youths and adults alike into the world of science, real science; by explaining to non-scientists how science works, and what great power it brings to us as individuals, to our civilization, and to the human race. (Thorne, 2014, p. ix)

The third proposition underpinning the research presented in this thesis is that, given the 'crisis' in science education described above, astronomy was thought to be a subject that would be more likely to be interesting and engaging for more students compared with other
science-based subjects. For this reason, the Gravity Discovery Centre (GDC) was considered an ideal context to investigate how students learn complex concepts by experientially engaging in a personal educational experience in a science centre. The research presented in this thesis was designed to investigate student learning related to three conceptual areas within the broader discipline of astronomy including Einstein’s theory of general relativity, gravity and the size and scale of the solar system.

**Purpose and Research Questions**

The purpose of this research was to investigate the effectiveness of educational programmes delivered through the Gravity Discovery Centre in influencing students' understanding of relevant science concepts.

The overarching question that guided the research was:

> What were students’ experiences of the educational programmes delivered at the GDC and what effect did these programmes have on students’ scientific understanding of astronomy?

This overarching research question was addressed through three case studies, each with its own research questions. The three case studies were all related to educational activities at the Gravity Discovery Centre and are listed below.

**Case Study 1:** An investigation of the impact an Einsteinian based enrichment program has on Year 6 students’ science knowledge and attitudes towards science

- **Research Question 1a.**
  What impact did the enrichment programme have on participating Year 6 primary school students’ understanding of basic concepts of Einsteinian physics including curved space geometry and gravity?

- **Research Question 1b.**
  What were the participating Year 6 students’ attitudes towards the enrichment programme on Einsteinian physics?

**Case Study 2:** Are we there yet? An exploratory study examining middle school students’ understanding of our place in the solar system
• Research Question 2a.
  What did Year 7, 8 and 9 students know about the solar system before participation in activities at the GDC?
• Research Question 2b.
  What impact did participation in the Solar System Walk activity at the GDC have on Year 7, 8 and 9 students’ understanding of the size and scale of the solar system?

Case Study 3: The impact of the Gravity Discovery Centre programmes on Year 8 students’ conceptual understandings about gravity

• Research Question 3a.
  What are Year 8 students’ pre- and post-instructional conceptions of gravity?
• Research Question 3b.
  What impact did the educational programmes delivered at the GDC have on Year 8 students’ conceptual understandings of gravity?

The next two sections of this chapter outline the theoretical and curricular contexts in which this research was conducted.

**Theoretical Context: Learning in Informal Contexts including Science Centres**

As a science outreach centre, the Gravity Discovery Centre (GDC) can be considered an informal learning context, the role of which is to promote and develop a strong relationship between educational and scientific communities. As discussed above, the challenge for science centres internationally is to make learning science more engaging, collaborative and relevant to the 21st Century (Office of the Chief Scientist, 2014). In 2015, the Australian Curriculum, Assessment and Reporting Authority (ACARA) acknowledged learning in informal environments as a valuable pedagogical tool, where education experiences are led by the learner and are intrinsically motivating (ACARA, 2015).

The theoretical context in which this research was conducted was that learning is a conceptual activity that involves changes in the way that students think about relevant concepts and that these changes occur in social contexts (Duit & Treagust, 2003, 2012) including science centres such as the GDC. Learning also involves motivational factors
including students’ attitudes towards and engagement with the subject matter they are learning and social factors such as their aptitude to interact with peers, teachers and the community through various means including digital means (Duit & Treagust, 2003, 2012).

Given the rapid advances in contemporary science, there have been many research studies on how students learn and the best ways to engage students in developing an interest in new perspectives in order to pursue that interest in further studies. The value of scientific knowledge lies in its power to transform the way students see their world (Thagard, 1992). To achieve this, conceptual learning has to be set in contexts that require the need for a scientific explanation, and the teaching presented in ways that reveal the significance and functionality of the new ideas. For example, “When thinking about the Universe, [students], in common with adults, have difficulty in coming to terms with the vast sizes and numbers involved. It is very important to begin to develop the idea of scale…” (Driver, Squires, Rushworth, & Wood-Robinson, 1994, p. 393). Lelliott and Rollnick (2010) emphasise the importance of teaching students about distance and size to help explain astronomical phenomena. They stressed the need for teaching “to counter the alternative conceptions acquired through informal sources of information (such as television), and poorly drawn, not-to-scale diagrams” (p. 1971). Misunderstandings occur because concepts are so removed from students’ comprehension of physicality that concrete methods of learning these abstract ideas are the closest approximation for them to make mental models.

The ideas of primary and middle school students in countries such as England, Greece, China, Australia, New Zealand and the USA have been researched and reveal a range of ideas about the scientific aspects of their surroundings, including ideas about the Earth and its place in the solar system and broader astronomical ideas (e.g. Tao, Oliver & Venville, 2013; Venville, Louisell, & Wilhelm, 2012). Researchers have found consistent patterns in secondary students' ideas across different countries, many of which are different to accepted scientific views (Harlen, 2015). Students' ideas about the world around them are developing throughout childhood and nonscientific views may hinder later learning.

Out-of-school learning takes students from the classroom and places them in a setting where there they have to manage the uncertainty of constructing meaning from self directed engagement with their environment. Vygotsky (1962), in his socio-cultural theory, described the benefits of social interactions and culturally organised activities. Vygotsky
argued that incidental learning involving self-motivation, curiosity, interaction and discourse had far-reaching benefits. Learning in out-of-school settings involves integrating cognitive, psychomotor and social gains during practical experience, as students work collaboratively and take responsibility for their learning (Vygotsky, 1962). When students are given the opportunity to explore subject matter that is designed to engage them in science, the learning material becomes more relevant as everyone incorporates new information into their personal knowledge (Dillon, 2015).

Science outreach centres are places where students of different ages and backgrounds have the opportunity to interact and explore the world from a scientific point of view. The Contextual Model of Learning provides a useful framework for understanding how complex combinations of factors influence student learning in informal settings such as outreach centres. Falk and Dierking (2000) put forward the Contextual Model of Learning as a way to organise the complexities of learning within free-choice environments. Free-choice learning environments, informal learning and outdoor learning, are all common terms used to describe various learning opportunities that are provided in out-of-school settings. Learning is a complex phenomenon and the Contextual Model of Learning emphasises context and the interaction between an individual’s personal, sociocultural and physical contexts over time. These three contexts are constantly changing across the lifetime of an individual.

Partnerships between schools and teachers, and outreach centres provide an opportunity to develop strong links between the formal education system and external providers of support and resources. Through encouragement and facilitation, and with close consultation, teachers and students could benefit from these opportunities.

**Curricular Context: Astronomy in Science Curricula across the World**

Curriculum documents internationally include requirements for students to learn about astronomy. There are some differences in the nature of the content that is to be covered and when in a students’ educational life it should be learned. Table 1 presents a summary and comparison of the relevant curriculum content from curriculum documents from Australia, England and the USA, to set the curricular context for this research.
Table 1: Comparison of Australian, English and USA Science Curricula

<table>
<thead>
<tr>
<th>Australia</th>
<th>Year 5 to 6</th>
<th>Year 7 to 9</th>
<th>Year 10</th>
</tr>
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</table>
| • Earth and space sciences  
• Physical sciences | • The Earth is part of a system of planets orbiting around a star (the Sun) | • Predictable phenomena on Earth, including seasons and eclipses, are caused by the relative positions of the Sun, Earth and the Moon  
• Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object | • The universe contains features including galaxies, stars and solar systems and the Big Bang theory can be used to explain the origin of the universe  
• The motion of objects can be described and predicted by using the laws of physics |

<table>
<thead>
<tr>
<th>England</th>
<th>Year 5 to 6</th>
<th>Year 7 to 9</th>
<th>Year 10 to 12</th>
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| • Earth and space  
• Space Physics  
• Forces and motion | • Describe the movement of the Earth, and other planets, relative to the Sun in the solar system  
• Describe the movement of the Moon relative to the Earth  
• Describe the Sun, Earth and Moon as approximately spherical bodies  
• Use the idea of the Earth's rotation to explain day and night and the apparent movement of the sun across the sky  
• Explain that unsupported objects fall towards the Earth because of the force of gravity acting between the Earth and the falling object | • Gravity force, weight = mass x gravitational field strength (g), on Earth g=10 N/kg, different on other planets and stars; gravity forces between Earth and Moon, and between Earth and Sun (qualitative only)  
• Our Sun as a star, other stars in our galaxy, other galaxies  
• The seasons and the Earth's tilt, day length at different times of year, in different hemispheres  
• The light year as a unit of astronomical distance  
• Forces as pushes or pulls, arising from the interaction between 2 objects  
• Using force arrows in diagrams, adding forces in 1 dimension, balanced and unbalanced forces  
• Forces measured in newtons  
• Non-contact forces: gravity forces acting at a distance on Earth and in space | • Acceleration caused by forces; Newton's First Law  
• Weight and gravitational field strength  
• The main features of the solar system |

<table>
<thead>
<tr>
<th>USA</th>
<th>Year 3 to 5</th>
<th>Year 6 to 8</th>
<th>Year 9 to 12</th>
</tr>
</thead>
</table>
| • The Universe  
• The Earth  
• Forces of nature | • The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons  
• Telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye  
• Planets change their positions against the background of stars  
• The Earth is one of several planets that orbit the Sun, and the moon orbits around the Earth  
• Stars are like the Sun, some being smaller and some larger, but so far away that they look like points of light  
• A large light source at a great distance looks like a small light source that is much closer | • The Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night  
• The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot  
• The Sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years  
• Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, | • The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements found on earth and behave according to the same physical principles  
• Unlike the sun, most stars are in systems of two or more stars orbiting around one another  
• On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass  
• Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released great amounts of energy over millions of years  
• Eventually, some stars exploded, producing clouds containing heavy elements from |
- Things on or near the earth are pulled toward it by the earth's gravity
- The earth is approximately spherical in shape. Like the earth, the sun and planets are spheres.
- The rotation of the earth on its axis every 24 hours produces the night-and-day cycle. To people on earth, this turning of the planet makes it seem as though the sun, moon, planets, and stars are orbiting the earth once a day.
- The earth's gravity pulls any object on or near the earth toward it without touching it.

Therefore, see them as they were that long ago in the past.

- Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity.
- The earth is orbited by one moon, many artificial satellites, and debris.
- Many chunks of rock orbit the sun. Those that meet the earth glow and disintegrate from friction as they plunge through the atmosphere—and sometimes impact the ground. Other chunks of rock mixed with ice have long, off-center orbits that carry them close to the sun, where the sun's radiation (of light and particles) boils off frozen materials from their surfaces and pushes it into a long, illuminated tail.
- Everything on or anywhere near the earth is pulled toward the earth's center by gravitational force.
- The moon's orbit around the earth once in about 28 days changes what part of the moon is lighted by the sun and how much of that part can be seen from the earth-the phases of the moon.
- Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass.
- The sun's gravitational pull holds the earth and other planets in their orbits, just as the planets' gravitational pull keeps their moons in orbit around them.

Which other stars and planets orbiting them could later condense. The process of star formation and destruction continues.

- Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.
- As the earth and other planets formed, the heavier elements fell to their centers. On planets close to the sun (mercury, venus, earth, and mars), the lightest elements were mostly blown or boiled away by radiation from the newly formed sun; on the outer planets (Jupiter, Saturn, Uranus, Neptune, and Pluto) the lighter elements still surround them as deep atmospheres of gas or as frozen solid layers.
- Our solar system coalesced out of a giant cloud of gas and debris left in the wake of exploding stars about five billion years ago. Everything in and on the earth, including living organisms, is made of this material.
- Gravitational force is an attraction between masses. The strength of the force is proportional to the masses and weakens rapidly with increasing distance between them.

1. Australia - www.acara.edu.au (Australian curriculum – Science)
3. USA - http://www.project2061.org
Concepts from physics and chemistry, insights from history, mathematical ways of thinking, and ideas about the role of technology in exploring the Universe all contribute to the astronomy sections of the curricula. Size and scale of the planets within the solar system, and the role of gravity are included in all of these curriculum documents. The content is covered from Year 3 to Year 10, depending on the country. The USA curriculum document is very prescriptive and in matters of size and scale for Years 6 to 8 recommends "activities that use a variety of astronomical tools, including star finders, telescopes, computer simulations of planetary orbits, or a planetarium."
(http://www.project2061.org/publications/bsl/online/index.php?home=true)

The USA curriculum also suggests that construction of 3-D models is preferable to diagrams, and making a model of the solar system in which the same scale is used for the sizes of the objects and the distances between them is also recommended. Chapters 3 to 5 of this study relate to this content and concepts related to Einstein's theories.

It is important to note that all three of the curricula presented in Table 1 focus on Newtonian perspectives of gravity. Yet it is Einstein’s theories of relativity that are studied at university and are the basis of contemporary exploratory research in physics (Blair, 2012). Teachers may not have the expertise though, to teach Einsteinian physics. The question arises as to whether school students should be exposed to these concepts earlier. If students were introduced to some of these fundamental Einsteinian concepts at a younger age, they could gradually build up a knowledge base to cope with these complex concepts in senior secondary school years. In addition, it is possible they would be more motivated to pursue science as a field of study in senior school because the Einsteinian concepts have more power to explain complex science.

Moreover, teaching science as a human endeavour where scientific knowledge changes over time with new discoveries and the development of theory is consistent with the Australian Curriculum: Science. It is possible that both Newtonian and Einsteinian perspectives on gravity could be taught, and explanations given to students about when these two theories are useful for understanding observations and empirical data, and their limitations (Blair, 2012).

At this stage, Einsteinian physics is absent from the curriculum, however, education researchers and physicists in a few countries, including Scotland, Norway and Korea, are
exploring methods for the presentation and inclusion of Einstein’s general relativity in new science curricula. This may be the beginning of worldwide acceptance of Einstein’s theories into the school curriculum.

Methodological Context
This study involved a multiple case study design and a mixed methods approach to data collection and analysis (Creswell, 2014). An overview of the methodology underpinning this research is provided in Chapter 2 and more detailed information about the methods of data collection and analysis are provided in the following chapters.

Scope of Study
The three case studies conducted as part of this research considered the impact and effect of student experiences related to visits to the Gravity Discovery Centre on their conceptual understanding of relevant physics concepts and attitudes towards science. The findings are limited to this particular context, however, findings from the case studies may be transferred and applied to similar contexts when appropriate, as determined by the reader (Guba & Lincoln, 2005).

Structure and Overview of the Thesis
This thesis is presented as a series of papers in accordance with Doctor of Philosophy rule 40.(1)(a) of the University of Western Australia. Chapters 3 to 5 are manuscripts that have been prepared or submitted for publication or presented at conferences and align with the three case studies and three research questions outlined above. The manuscript from Chapter 3 was published in the journal, Research in Science Education (Pitts, Venville, Blair, & Zadnik, 2013). Chapter 4 was presented at the annual international conference for the National Association for Research in Science Teaching (NARST) in Chicago in 2015 (Pitts & Venville, 2015) and Chapter 5 was accepted for presentation at the annual conference of the Association for Science Education (ASE) in Liverpool in 2012 (Pitts & Venville, 2012), but had to be withdrawn due to the author not being able to travel. It will be submitted to a journal on the completion of the examination process.

The manuscripts can be read as separate stand-alone studies; each with its own introduction, literature review, methodology, results and discussion. The common thread through the studies is the Gravity Discovery Centre as an educational outreach centre as outlined in this introductory chapter of the thesis. A general discussion and conclusion
integrates the findings from all three manuscripts and makes connections between the findings and the three propositions outlined in this chapter. A single reference list combines references from all the chapters.

Chapter 1 has included a description of the rationale, purpose and research questions related to this study as well as the theoretical and curricular contexts for the study. Chapter 2 discusses the methodology and specific methods employed in this research to investigate students' learning at a science outreach centre and provides a discussion of the procedures used. The Contextual Model for Learning in Informal Settings (Falk & Dierking, 2000) is introduced as a constructivist model appropriate for this research, conducted in the informal educational context of the Gravity Discovery Centre. Chapters 3 to 5 report the three case studies that were conducted as part of this research.

Chapter 3 presents a study that explored the impact of an Einsteinian-based enrichment programme. Concepts related to Einstein’s theory of general relativity are usually not taught until students are in university denying younger children access to this powerful way of understanding space, time and gravity. Considerable research has shown, however, that complex and abstract scientific ideas can be presented in age appropriate ways that result in measurable learning. The purpose of this part of the research was to explore the impact of an enrichment programme on aspects of Einstein’s theory of general relativity on Year 6 children’s understanding of, and attitudes towards this topic. The research design was an exploratory case study of one class of 26 students who participated in six in-class lessons as well as an excursion to the Gravity Discovery Centre.

Mixed methods of data collection included pre/post-instruction questionnaires and classroom observations through formative assessment. The results indicated a statistically significant improvement in children’s conceptual understanding on the pre/post questionnaire with a small effect size. Analysis of individual items on the questionnaire indicated variable results with regard to particular concepts. For example, after the enrichment program students were better able to understand curved space, but little improvement was observed in their understanding of gravity on the Moon. Most students reported being interested in the programme of activities and engaged in the challenge of learning concepts related to Einstein’s physics.
Chapter 4 presents a study that explored students' understanding of astronomical distances, size and scale, by walking a scale-model of the solar system. The Solar Walk at the Gravity Discovery Centre is about 1 km long, beginning at the 'Sun' and following a path that leads to the other planets, their moons and the asteroid belt in our solar system. The research design was a multiple case study with three cases, each comprised of a class of students from very different schools on an excursion to the Gravity Discovery Centre. A mixed-methods approach involved the collection of qualitative and quantitative data, including a ‘What Do You Already Know’ solar system questionnaire and a post-exursion solar system diagram drawn by students, to document the changes in student understanding of their place in the solar system. The findings indicated that students’ prior knowledge impacts their assimilation of new concepts, the length of time spent at the science centre affects student learning and the kinaesthetic nature of the activity supports learning by some students.

Chapter 5 presents a study that investigated Year 8 students' conceptual understandings of gravity and the influence that a visit to a science centre can make. Students conducted gravity experiments including dropping water filled balloons of different masses from the top of the 45 metre high Leaning Tower of Gingin. The balloon drops were timed, videoed and analysed by the students. Data collection for the case study included pre-exursion and post-exursion workbooks that qualitatively evaluated students' conceptions of gravity.

Students could consider Galileo's experiments when he discussed free fall from the Leaning Tower of Pisa, and learned about human reflex time delays and air resistance. Misconceptions that emerged included confusion between gravity and the Earth's magnetic field, and the effect of air resistance and acceleration due to gravity. Interestingly, these results compared with research findings that show students have alternative conceptions, indicating misconceptions are common in students worldwide.

Chapter 6 integrates the findings of the three case studies and how they can be applied to the improvement of student learning. The aim of this investigation was to rectify misconceptions and to address the question educators have about age-readiness in understanding ‘difficult’ concepts. This chapter offers recommendations for further research given that the findings indicate that students are able to grasp abstract scientific concepts. A Model of Student Outreach Centre Engagement has been developed from a combination of research findings from the three case studies and is presented in this
Conclusion

This chapter has introduced the research on the impact of three different programmes at the GDC, which are presented in later chapters as three case studies. Case study 1 (Chapter 3) investigated the impact an Einsteinian based enrichment programme had on Year 6 students’ science knowledge and attitudes towards science. Case study 2 (Chapter 4) examined middle school students’ understanding of our place in the solar system and Case study 3 (Chapter 5) described the impact of the Gravity Discovery Centre programmes on Year 8 students’ conceptual understandings about gravity. The next chapter presents the methodology of the research.
Chapter 2: Methodology

Introduction
This study focused on student learning and attitudes towards science through participation in activities at a science outreach centre, the Gravity Discovery Centre (GDC), located near Gingin in Western Australia. This chapter provides an overview of the constructivist research paradigm within which the research was conducted, including the subjective ontology and interpretive epistemology underpinning the paradigm. The Contextual Model for Learning in Informal Settings (Falk & Dierking, 2000) is introduced as a constructivist model appropriate for this research conducted in the informal educational context of the Gravity Discovery Centre. The chapter also describes the multiple case study research design and its implementation including an introduction to the methods of data collection and analysis that are described in more detail in the following case study chapters of this thesis. Approaches taken to the ethics in conducting the research with young people and for enhancing the research rigour including the employment of a pilot study to trial and improve the research instruments and procedures are described.

Research Paradigm: A Constructivist Approach
Figure 1 provides a diagrammatic representation of the constructivist research paradigm within which this research was conducted. Constructivism is a philosophical paradigm, based on relativist/subjective ontology and an interpretivist epistemology as represented in the top half of the model in Figure 1. "That humans actively construct knowledge is a foundational element of all constructivist theory" (Staver, 2012, p. 1019).

Lincoln and Guba (2000) explain that users of the constructivist paradigm are oriented to the production of reconstructed understandings of the social world. As this research was educational and involved the social interaction of teachers, students, education providers and other stakeholders, including the researcher, in the context of the GDC, the constructivist paradigm provided helpful ways of conceptualising the nature of reality and knowledge as well as appropriate methodologies to conduct the research. Moreover, constructivism is a paradigm that connects action to praxis (Denzin & Lincoln, 2005) that is consistent with the goal of this research to improve the learning of astronomy related concepts by students visiting the Gravity Discovery Centre.
Ontology can be considered as how reality is viewed. Ontological assumptions can be broadly divided into objective and subjective.

An objective perspective might be thought of as looking at reality as made up of solid objects that can be measured and tested, and which exist even when we are not directly perceiving or experiencing them. In particular, an objective perspective would allow that something as simple as measuring your height would result in the same answer, regardless of who does the measuring. In more complex settings, we might aspire that our objectivity allows us to make the judgements necessary to decide upon the guilt of a defendant in a court of law. In contrast, a subjective perspective looks at reality as made up of the perceptions and interactions of living subjects (O'Gorman & MacIntosh, 2015, p. 56).
Relativist ontology views facts as culturally and historically located, and subject to the variable behaviours, attitudes, experiences and interpretations of both the observer and those being observed. Questions of objective and subjective ontologies continue to fuel philosophical debate (O’Gorman & MacIntosh, 2015). Regardless of this ongoing debate, the constructivist paradigm and relative ontology underpinning the research were consistent with the research being conducted in the complex cultural context of the Gravity Discovery Centre and dependent on the complex and variable behaviours, attitudes and experiences of the participants including the students, teachers, GDC staff and the researcher herself. Moreover, the interpretations presented in the thesis also result from complex social interaction of the same participants and are clearly culturally and historically located as described in the previous chapter. "The investigator and the object of investigation are assumed to be interactively linked so that the 'findings' are literally created as the investigation proceeds" (Guba & Lincoln, 1994, p. 111).

Epistemology concerns the way in which we obtain valid knowledge. As researchers, we are required to draw connections between the assumptions we hold about reality (ontology) and the ways in which we might develop valid knowledge (epistemology). This is represented in Figure 1 by the arrow connecting the subjective ontology and interpretive epistemology. An objective ontology, that is, what O’Gorman and MacIntosh (2015, p. 56) described as “looking at solid objects that can be measured and tested”, is typically aligned with what is called a positivist epistemological approach to knowledge. In contrast, subjectivity tends to be driven by an interpretivist epistemology, that is, “knowledge that is made up of the perceptions and interactions of living things” (O’Gorman & MacIntosh, 2015, p. 56). This research was situated within an interpretive epistemology.

An interpretive epistemology takes into account the multiple realities that are revealed by the perspectives of different individuals, the context of the phenomenon under investigation, the contextual understanding and interpretation of the collected data and the nature and depth of the researcher’s involvement. Consistent with a subjective ongology, interpretivism allows the focus to be fixed on understanding what is happening in a given context rather than just measuring it in a decontextualized manner (Patton, 1990; Klein & Myers, 1999).
In terms of epistemology, interpretivism is closely linked with the constructivist paradigm. Interpretivism asserts that natural reality (and the laws of science) and social reality are different, and therefore, require different methodologies.

Interpretive research allows the researcher to take an active role in the study. The research can take place in a natural setting in which the researcher is in a position of trust and can therefore offer insights not available in more impersonal methods of data collection. Some methodological concerns associated with an interpretive approach include the need to set appropriate boundaries and find a focus to ensure that the process is consistent and confirmable (Lincoln & Guba, 1988).

Consistent with the description of interpretive research by Lincoln and Guba (1988), the research presented in this thesis was conducted in the natural, informal educational setting of the Gravity Discovery Centre. The researcher was in a position of trust with the participating schools, teachers, students and GDC staff. She took an active and visible role in the study, for example, by attending relevant classroom lessons and excursions, providing student workbooks and materials to teachers and actively discussing the nature of the learning activities with the participants. This type of research methodology relies on the observations of interactions of participants to discover patterns and their meanings. "These patterns and meanings form the basis for generalizations, which are then tested through further observation and questioning" (Tuckman, 1988, p. 389).

Due to the nature of this study where the researcher was working with various schools, groups of students and their teachers, it was important to ensure that there was minimal disruption to the participants. Each school came with its own constraints, requirements and time limitations which impacted on the actual student activities that could be completed and therefore, the data that could be collected.

**Contextual Model of Learning in Informal Settings**

Falk and Dierking (2000) developed a Contextual Model of Learning (Figure 2) as a way of explaining student learning during school visits to museums. This model has been a major influence in guiding research in informal settings and is a useful tool in comprehending and explaining student experiences. The Contextual Model of Learning developed by Falk and Dierking (2000) is consistent with an interpretive epistemology.
because it describes "three overlapping contexts: the personal, the sociocultural, and the physical", as well as "a fourth dimension - time" (p. 10).

"... view the personal context as moving through time; as it travels, it is constantly shaped and reshaped as it experiences events within the physical context, all of which are mediated by and through the sociocultural context" (Falk & Dierking, 2000, p. 11).

Figure 2: The Contextual Model of Learning (Falk & Dierking, 2000)

Figure 2 represents the personal, physical and sociocultural contexts of learning in informal contexts as three overlapping spheres. The repetition of the three spheres from small to large across a distant to near perspective represents the fourth dimension of time. Falk and Dierking (2000) argue that learning experiences in museums need to be situated within the larger framework of the visitor’s life, before and after the visit. Similarly, a school visit to a museum or outreach centre needs to be situated within the larger framework of learning at school. The Contextual Model of Learning was used to guide the research conducted in this thesis and to interpret the findings. It was derived from observations of people as they interacted with exhibits in museums.

Falk and Dierking (2000) found that eight key factors emerged as fundamental in relation to museum learning experiences:

Personal Context
1. Motivation and expectations
2. Prior knowledge, interests, and beliefs
3. Choice and control
Sociocultural Context
   4. Within-group sociocultural mediation
   5. Facilitated mediation by others

Physical Context
   6. Advance organizers and orientation
   7. Design
   8. Reinforcing events and experiences outside the museum (p. 137)

These factors were significant in contributing to the quality of a museum experience. In relation to this study, specifically related to a science outreach centre, the Gravity Discovery Centre, the above factors were a framework that was useful in considering the students and their engagement with the specific activities described in the following chapters. This was the basis for the Model of Student Outreach Centre Engagement presented in Chapter 6.

**Multiple Case Study Research Design**

Merriam (1988) explains that case study design is based on "the nature of the research problem and the questions being asked" (p. 32).

> Its strengths outweigh its limitations. The case study offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon. Anchored in real-life situations, the case study results in a rich and holistic account of a phenomenon. It offers insights and illuminates meanings that expand its readers' experiences. These insights can be construed as tentative hypotheses that help structure future research; hence, case study plays an important role in advancing a field's knowledge base. (p. 32)

The case study design is consistent with the constructivist paradigm for this research, and, as Merriam (1988) explains, is dependent on the question that guided the research. In this study, the overarching research question was:

What were students’ experiences of the educational programmes delivered at the GDC and what effect did these programmes have on students’ scientific understanding of astronomy?
This research question was addressed through three separate case studies. The three case studies were all related to activities at the Gravity Discovery Centre and were listed in Chapter 1 along with the subsidiary research questions aligned with each case study.

Interpretive research allowed the researcher to gain a greater understanding of the students' interactions at the Gravity Discovery Centre. The data obtained through this approach provided in-depth descriptions of events, where the researcher acted as a participant observer when visiting a field location to observe the phenomena that occurred in that setting (Tuckman, 1988). As the research was conducted at the GDC, this approach was appropriate.

The researcher also interviews people in and around the setting. The researcher attempts to identify the chief concerns of the various participants and audiences, and to assess the merit, worth, or meaning, of the phenomena to the participants. To accomplish this, the researcher must determine what effects the setting, the participants, and the observed phenomena have on each other (Tuckman, 1988, p. 389).

Stake (2005) explains that many case studies utilise both qualitative and quantitative methods of data collection and analysis. Stake (2005) views case study research, not as a methodology, but rather a choice of what is to be studied (i.e. a case within a bounded system, bounded by time and place). Other researchers consider it to be a methodology, or a comprehensive research strategy used in combination with other methods, as part of a larger mixed methods study (Denzin & Lincoln, 2005; Merriam, 1988; Yin, 2009, 2014). Creswell (2013) views case study research as "a methodology: a type of design in qualitative research that may be an object of study, as well as a product of the inquiry" (p. 97). In this study, Stake’s (2005) view of a ‘case study’ as a choice of what is to be studied within a certain time and place was adopted.

The study presented in this thesis was designed in the form of a multiple case study (Stake, 2006), each of the three case studies being a featured activity at the Gravity Discovery Centre in the state of Western Australia in the period 2010 to 2015. The logic of using a multiple case study is replication (Yin, 2009), which is analogous to multiple experiments.

Each case study was designed to address the overarching research question, that is:
What were students’ experiences of the educational programmes delivered at the GDC and what effect did these programmes have on students’ scientific understanding of astronomy?

In this way, the multiple case study design contributed to the rigour of the research (Yin, 2014). Each case study addressed the overarching research question in different ways, with different educational activities in the GDC and with different students and teachers from different schools. The multiple layers of complexity from the three case studies was planned to provide more complete, detailed and rigorous findings regarding the overarching research question than would be possible with a single case study.

Students from primary and secondary schools in Western Australia visited the Gravity Discovery Centre (GDC) and were involved in the three case studies, participating in a variety of learning activities. The case studies aimed to provide an indication of the effectiveness of student participation in practical activities and the impact of experiential learning at informal learning centres, specifically the Gravity Discovery Centre, on student learning. Each case study had a different context, as each participating school and its students were involved in different ways and each brought its own unique situation and challenges.

Multiple case studies involve collecting and analysing data from several cases, as in this research. "In a multiple case study, there are two stages of analysis - the within-case analysis and the cross-case analysis" (Merriam, 2014, p. 204). When considering the within-case analysis, each case was first considered as a detailed case in its own right. A model of student outreach centre engagement was then developed (see Chapter 6).

Yin (2009) describes some common concerns with the case study approach. Case studies have been considered by some commentators to be less rigorous than surveys or experiments.

Case study researchers need to follow systematic procedures and remain unbiased in reporting findings and conclusions fairly. Bias can affect experiments or survey design as well, but in case study research problems may be more difficult to overcome (Yin, 2009). "A second common concern about case studies is that they provide little basis for scientific generalization" (Yin, 2009, p. 15). The length of time taken to complete case studies is also of concern. However, this concern may be due to confusion with ethnography, which
usually requires long periods of time spent collecting detailed, observational evidence, whereas case studies can be conducted with efficient and less time consuming methods of data collection.

**Mixed Methods of Data Collection and Analysis**

A combination of quantitative and qualitative methods was employed to collect and analyse the data in each of the three case studies. In this chapter, a generic overview of the methods of data collection and analysis is provided. More detailed information about the specific methods of data collection and analysis relevant to each case study is included in Chapters 3, 4 and 5.

The advantage of using mixed methods research is that a richer and stronger array of evidence can be provided for studying a problem than either qualitative or quantitative research alone (Creswell & Plano Clark, 2011). The methods of data collection used in the three case studies presented in this thesis included interviews, participant observation using field notes, as well as questionnaires that probed students’ pre- and post-excursion understanding of relevant science concepts and where relevant, their attitudes and general perspectives on science. The questionnaires included different types of questions including closed, multiple choice items and open-ended questions where students were asked to write or draw answers. In two of the studies, student workbooks, where they answered questions about and documented their participation in GDC activities, also were used to collect data.

This form of research was challenging in terms of "the need for extensive data collection, the time-intensive nature of analysing both text and numeric data, and the requirement for the researcher to be familiar with both quantitative and qualitative forms of research" (Creswell, 2009, p. 205).

A four-step procedure as outlined in Figure 3 guided the data collection for each case study. This procedure ensured an ethical approach to data collection (more information provided later in this chapter) and collecting the data before and after the GDC experience captured any change in students’ understanding of relevant science concepts.
Development of Research Instruments for Data Collection

An instrument was developed for each case study to provide data to address the relevant research questions (see Table 2). The instruments were designed to gather information about students' understanding of concepts related to specific activities at the Gravity Discovery Centre. The implementation of the instruments was also a consideration and the time required by students to complete them was a factor, i.e. not take too much time to complete. The questionnaires were embedded in student workbooks (see Appendices A, B, C) that were developed by the researcher and provided to the participating teachers to use with their students.

Student workbooks were used for pre- and post-data collection in Case Studies 1 and 3. Case Study 2 involved pre-knowledge quiz from the workbook and post-activity involving a drawing of the solar system (without access to their workbook).

Table 2: Data Collection Instruments

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Instruments (see Appendix A, B, C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Einsteinian-based enrichment programme</td>
<td>Chapter 3: Science Questionnaire</td>
</tr>
<tr>
<td>2. Are we there yet?</td>
<td>Chapter 4: Solar System Walk Student Workbook</td>
</tr>
<tr>
<td>Size and scale of the solar system</td>
<td></td>
</tr>
<tr>
<td>3. Understanding gravity</td>
<td>Chapter 5: Leaning Tower of Gingin Student Workbook</td>
</tr>
</tbody>
</table>
Creswell and Plano Clark (2007) describe how "the best instruments are rigorously developed using good procedures of scale development" (p. 124). Procedures recommended by DeVellis (1991) emphasise the importance of having the item pool reviewed by experts, pilot testing, validation and evaluating the items (Creswell & Plano Clark, 2007).

**Pilot Study**

New research instruments were developed by the researcher to measure and collect data in the three case studies as described in the previous section. After the initial trial versions of the instruments were prepared, there was a cycle of pilot testing using students similar to those who were included in the final case studies, under actual field conditions at the Gravity Discovery Centre. Pilot testing provided the opportunity to check that the students understood the meaning of the questions or statements, to gauge whether questionnaire items were at an appropriate level of difficulty, and to develop suitable code values for responses. A pilot study allowed procedures for data collection, data preparation and analysis to be refined prior to the main data collection occurring. Sixty students and two teachers from one secondary school in Perth participated in the pilot study excursion to the GDC and pre- and post-excursion data collection. Observations made during the pilot study and initial analysis of the data generated by the instruments was used to adapt and improve both the instruments and the procedure for the case studies.

**Approach to Data Analysis**

Data analysis was complex, multi-layered and ongoing during all three case studies in this research. Quantitative survey data were scored and entered into the SPSS software program (Statistical Packages for the Social Sciences) and analysed through a process of analysis of variance to determine if there were significant differences between the pre- and post-GDC visit scores, and to determine patterns in the data relevant to the research questions.

Qualitative data were coded "to catch the complexity and comprehensiveness of the data" (Cohen, Manion & Morrison, 2011, p. 560). Qualitative and quantitative data from each case study were analysed on an individual basis so that case reports could be constructed.
Data coding

The first step in the coding process in each of the case studies was organising the data. It involved taking text data and drawings gathered during the data collection phase, "segmenting sentences (or paragraphs) or images into categories, and labelling those categories with a term, often a term based in the actual language of the participant" (Creswell, 2014, p. 198).

Data coding allows for detection of "frequencies (which codes are occurring most commonly) and patterns (which codes occur together)" (Cohen et al., 2011, p. 560). Coding is the starting point in qualitative analysis and the foundation for what comes later. During the process of analysing the qualitative data in order to make sense of it, "initial coding will typically be descriptive and low-inference, whereas later coding will integrate data by using higher-order concepts" (Punch, 2009, p. 179).

Creswell (2014) describes three categories of codes, including (1) codes on topics that you would expect to find, based on past literature and common sense; (2) codes that were not anticipated at the beginning of the study; and (3) codes that are unusual and that may be of interest.

For each of the three case studies, a codebook was developed "to provide definitions for codes and to maximize coherence among codes" (Creswell, 2014, p. 199). The codebook evolved as the codes emerged during the data analysis. Once the initial coding was completed and checked, then emergent themes and frequencies of codes were determined. Codes were checked for "inter-coder agreement" (Creswell, 2014, p. 203). High consistency in coding is important for qualitative data reliability. Separate code sheets were developed and used when coding student work.

Coding of the open-ended questions required response categories to be developed. A random selection of student workbooks was selected and the responses were entered into a spreadsheet. This process was continued until a pattern emerged of repeated responses and no new ones appeared. The responses were then examined to observe the similarities and differences. If there were two or more student responses with similar meaning they were combined under one category. In some instances a code was divided into two when it was considered by the researcher to provide a more appropriate grain size for the code and
better data to address the research questions. A descriptive name was given to each category that emerged.

Kumar (2011) identified three important considerations when developing categories that were taken into consideration during this research:

1. The categories should be mutually exclusive. A response should not be able to be placed within two different categories.
2. The categories should be exhaustive; that is, almost every response should be able to be placed within one of the categories.
3. The use of the 'other' category should be used sparingly, i.e. less than 5 per cent of the total responses. (p. 264)

Validity in interpretive research is measured in terms of whether the researcher's representations of reality are consistent with the different data sources. The best case for validity, according to Erickson (1986), "rests with assertions that account for patterns found across both frequent and rare events" (p. 149).

**Research Rigour**

Stake (2010) noted that the primary reason for a researcher to adopt a mixed-methods approach "is to improve the quality of the evidence" (p. 125). In this study, the primary approach to ensure the quality of the evidence and findings was the mixed methods of data collection. Mixed methods also can be described as ‘triangulation’, that is, the use of more than one method to study a phenomenon (Lincoln & Guba, 1985). The phenomenon under study in this research was student learning in the context of activities at the Gravity Discovery Centre.

Denzin (1978) was one of the early methodological researchers who first explained that triangulation could uncover new perspectives that a single data collection method might not reveal. The use of triangulation is, therefore, consistent with the multiple perspectives expected with a subjective ontological view of reality and the interpretive epistemology of the constructivist paradigm in which this research was conducted. The comparison and analysis of evidence from field notes, interviews and student workbooks including student conceptual questionnaires in this study was designed to increase confidence in the interpretation of data. Denzin (1978) also explained that the use of multiple methods of
data collection in an investigation can overcome any potential weaknesses of any individual method.

No single research method can capture all of the features of a study and the use of more than a single method increases the potential that more balanced findings that better reflect complex, real-world situations will eventuate. When a researcher utilises triangulation strategies, stronger interpretations can result. Triangulation also was recommended by Mathison (1988) as a way of combining data collection methods to improve the quality and rigour, in particular, for educational research. Since that time, triangulation has become a more accepted and mainstream approach to enhancing the rigour of qualitative and mixed methods research (Creswell & Plano Clark, 2007). In order to maximise understanding of the impact the Gravity Discovery Centre (GDC) programs had on student understanding of astronomy and student interest in science, mixed methods were utilised, including both qualitative and quantitative forms of data collection.

Lincoln and Guba (1985) described confirmability, dependability and transferability as alternative criteria for the quality of research that can be used instead of the terms usually used for research conducted in the positivist paradigm such as validity and reliability. In terms of confirmability and dependability, rigour can also be achieved by outlining the decisions made during the research process, to provide a rationale for the methodological and interpretative judgements made. In this study, observational field data were collected using field notes and digital voice recordings. Moreover, students recorded their learning experiences as they completed activities at the GDC in workbooks that were specifically designed for this study. Teachers also participated in informal interviews during the excursions or in more formal interviews within a few days of the visit to the GDC.

To determine transferability, the original context of the research should be adequately described so that judgements can be made. The responsibility of the researcher lies in providing detailed descriptions for the reader to make informed decisions about the transferability of the findings to their specific contexts (Lincoln & Guba, 1985). The emphasis should be on creating ‘thick’ descriptions, including accounts of the context, the research methods and examples of the data, so that interpretations can be considered. The following three chapters describing each of the case studies conducted as part of this research convey the relevant data in detail, including presentation of the case study findings, with direct quotes from the participants, to enhance transferability.
**Ethical Issues**

"Data collection should be ethical and it should respect individuals..." (Creswell, 2008, p. 179). This research was broadly focussed on supporting and improving the science education of young people, and it is unlikely it could be considered controversial or harmful in any way. Regardless, the involvement of young people appropriately requires careful consideration of ethical issues to ensure their safety and wellbeing and to ensure the researcher considers issues such as the participating children’s capacity to understand what the research entails, and potential conflicting values and interests of the researcher, schools, teachers, the GDC, the participating children, their parents and any other stakeholders.

This research included a number of processes to ensure it was conducted in an ethical manner and was consistent with the Australian National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research (Australia. National Health and Medical Research Council, 2015). In particular, Section 4.2 of the NHMRC’s statement relating to children and young people was considered carefully in the design of this research.

The NHMRC document emphasises the need to consider a number of factors when designing research that involves children, for example: that the research has merit and integrity; that it is justifiable to involve children; that it provides for the child’s “safety, emotional and psychological security, and wellbeing” (p. 51); and, that there is no reason to believe that participation is contrary to the child’s best interests. These factors were considered during the design, implementation and writing up of this research. The two cornerstones to the ethical approach to the conduct of this research were informed consent for all participants and anonymity and confidentiality.

**Review and Permission from the University Human Research Ethics Committee and the Department of Education Research Ethics Committee**

Prior to the collection of any data for this research, ethics approval was obtained from the University of Western Australia’s Human Research Ethics Committee and the Western Australian Department of Education Research Committee. An outline of the proposed research was provided to both committees, as well as the required application form, descriptions and copies of data collection instruments and copies of all participant information and consent forms. The approval number from the UWA Human Research
Ethics committee to conduct the research was RA/4/1/4434. For the WA Department of Education Research Committee, additional documentation was required including the approval letter from the University Human Research Ethics Committee, and copies of Working With Children Check cards. The approval number from the Department of Education to conduct the research was D11/0303977.

**Informed Consent**

Schools in Perth, Western Australia were invited to consider participating in this research in relation to the educational activities at the Gravity Discovery Centre. Participating schools were selected based on professional contacts of the doctoral candidate, the school’s willingness to participate in the research and the schools’ capacity to bring a variety of educational contexts to the research.

The researcher contacted the principals of potential schools by phone or email, provided a brief overview of the research and asked for an initial indication of their possible willingness to participate in the research. If they were interested, principals were provided with detailed written information about the research, a copy of letters of ethics approval from the University Human Research Ethics Committee and Department of Education and Working With Children Check cards of all researchers who visited the schools or made contact with the students at the GDC. The principals were afforded the opportunity to ask any questions of the researcher and formal written permission from all participating schools was obtained from the principal prior to any data collection.

After permission was obtained from the school principals, the researcher approached teachers at the relevant schools to inquire if they were willing to volunteer to participate in the research at the Gravity Discovery Centre with their class. All teachers approached were enthusiastic about volunteering because support to organise and fund the excursion for their class was provided as part of the research. Teachers were provided with detailed written information about the research and an opportunity to ask any questions of the researcher. All teachers provided written consent to participate in the research.

Written permission was required from parents or guardians and students prior to participating in an excursion to the Gravity Discovery Centre and completing written materials that were used as data collection in this research. All parents and students were
provided with written information about the research and had an opportunity to ask any questions of the researcher before they submitted their consent to participate.

The researcher informed "participants of their rights to refuse to take part in any or all of the research" (Cohen et al., p. 91) and obtained all of the necessary ethical clearances to conduct the research presented in this thesis. Individuals were told that if they chose not to participate in this research, or withdraw from the research at any time, that they would not be penalised in any way.

Information sheets to all participants included the purpose of the research, information about who was conducting the research, the nature and types of data collection that participants would be involved in and the time it would take to participate. Participants also were provided with the name, phone number and email address of an independent person that could be contacted should they have any concerns about the conduct of the research.

**Anonymity and Confidentiality**

The anonymity of the schools, principals, teachers and students that participated in this research was an important consideration. The researcher was aware that it may be "impossible to guarantee the anonymity of a person or an institution" (Cohen et al., 2011, p. 93), as Western Australia and the research community are relatively small and this research has received publicity locally. Assigning identification codes as early in the research process as practical helped to ensure that the anonymity of schools and individuals was protected. The information from all participants was transferred to "coded, unnamed data sheets" (Cohen et al., 2011, p. 91). Codes were kept in a separate document in a password-protected computer to which only the doctoral researcher had access. Care was taken to ensure that data were not used in a way that would publicly identify the schools or individuals involved. Pseudonyms and/or codes were used for all participating schools, principals, teachers and students throughout this thesis and any publications that have arisen from the research.

Participants' identities remained confidential and upmost care was taken not to use the information provided by participants in a way that revealed personal information. During and after data collection, the data were viewed as confidential and were not shared with other participants or individuals outside the research group. However, the communication
of findings is important to realise the value or benefits of any research to the community and the process of communication necessarily means that the findings do not remain confidential. The findings of this research are publically communicated through this thesis and other publications that have and will result from the research. However, the anonymous nature of the reporting of the findings in these publications will ensure that any personal information is not revealed and this protects the confidentiality of schools and individuals.

**The School Index of Community Socio-Educational Advantage (ICSEA)**

The schools in this study draw their students from a number of suburbs with a wide range of socio-economic and ethnic backgrounds. The Australian Curriculum, Assessment and Reporting Authority (ACARA) created the Index of Community Socio-Educational Advantage (ICSEA). The ICSEA aims to enable meaningful comparisons of national test results across the diverse schools within Australia. It is believed that key factors in students' family backgrounds (parents' occupation, school education and non-school education) have an influence on students' educational outcomes at school and the index takes these factors into consideration.

In addition to these student-level factors, school-level factors (a school's geographical location and the proportion of indigenous students a school caters for) are considered when summarising educational advantage or disadvantage at the school level. ICSEA provides a scale that numerically represents the relative magnitude of this influence, and is constructed taking into account both the student- and the school-level factors. The mean ICSEA for all Australian schools is 1000 with a standard deviation of 100. Table 3, below, indicates the ICSEA values for schools in this study. It indicates that schools A, B, C and E had an ICSEA well above the national mean. School D had an ICSEA below the national mean. Detailed information on ICSEA and Australian schools in general can be obtained from the MySchool website (http://www.myschool.edu.au).
Table 3: Summary of participating schools' ICSEA and student groups involved in the case studies

<table>
<thead>
<tr>
<th>School</th>
<th>ICSEA 2014</th>
<th>Year Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 3: Case study 1 - (School A)</td>
<td>1207</td>
<td>6</td>
</tr>
<tr>
<td>Chapter 4: Case study 2a - (School B)</td>
<td>1132</td>
<td>7</td>
</tr>
<tr>
<td>Chapter 4: Case study 2b - (School C)</td>
<td>1138</td>
<td>8</td>
</tr>
<tr>
<td>Chapter 4: Case study 2c - (School D)</td>
<td>959</td>
<td>9</td>
</tr>
<tr>
<td>Chapter 5: Case study 3 - (School E)</td>
<td>1138</td>
<td>8</td>
</tr>
</tbody>
</table>

Further details of the case study schools are provided in Chapters 3 to 5. As the case studies were undertaken in different years, the ICSEA values reported in these chapters may vary. Student comments reported in this thesis have been labeled with the school letter (as shown in Table 3 above) and a unique number that was assigned during the coding process.

**Conclusion**

This chapter described the research methodology including the constructivist research paradigm and the underpinning subjective ontology and interpretive epistemology. The multiple case study design was justified in terms of the constructivist research paradigm and an overview of the mixed methods approach to data collection was provided. The principles used to design the data collection instruments were introduced and an outline of the approach to data analysis was included. The approach taken to ensure the quality and rigour of the research was described including the multiple case study design with each case converging to provide information to address the overarching research question, triangulation of methods of data collection, and the pilot testing of research instruments.

Finally, the approach used to ensure the ethical conduct of research with young people was delineated including informed consent, anonymity and confidentiality. The following three chapters present the three case studies conducted as part of this research. Each chapter is written in the style of a journal paper and addresses the subsidiary research questions outlined in this chapter.
Chapter 3: An Exploratory Study to Investigate the Impact of an Enrichment Programme on Aspects of Einsteinian Physics on Year 6 Students

Abstract
Concepts related to Einsteinian physics are usually not taught until students are in university, denying younger children access to this powerful way of understanding space, time and gravity. Considerable research has shown, however, that complex and abstract scientific ideas can be presented in age appropriate ways that result in measurable learning.

The purpose of the research presented in this chapter was to explore the impact of an enrichment programme on aspects of Einsteinian physics on Year 6 (10 and 11 year old) children’s understanding of and attitudes towards this topic. The research design was an exploratory case study of one class of 26 students who participated in six in-class lessons as well as an excursion to a science centre, the Gravity Discovery Centre, and a scripted play about relevant key scientists. Mixed methods of data collection included a pre/post-instruction questionnaire, classroom observations and an interview with the physics professor who conducted the programme. The results indicated a statistically significant improvement in children’s conceptual understanding on the pre/post questionnaire with a small effect size.

Analysis of individual items on the questionnaire indicated variable results with regard to particular concepts. For example, after the enrichment programme, students were better able to understand curved space, but little improvement was observed in their understanding of gravity on the Moon. The majority of students reported being interested and engaged in the programme of activities and did not feel that they were too young to learn concepts related to Einstein’s physics.
Introduction
Despite Einstein’s theories of general and special relativity now being known and celebrated by the science community for one hundred years, related concepts are still only made accessible to students in the final years of high school or more often in university, to gifted students, or those taking advanced science classes.

There are many who believe that concepts included in the conceptual scheme of relativity can be understood only by an elite group of scientists. ... this notion of unintelligibility of relativity was not shared by the scientists who developed it. (Haddad & Pella, 1972, p. 22)

The reason relativity is often ignored in the school science curriculum is that this knowledge is assumed to be too difficult for younger children to grasp. Consequently, nineteenth century concepts about matter, space and time are still taught in schools as if these were the way that today’s scientists also perceive reality. For example, the science content standards for USA public schools (Next Generation Science Standards (NGSS), 2013) state that from Grade 9 through Grade 12, all students are expected to achieve a list of standards based on Newton’s laws, including “the universal law of gravitation and the effect of gravity on an object at the surface of the Earth”. The same standards list includes as optional material, that is, something that all students should only have the opportunity to learn, that “Newton’s laws are not exact but provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important”. Moreover, relativity is not mentioned anywhere in the Next Generation Science Standards (NGSS) (2013) document.

Einstein's general theory of relativity presented a new theory of gravity that included Newton's theory as a special case. Einstein recognised that acceleration was equivalent to the force of gravity, "explaining how a mass can cause distortion of the space in which it is located, and that it is this distortion that causes other masses in the vicinity to experience the force of gravity" (Falla, 2012, p. 60). In general relativity theory, the three dimensions of space and one of time are combined into a four-dimensional space-time metric. General relativity can be imagined by visualizing space-time as a tautly stretched rubber sheet and the presence of objects with mass in space-time represented by a dent in the surface of the sheet. An object nearby experiences an attractive force as a result of the distortion, like a marble rolling towards the bottom of a depression in the rubber sheet. Einstein understood
that near a very large mass, such as the Sun, light would be deflected as it passed nearby. On 29 May 1919, a total eclipse of the Sun took place, and when the results obtained by the astronomers on measured stellar positions were compared, they were found to be consistent with those predicted by Einstein's general theory.

While the authors of this exploratory study are interested in students' understanding of Einsteinian physics in general, the focus of the research presented in this chapter was on Einstein’s theory of general relativity. Ideas related to relativity are very difficult to think about due to our limited experiences living on the surface of the Earth where space, time and gravity are perceived to be fixed. We cannot travel close to the speed of light when we might experience the effects of relativity and cannot experience how matter curves space.

As a consequence, relativity is an abstract concept, that is, we cannot experience relativity in a tangible, physical way and we must visualise the related ideas in our mind. For many people, this process of visualisation is too difficult. Thus, to understand abstract concepts such as relativity, some people need models, animations, simulations, role plays or other analogical tools that allow them to think about the abstract ideas in more concrete or experiential ways (Aubusson, Harrison, & Ritchie, 2006).

Curved space gives rise to surprising phenomena like the effect of gravity on clocks and changes in standard geometrical formulae. Modern physics that embraces Einstein’s ideas about relativity is essential for the development and understanding of space engineering and modern electronics. The exploratory study presented in this chapter was underpinned by the assertion that it is important that school students of all ages are exposed to current scientific thinking and ways of knowing. This research was designed to explore whether it is possible, and indeed beneficial, to begin to teach Einsteinian physics in Year 6 of school when children are 10 or 11 years of age. Given that there is some evidence that primary school aged students can understand concepts related to Einstein’s physics, at least at the knowledge level (Haddad & Pella, 1972), it is surprising that a search of the literature revealed very little research has been conducted in relation to school students’ understanding of Einstein's concepts.

**Purpose and Research Questions**

The purpose of the research presented in this chapter was to explore the impact of an enrichment programme based on Einsteinian physics on a class of Year 6 students' science
knowledge and attitudes towards science. The enrichment programme included six in-class lessons for the participating students from a visiting university physics professor (in Australia "professor" refers to the highest level of a university academic position), an excursion to the Gravity Discovery Centre (a science centre) and participation in a scripted play, an exposition on the history and development of ideas related to space, time and gravity (more details about the programme are provided later in the chapter). The research was guided by the following two research questions:

1. What impact did the enrichment programme have on participating Year 6 primary school students’ understanding of basic concepts of Einsteinian physics including curved space geometry and gravity?
2. What were the participating Year 6 students’ attitudes towards the enrichment programme on Einsteinian physics?

**Literature Review and Conceptual Framework**

Relevant themes and key findings from three main areas of the literature are presented and reviewed in this section. This literature provided a conceptual framework for the research presented in this chapter. The three areas of the literature include:

1. The notion of developmentally appropriate teaching practice;
2. Prior research on the teaching and learning of Einsteinian physics; and
3. Students' attitudes towards science.

**Developmentally Appropriate Practice**

The issue of when it is appropriate to teach Einsteinian physics provides an interesting theoretical context for the research presented in this chapter. The question of age appropriate teaching has been raised in various literature reviews and remains a contentious issue in education (Bliss, 1995). The work of developmental psychologist Jean Piaget and his colleagues (e.g. Piaget & Inhelder, 1969) first introduced the idea of stages in intellectual development. For example, based on Piaget’s work, it is understood that there is a change from concrete operational to formal operational thought patterns at about the age of 14 years when children are more able to think in abstract ways. Piagetian-based theory is well known and widely applied by educators and curriculum developers. Based on this theory, the concept of developmentally appropriate practice has emerged, particularly in early childhood education. This term is intended to refer to pedagogy that is carefully developed by the teacher to meet the diverse needs of his or her students. Some interpretations of developmentally appropriate practice, however, are characterised by
extensive use of play-based learning, at the expense of content knowledge or the restriction of the type of content taught because it is considered to be too abstract or too difficult for the learners (Aldwinckle, 2001).

There is a growing body of work (e.g. Hirsch, 2006; Stone, 1996; Tytler & Prain, 2010; Willingham, 2008) that vigorously questions whether students have been held back by the narrow interpretation of Piaget’s stage theory and the widespread adoption of inappropriate forms of developmentally appropriate practice. Research has shown that the nature of the content, the way it is presented and students’ prior experiences are important factors impacting on whether what is being taught is accessible to the students. Willingham (2008) points out that:

If a child, or even the whole class, does not understand something, you should not assume that the task you posed was not developmentally appropriate. Maybe the students are missing the necessary background knowledge. Or maybe a different presentation of the same material would make it easier to understand. (p. 39)

Based on a longitudinal study of students' learning about evaporation, Tytler and Prain (2010) demonstrate that learning of science is far more individual, contextual and perceptual than previously acknowledged and that children can be seen to draw on perceptual analogies and personal narratives as they learn and make meaning in science. Tytler and Prain (2010) argue that science concepts need to be understood as ways of thinking that provide the means of explaining a variety of phenomena. They concluded that the teaching of science to young children should have a greater emphasis on inducting students into powerful representations, including "abstract models such as energy flow diagrams and systems representations" (p. 2075) and developing an explicit language for discussing them. Another study by She and Liao (2010) provides evidence for the importance of students’ scientific reasoning capacity when they are learning about abstract science concepts such as atoms. If students are able to reason well, they are more likely to be able to learn about abstract science concepts at a younger age.

An extensive search of the literature has revealed that there has been minimal evaluation of primary age students' ability to understand relativity and/or the teaching approaches that may be best suited to the teaching and learning of concepts related to Einsteinian physics.
The research presented in this chapter begins to address this dearth of information by exploring the impact on Year 6 students of a specially designed enrichment programme on Einsteinian physics including the Theory of General Relativity. One important tool used by the professor in the programme that he delivered to the students was the use of analogies, metaphors and models. Duit (1991) refers to these aids as common devices and a vital aspect of instruction in science. Venville and Treagust (1996) analysed the use of analogies in the classroom and described in their findings how they could act as aids for students in recalling concepts, as well as motivation and confidence builders, helping students to make sense of new material that is covered as well as assisting in the transformation of student meaning making. Harrison and Treagust (1993) also considered the possible disadvantages of analogies, describing how they could cause misunderstanding amongst some students who hold alternative conceptions about particular scientific concepts.

**Previous Research on the Teaching and Learning of Einsteinian Physics**

A study by Haddad and Pella (1972) investigated the degree to which Lebanese students in Years 4 to 8 could understand relativity concepts. These researchers developed tests with questions corresponding to the first three levels of Bloom’s taxonomy of educational objectives. These levels include knowledge, comprehension and application (Bloom, 1956). Knowledge is the lowest level in the taxonomy simply requiring students to recall data or information. The next level, comprehension, requires students to demonstrate an understanding of a term or concept through a form of translation, for example, by stating something in their own words. Application, the third highest of the levels in Bloom’s taxonomy used by Haddad and Pella, requires students to use a concept in a new situation.

Unsurprisingly, Haddad and Pella found that high ability groups of students achieved significantly higher results than low ability groups. They also concluded that Year 6 students could be taught concepts of relativity at the knowledge level only. Given the findings by Haddad and Pella (1972), that students could at least learn something at the knowledge level, it is surprising that a search of the literature revealed that there was very little research conducted, particularly more recent research, on primary students’ understanding of Einstein’s concepts of relativity. The research that was located tended to focus on undergraduate physics students. For example, one analysis of how physics undergraduates view the basic ideas of relativity revealed a large number of alternative conceptions amongst many students (Bandyopadhyay & Kumar, 2010). The issue of students entering university and finding that their physics course contradicts their prior
learning in science was raised as a major problem (Bandyopadhyay & Kumar, 2010; Baily & Finkelstein, 2008). Bandyopadhyay and Kumar (2010) discussed how students' prior knowledge and conceptions interfere with and affect their learning of new concepts. Baily and Finkelstein (2008) described how “student beliefs about physics [are] correlated not only with self-reported student interest, but also with [prior] conceptual understandings” (p. 70). Similarly, Bandyopadhyay and Kumar (2010) discussed how “alternative conceptions … reappear and affect students’ learning of new concepts based on them” (p. 13).

The findings from the literature about alternative conceptions (eg. Vosniadou, 1991, 2003) contributed to our rationale for working with primary school aged children in this study. It is possible that students may be better off being exposed to Einsteinian physics at a younger age when they are less likely to have developed prior conceptions that are inconsistent with the new ideas. Further, earlier introduction to these ideas may prepare students for more in-depth teaching and learning when they are in high school or university.

**Students’ Attitudes Towards Science**

Recent research demonstrates that the proportion of high school students selecting traditional physical science subjects in developed countries like Australia, the USA and the UK is declining (Lyons & Quinn, 2010). This phenomenon has raised considerable national concern, not only about the diminishing number of students selecting science-based tertiary courses and science-based occupations but also about the scientific literacy of the general population. A report by Universities Australia (2012), commissioned by Australia’s Chief Scientist, Professor Ian Chubb, highlighted Australian students’ growing lack of appreciation of the relevance and role of science in their lives and communities and of its potential for rewarding career opportunities.

In the past 20 years, a much wider range of courses has become available to school students including science-based subjects like environmental science, integrated science, sports science, engineering and aviation and other discipline-based subjects such as media studies, childhood studies, politics and legal studies and performing arts (Young, 2008; Lyons & Quinn, 2010). Subjects such as these may be perceived as more contemporary and exciting than traditional science disciplines including physics which is often considered to be too difficult, not relevant and only for the intellectual elite (Haynes, 2008;
Lyons & Quinn, 2010). In addition, the greater numbers of students staying on to complete high school could also be contributing to the reduced percentage of students choosing science subjects at this level (Lyons & Quinn, 2010).

In a study by Logan and Skamp (2008), factors such as the enjoyment of practical science, new content and unusual equipment appeared to help students maintain positive attitudes to science. Wulf, Mayhew, and Finkelstein (2010) reported that some factors that influence attitudes include “gender, support, teacher effectiveness, curricula, and the perceived difficulty of science” (p. 337). These findings were based on results over three years measuring the impact of informal science education on children’s attitudes to science.

Their recommendations included “small student to instructor ratio, providing quality teaching training, providing research-based curricula, and providing opportunities for the children to take control of their own learning” (Wulf et al., 2010, p. 337). These studies provide support for the potential educational benefits of a teaching and learning programme, such as the one that is the focus of this research, that addresses the novel ideas underpinning Einseinian physics, includes interesting hands-on activities and non-traditional pedagogies such as a scripted play about scientists. "If students’ attitudes to school science are to remain positive it is important that their school science experiences capture and maintain their interest over their schooling years" (Logan & Skamp, 2008, p. 523).

**Research Context**

Information on the research context is provided in this section including information about the Australian curriculum and the school in which the research was conducted. One of the key aspects of the enrichment programme was that it included an excursion to a local science centre called the Gravity Discovery Centre (GDC). Consequently, background information about this centre and a brief overview of the literature on learning in informal science contexts is provided. This section concludes with more detailed information about the enrichment programme including the concepts and the learning activities.
Curriculum

As this research was conducted in Australia, it is important to consider the curricular context in this country. Australia has only recently introduced for the first time a national curriculum that was being implemented at the time the research was conducted. The Australian Curriculum: Science has three interrelated strands: Science Understanding, Science as a Human Endeavour and Science Inquiry Skills (ACARA, 2012). Science is mandatory for all Year 6 students, with 25% of the allotted time allocated to the Physical Sciences.

Science Understanding includes four sub-strands: Biological Sciences; Chemical Sciences, Earth and Space Sciences, and Physical Sciences (ACARA, 2012). The Physical Sciences sub-strand for kindergarten to Year 10 indicates that students should be taught concepts including how an object's motion (direction, speed and acceleration) is influenced by a range of contact and non-contact forces such as friction, magnetism, gravity and electrostatic forces. While the curriculum states that students should appreciate that concepts of force, motion, matter and energy apply to systems ranging in scale from atoms to the universe itself, it does not allow for the geometry of curved space and the quantum reality of the universe with concepts that reflect quantum "weirdness".

Through the Science as a Human Endeavour strand, teachers are required to focus on the idea that through science, humans seek to improve their understanding of the natural world. There are two sub-strands including the Nature and Development of Science and the Use and Influence of Science. Teachers are encouraged to teach students about how current science knowledge has developed over time through the actions of many people and to explore how science knowledge and applications affect people’s lives and influence society (ACARA, 2012).

The Science Inquiry Skills strand requires teachers of science to involve students in identifying and posing questions that they can investigate. Students should be provided opportunities to plan and conduct investigations, collect and analyse data and make evidence-based arguments and conclusions. Students should also be exposed to a variety of methods of representing data and information including creating graphs, tables, spreadsheets, flowcharts and diagrams.
There are five sub-strands of Science Inquiry Skills including:

1. Questioning and predicting;
2. Planning and conducting;
3. Processing and analysing data and information;
4. Evaluating; and

At the time the research was conducted the national Australian senior secondary curriculum for Year 11 and Year 12 (16 -18 years of age) was being developed. The current Western Australian Certificate of Education Physics course unit description for Unit 3B provides the focus for teaching the specific content.

The study of mechanical and electromagnetic waves allows students to appreciate both classical and modern interpretations of the nature and behaviour of waves. They learn how waves are used in a variety of technologies, such as in musical instruments, communication systems or sensing systems. They encounter the scale of the observable entities in our Universe, and relate physical principles about waves to the study of the Universe and its parts . . . They also learn about some aspects of modern physics such as relativity and cosmology (Curriculum Council, 2012, p. 19).

The new senior secondary Australian Curriculum Physics materials may extend this development of knowledge and understandings to include greater emphasis on Einstein’s theories of relativity (general and special). At present, students are only exposed to some "qualitative aspects of the special theory of relativity such as reference frames and the mass-energy equivalence principle" (Curriculum Council, 2012, p. 19). The senior secondary Australian Curriculum materials were in the final stages of development prior to publication of this chapter as a journal paper.

**An Informal Learning Environment: The Gravity Discovery Centre**

Science learning takes place not just in the classroom but more often outside it, in many environments including informal contexts such as outreach centres, through the media, and experiences with the family (Rennie, 2007). The opportunity for students to participate in a science excursion allows them to explore and learn in an enjoyable way without the
pressure of being assessed or competing with other students. This type of learning is intrinsically motivating for students and is learner-led, not controlled by the teacher as in the classroom (Rennie & Johnston, 2007). Students have more freedom to follow their own interests and explore for themselves, and, as a result, take ownership of what they have learnt.

The GDC is an outreach centre co-located with a working research facility. It provides students with educational opportunities to learn science concepts by conducting exciting experiments with equipment that is not available anywhere else. The GDC was established at the same time as the Australian International Gravitational Observatory Research Centre where research personnel conduct experiments related to the search for gravitational waves at a location 80km north of Perth, Western Australia. The GDC is a learning centre that focuses on modern physics, astronomy and biodiversity. In parallel with the development of the buildings and exhibitions, the GDC works with a group of teachers to develop educational programmes linked to exhibits.

The GDC gives school students access to exciting, state-of-the-art science learning facilities and provided a unique context for the research that is presented in this chapter. It combines art with science, scientific research with learning modules linked to the facilities, cosmology linked to astronomy, geology, palaeontology and traditional cultural beliefs (Venville et al., 2012).

**The School Case Study**

The programme was a collaboration between a university physics professor and a Year 6 teacher at a local primary school. The physics professor is a member of the research team and a co-author of this paper. The teacher agreed to participate in the research and a one-term (10 week) period of science lessons was allocated to the project.

The participating school is a fully government funded primary school that caters for 477 children in kindergarten to Year 7. It is located in a high socio-economic status suburb 5 km from the Perth central business district. The school Index of Community Socio-Educational Advantage (ICSEA) value is 1,188. The average school ICSEA value in Australia is 1,000 with a standard deviation of 100 points. The official school website (part of the Australian Government MySchool website, www.myschool.edu.au) explains that the school has a strong academic tradition and is dedicated to excellence in teaching and
learning, striving to be recognised as a school that maximises learning opportunities to ensure students develop a broad range of skills and strong sense of values. Results in national testing presented on the website consistently show academic achievement that is well above state and national means. The website claims that the school community displays a high level of educational awareness and the school enjoys strong and active parental support. Special programmes at the school include environmental projects such as rural tree planting, a vegetable garden, solar energy generation and a chicken run.

**The Enrichment Programme**

The description of the enrichment programme provided in this section was developed through information collected from lesson plans, classroom observations and an interview with the physics professor who delivered the programme.

This enrichment programme was conceived by an Australian university professor to provide an opportunity for the early exposure of Year 6 students to physics concepts related to Einsteinian physics, in particular, the general theory of relativity that have typically only been taught at university level. A major aim of the programme was to present the physics in a novel and stimulating way by initially providing the students with real world examples to which they could relate. It was considered important to present and discuss the concepts at an appropriate level for the students' interests and abilities.

The programme included three phases:

- Six in-class sessions delivering conceptual ideas related to Einsteinian physics;
- An excursion to the Gravity Discovery Centre to reinforce the classroom theory lessons through hands-on activities; and,
- The programme culminated with the students performing a play, entitled *Free Float*, at the School of Physics, University of Western Australia. The play was an exposition on space, time and gravity.

**Phase 1: Six In-class Lessons from a Guest Physics Professor**

Over a 6-week period, the students were presented with the fundamental conceptual ideas that describe Einsteinian physics. The aim was to initially expose them to novel ways of looking at science with relevance to their interests. Table 4 provides an overview of the
content and pedagogical approaches used during the 6-week period. Each weekly lesson took between 60 to 90 minutes of class time. Instruction was directed by the university physics professor who was considered by the students as a guest teacher, but a teacher from the primary school remained in the class at all times.

The programme included topics such as connecting space and time, curved space geometry with balloons and fun with black holes. The students drew triangles on balloons and traced the paths of parallel lines. They also explored the history of ideas about space from Pythagoras to Einstein, discussed the meaning of a straight line and learnt about observations of the curvature of space. Newtonian and Einsteinian conceptions of gravity were presented in the lessons provided to the students by the university professor.
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Content</th>
<th>Pedagogical Approach</th>
</tr>
</thead>
</table>
| 1    | Space-time diagrams | • Your journey to school  
        • Falling objects | Group discovery of answers: students contributing their ideas, joint work on a whiteboard.  
                                      • Idea of distance-time relations, slope = speed, steeper the slope the faster you are going  
                                      • Idea of acceleration: steadily speeding up from zero speed |
| 2    | Connecting space and time | • The problem of units  
        • Speeds that connect space and time  
        • What speed do we use? | Group discovery of answers  
                                      • Arbitrariness of human-invented units  
                                      • Where did seconds come from? How would you time anything before we had clocks?  
                                      • Where did metres come from? How would you measure things before we had rulers?  
                                      • Idea of measuring distance with time “McDonalds 3 minutes away”. You need an agreed speed to connect space and time. |
| 3    | Two stories about space and the story of Pi | • The story of Euclid and Gauss  
        • The story of Pi  
        • The story of Newton and Einstein  
        • Curved space | Storytelling using PowerPoint: people and their discoveries  
                                      • Progressive discoveries over millennia and across cultures  
                                      • Proof and disproof of ideas |
| 4    | Curved space geometry with balloons | • Making "straight lines"*  
        • Do parallel lines ever meet?  
        • “The sum of the angles in a triangle is 180 degrees”: true or false? | Experiments in geometry  
                                      • Concept of a straight line  
                                      • Geometry on balloons |
| 5    | Fun with black holes | • Idea of a black hole  
        • Movies of black holes  
        • Balloon black holes | Classroom discussion and videos  
                                      • Black holes: what are they, where are they?  
                                      • Videos of black holes and Stephen Hawking |
| 6    | What is gravity? | • What would it be like to live amongst the asteroids?  
        • Matter always tries to follow straight lines in space-time  
        • Gravity is the force you need to bend the lines | Classroom group discussion, videos and PowerPoint animations  
                                      • Einstein versus Newton  
                                      • Einstein’s idea of gravity |
| 7    | Free Float play | • Reinforcement of learning | Gravity Discovery Centre excursion  
                                      • Classroom Play: Free Float |

* straight lines means shortest path, a geodesic

**Phase 2: Excursion to the Gravity Discovery Centre**

The second phase of the enrichment programme was a full-day excursion to the GDC. At the GDC, the participating students were given the opportunity to experience the physics concepts that had been discussed in class through guided interaction with the exhibits and
by performing experiments. Table 5 provides an overview of the programme that the students participated in at the GDC.

Table 5: The programme of activities at the GDC

<table>
<thead>
<tr>
<th>Exhibit</th>
<th>Description/activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lycra space and curved space landscapes</td>
<td>experiments with curved space landscapes and multiple spheres representing the relative movements of astronomical bodies in space</td>
</tr>
<tr>
<td>• representing curved space</td>
<td></td>
</tr>
<tr>
<td>The Time Coil</td>
<td>use your ears to hear yourself in the past</td>
</tr>
<tr>
<td>• the speed of sound in air</td>
<td>comparison between the speed of sound and the speed of light</td>
</tr>
<tr>
<td>• time travelling into your past</td>
<td></td>
</tr>
<tr>
<td>Navigating the curves of space</td>
<td>using 'black hole' exhibits to study the effects on orbiting objects</td>
</tr>
<tr>
<td>• toy cars on the black hole</td>
<td></td>
</tr>
<tr>
<td>Floaters and fallers at the Leaning Tower of Gingin</td>
<td>balloon drops from the Leaning Tower of Gingin</td>
</tr>
<tr>
<td>• free fall water balloons from the Leaning Tower of Gingin</td>
<td>space-time plots for a falling balloon</td>
</tr>
<tr>
<td>• space-time diagrams for the water balloons</td>
<td></td>
</tr>
<tr>
<td>Curved space whiteboard</td>
<td>Does the sum of the angles of a triangle always equal 180°</td>
</tr>
<tr>
<td>• curved space geometry with protractors</td>
<td></td>
</tr>
<tr>
<td>Our planet is a time machine</td>
<td>floating free vs free falling</td>
</tr>
<tr>
<td>• space-time diagrams</td>
<td></td>
</tr>
<tr>
<td>Full Dome Projection in the Cosmology Gallery</td>
<td>Movie: Black Holes</td>
</tr>
</tbody>
</table>

Phase 3: Free Float, a Scripted Play

The Year 6 students who participated in this 6-week enrichment programme performed a scripted play, Free Float, at the School of Physics, in the local university. This was the culmination of the programme, synthesising the ideas of space and time that they had been learning. In the play, the students acted as scientists such as Kepler, Newton and Einstein. It also included modern scientists who provided strong evidence to support Einstein’s theory of gravity. They all come together with a group of students to discuss, question and criticise each other.

In the roles of Euclid, Einstein, Stephen Hawking and other luminaries from the past, including Pythagoras and Carl Friedrich Gauss, the students recited a dialogue in which each scientist presented his theories. A student portrayed Professor Alexander Ross,
foundation professor of Physics at the University of Western Australia, as he presented his findings from the Wallal Downs expedition that confirmed the curvature of space around the Sun, and another student acted as Stanford physicist Francis Everitt, reporting his measurements of curved space around the Earth.

**Method**

The research design was an exploratory case study delineated by the enrichment programme on Einsteinian physics presented in the Year 6 class in one primary school (Yin, 2009). In order to explore the impact of the enrichment programme on the students, mixed methods of data collection (Creswell, 2009) was used. Mixed methods research enables researchers "to address more complicated research questions and collect a richer and stronger array of evidence than can be accomplished by any single method alone" (Yin, 2009, p. 63). The case study involved the following three data collection strategies.

1. **Observation**

   While the physics professor who delivered the programme is a member of the research team (and a supervisor of the doctoral student), different researchers observed the classroom lessons during the in-class phase of the enrichment programme as well as the excursion to the Gravity Discovery Centre and the delivery of the scripted play at a local university. "A common procedure to increase the reliability of observational evidence is to have more than a single observer making an observation" (Yin, 2009, p. 111). The students were accustomed to having observers and visitors in their classroom and the presence of researchers did not disrupt the normal learning activities in any noticeable way.

   The students were observed and video recorded performing the Free Float play at the local university, in front of an audience of lecturers, professors and other staff from the School of Physics. The video data were useful as a point of reference and discussion for the research team during the data analysis phase; however, these data are not presented in this chapter because it did not contribute to answering the research questions outlined above.

2. **Interview with the physics professor**

   An open-ended interview was conducted with the physics professor after he had taught the enrichment programme. The purpose of the interview was to ascertain his goals for the programme, to clarify the content and pedagogical activities used during the programme.
and to elicit the professor’s reflections on the successes and challenges of teaching Einstein’s physics to these 10- and 11-year-old children (see Tables 4 and 5 for a summary).

3. Student pre/post questionnaire

The doctoral researcher developed a questionnaire specifically for this programme. Two experienced physics teachers, two Australian university physics professors and one science educator, experienced in working with primary school aged children, then considered the questionnaire. They were asked to comment on the validity of the items with regard to the planned enrichment programme and the appropriateness for Year 6 children. The experts suggested minor changes to the initial draft items, which were incorporated into the final version (see Appendix A). For example, the order of questions was changed so that similar ideas were presented in a developmental way and the wording of specific questions was altered to be less confusing for young children.

The final questionnaire consisted of ten items that focused on the students’ understanding of the terms speed and parallel, their understanding of the angles of a triangle, black holes, and gravity on the Earth and the Moon. The majority of questions were open-ended so that the researchers were more likely to capture any change in the students’ conceptions from fixed and absolute, Newtonian views of space and time to conceptions more consistent with Einstein’s theory. Moreover, open-ended items are more likely to demonstrate comprehension of ideas rather than lower level knowledge demonstrated by recall (Bloom, 1956).

The questionnaire was administered to the class of Year 6 students prior to and after the enrichment programme (Table 4). A marking rubric with a total score of 20 points was developed to score the students’ responses to the questionnaire and shared with the group of researchers. After minor modifications, the researcher used the rubric to mark each student’s pre- and post-questionnaire.

All students responded to all items, and as a result, there were no blank responses that needed to be categorised. The questionnaire did not cover all of the topics in the enrichment programme because it was developed prior to the delivery of the enrichment programme and focused on what was known about students' misconceptions from the literature (Treagust & Smith, 1989; Dostal, 2005; Feeley, 2007) and the new Australian
Curriculum for Year 7. Student responses to the questions were marked according to the rubric with increasing marks (up to a maximum of two for each question) for responses that were considered to be correct and explicitly consistent with Einsteinian physics. Examples of the students' responses to questions and the marks given are provided in the Findings section.

- 0 - No response, incorrect or unsure;
- 1 - Partially correct and/or could be interpreted as being partially consistent with Einsteinian physics; or
- 2 - Correct and consistent with Einsteinian physics.

The panel of researchers agreed that the test items would give an indication of participating students' understandings of Einsteinian physics; however, they acknowledged the limitations of the test and the difficulties of developing a suitable instrument for 10- and 11-year-old students on this topic. The professor modified the course in a limited way as he proceeded, in response to the students' interests and their perceived understanding. This led to problems with maintaining the complete alignment of test questions with the content of the enrichment programme.

All scores were entered into the Statistical Program for the Social Sciences (SPSS) software package and descriptive statistics generated. A paired samples t-test was used to ascertain if there was any statistical difference in the students’ mean scores over the period of the enrichment programme and an eta squared effect size statistic was calculated as suggested by Pallant (2011). The guidelines (proposed by Cohen, 1988, pp. 284-287) for interpreting this value are: 0.01 = small effect, 0.06 = moderate effect, 0.14 = large effect (Pallant, 2011, p. 247).

The hand written answers to the questionnaire items that had already been evaluated using the marking rubric were scrutinised a second time to find questions that showed change in both large and small proportions of students to use for more detailed presentation in the findings. Question 2, about the sum of angles of a triangle, and Questions 4 and 5, about black holes, were selected as examples of questions that showed change for a large proportion of students. Question 7, about gravity on Earth, and Question 9, about gravity on the Moon, were selected as examples of questions that only showed change in a comparatively small proportion of students. Student samples that demonstrated a change and those that did not demonstrate any change over the period of the enrichment
programme were selected as quotations to include in the findings to exemplify the quantitative results.

Students' attitudes towards participation in the enrichment programme were ascertained after completion of the programme. First, students were asked to identify which parts of the programme they found most enjoyable. The following questions were also asked of the students:

- Was it interesting to find out about space and time and gravity? Why? Why not?
- Do you think you are still too young to understand Einstein’s ideas? Why? Why not?

The first item had a five point Likert scale for the students’ responses (e.g. very interesting, a bit interesting, a bit boring and a bit interesting, a bit boring, and very boring). The second part of the item (asking Why? or Why not?) allowed the students to write responses using their own words. Students’ responses to the Likert scale item were entered into SPSS and descriptive statistics and a chart generated. Open-ended responses were scrutinised and classified as mostly positive, mostly negative or neutral with regard to the enrichment programme. Examples from each of these categories were selected to include in the findings.

**Findings**

**Students’ Understanding of Einsteinian Physics (RQ 1)**

The findings from the pre/post-instruction questionnaire are presented in Figure 4 with the students arranged in descending order by pre-instruction score. The figure shows that 15 of the 26 students improved their questionnaire score over the period of the enrichment programme, four students’ scores remained the same and seven students’ scores went down. Students’ scores only went down by one or two points, but improvements tended to be three or four points (Figure 4). The paired-samples t-test indicated that there was a statistically significant increase in science questionnaire scores from Time 1 (pre-test) (M = 10.5, SD = 4.0) to Time 2 (post-test) (M = 12.5, SD = 3.7), t(25) = 3.8, p = 0.001 (two-tailed). The mean increase in science questionnaire scores was 2.0 with a 95% confidence interval ranging from 0.9 to 3.0. The eta squared statistic (0.02) indicated a small effect size.
Figure 4: The pre/post questionnaire results from the 26 Year 6 participants in the enrichment programme.

Figure 4 shows that the improvement in questionnaire scores mostly came from students who had medium and lower initial scores and that there were several students in this class who had high pre-instruction questionnaire scores that could not show much improvement over the period of the enrichment programme (a "ceiling effect"). This indicates that either the enrichment programme did not improve these high-end achieving students’ understandings of Einsteinian physics or the questionnaire was not sensitive enough to capture any change in their thinking.

Qualitative analysis of the pre/post questionnaire responses from the participating children indicated that Question 2 was sensitive to changes in the children’s thinking about curved space from before to after the enrichment programme. Question 2 asked children what the sum of the angles of a triangle would add up to and then asked them, “If we drew the triangle on an inflated balloon, would the angles add up to the same value?”
Prior to the enrichment programme, most children in the class (21/26) knew that the angles of a triangle drawn on a flat piece of paper would add up to 180°. Half of the children (13/26) said that if the triangle was drawn on an inflated balloon then the angles would still add up to the same value. Ten of the 26 children said that the angles would not add up to the same number with reasoning that was considered to be incomplete or not consistent with Einstein’s theory, for example “I think it wouldn’t because the balloon is round” (Student A9) or “No, because it could be a different size” Student A25. Only three students (of 26) provided pre-instructional explanations for this question that were considered consistent with Einsteinian physics, for example “No, because the surface of the object has changed/stretched so the angle will change” (Student A5) and “No because the angles are changed by the curve on the balloons [sic] surface” (Student A1).

On the post-instruction questionnaires, 20 of the children said that the angles of a triangle add up to 180°, five said 90° and one said 45°. Post instruction, only two children said the angles would still add up to the same amount on an inflated balloon, one child wrote no explanation and ten children said the angles would not add up to the same amount but gave explanations that were considered to be partially consistent with Einsteinian physics (e.g. “No, because the balloon is curved” (Student A24); “No because they’re different shapes” (Student A12). Half of the students in the class (13/26) said that the angles of a triangle drawn on a balloon would not add up to the same amount and also provided an explanation in their own words that was considered to be consistent with Einstein’s theory. For example, “No because a balloon is curved so the angles are different” (Student A20) or “No. My explanation for this answer is that on a balloon the matter you draw the triangle on is curved therefore changing the shape of the angles” (Student A1). Provided below are examples of pre- and post-questionnaire explanations from a variety of students to question two.

Student A4 (pre-instruction score 17; post-instruction score 15 [-2]) provided a better explanation prior to instruction than after instruction partially explaining why his overall score on the questionnaire went down from pre to post-instruction:

Pre-instruction: No, on a sphere every corner will be bigger.

Post-instruction: No, because a balloon is rounded.
Student A8 (pre-instruction score 12; post-instruction score 17 [+5]) demonstrated considerable change on his response to item two providing a fixed, Newtonian view prior to instruction and an explanation consistent with Einsteinian physics post-instruction.

Pre-instruction: Yes, because a triangle always adds up to 180°.

Post-instruction: No because curved space changes the angles.

Student A15 (pre-instruction score 9; post-instruction score 16 [+7]) also demonstrated considerable change in thinking from pre to post-instruction.

Pre-instruction: Yes, even though a balloon is round you still draw the shape the same size.

Post-instruction: No because they have been stretched and the surface is round.

Student A21 (pre-instruction score 8; post-instruction score 8 [no change]) changed her mind saying post-instruction that the angles would not add up to 180° but was unable to provide an explanation in her own words.

Pre-instruction: Yes, because all triangles angles allways [sic] add up to 180° no matter how abnormal, large or small.

Post-instruction: No.

In summary, it is evident that prior to instruction only three students were able to provide explanations on this item that were completely consistent with Einsteinian physics. After instruction, half of the students (13/26) were able to provide explanations in their own words that were consistent with Einsteinian physics. Another ten students were able to provide explanations that were partially consistent with Einsteinian physics (Table 6).
Table 6: Summary of student responses to Question 2 of science questionnaire about the sum of the angles of a triangle (see Appendix A)

<table>
<thead>
<tr>
<th>Student Responses</th>
<th>Pre-Instruction</th>
<th>Post-Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconsistent</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Partially consistent</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Consistent</td>
<td>3</td>
<td>13</td>
</tr>
</tbody>
</table>

Questions 4 and 5 concerned black holes (see Appendix A for full questions). Nine of the 26 students responded to Questions 4 and 5 “I don’t know” on the pre-instruction questionnaire.

Fourteen students gave responses to Questions 4 and 5 that were inconsistent with Einsteinian understandings. Only three students (of 26) provided pre-instructional explanations for these questions that were considered consistent with Einsteinian physics, for example "A black hole is a [sic] imploded star that spageties [sic] everything that gets too close, including light" (Student A9).

On the post-instruction questionnaires, only one student responded “I don’t know” to Questions 4 and 5 (Student A24). Sixteen students provided explanations that were considered to be partially consistent with Einsteinian physics (e.g. "A Black Hole is what happens when the sun runs out of gases to burn and dies” (Student A11). Nine students provided post-instructional explanations for these questions that were considered to be consistent with Einsteinian physics.

Provided below are examples of pre and post-questionnaire explanations to Question 4. Student A4 (pre-instruction score 10; post-instruction score 13 [+3]).

Pre-instruction: I’m not very sure but possibly a kind of portal between space and time which sucks things into it.

Post-instruction: A warp in time that slows time.
Student A6 (pre-instruction score 18; post-instruction score 18 [no change]).

Pre-instruction: A black hole is like the Earth with a gravitational field that even sucks light in.

Post-instruction: It is a star that has become a black hole and not even light can escape.

Some examples of pre and post-questionnaire explanations to Question 5 are provided below.

Student A20 (pre-instruction score 9; post-instruction score 8 [−1]) tried to use newly acquired terminology in her post-instruction response.

Pre-instruction: The Earth would go into another galaxy.

Post-instruction: If the Sun became a black hole the Earth would be sucked in and we will spagettified [sic]. It’s a black hole that’s what it does.

Student A21 (pre-instruction score 12; post-instruction score 17 [+5]) changed his viewpoint between pre and post-instruction responses. His pre-instruction response focussed on the destruction of the Earth by the black hole, whereas the post-instruction response considered the importance of the Sun to human beings.

Pre-instruction: The Earth would get sucked into it and everything in it would get crushed. A black hole has a stronger gravity than Earth so it will suck earth up.

Post-instruction: We would die from the cold and darkness. The sun provides heat and light to Earth.

In summary, it is evident that prior to instruction many students were unable to provide a suitable response to Questions 4 and 5. After instruction, most students provided explanations in their own words that were considered to be partially or fully consistent with Einsteinian physics (Table 7).
Table 7: Summary of student responses to Questions 4 and 5 of science questionnaire about black holes (see Appendix A)

<table>
<thead>
<tr>
<th>Student Responses</th>
<th>Pre-Instruction</th>
<th>Post-Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Inconsistent</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Partially consistent</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Consistent</td>
<td>23</td>
<td>25</td>
</tr>
</tbody>
</table>

In further analysing the pre/post questionnaires, responses to Question 7 relating to gravity on Earth (see Appendix A), showed that in pre-instruction, 23 out of 26 students chose the correct answer (D). Out of the 3 students who chose incorrectly pre-instruction, two of these students chose the correct answer post-instruction. These students correctly identified that gravity was responsible for objects falling towards the centre of the Earth. Only one student (Student A17) did not choose the correct answer pre-or post-instruction (Table 8).

Table 8: Summary of student responses to Question 7 of science questionnaire about gravity on Earth (see Appendix A)

<table>
<thead>
<tr>
<th>Student Responses</th>
<th>Pre-Instruction</th>
<th>Post-Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconsistent</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Consistent</td>
<td>23</td>
<td>25</td>
</tr>
</tbody>
</table>

Question 9 relating to gravity on the Moon, adapted from Feeley (2007), has an astronaut dropping a feather and a hammer (see Appendix A for full question). Half (13) of the 26 students' pre-instructional responses indicated the incorrect idea that these objects would float off the Moon due to the absence of gravity. Ten of the 26 students correctly indicated that the objects would hit the Moon's surface at the same time. The three remaining students were unsure of an answer prior to the enrichment programme. As a result of the enrichment programme, three more students provided a correct response by stating that the
objects would land at the same time. These students now correctly indicated that the objects fell due to the Moon having its own gravity but no air resistance.

Provided below are examples of pre- and post-questionnaire explanations to Question 9. Student A15 (pre-instruction score 9; post-instruction score 15 [+6]) provided an incorrect but commonly held misconception pre-instruction but was able to provide a correct response post-instruction:

Pre-instruction: The hammer and the feather will both float.

Post-instruction: They will hit at the same time because of gravity.

Student A22 (pre-instruction score 7; post-instruction score 6 [-1]) was unable to provide a correct explanation pre or post-instruction, displaying a common misconception amongst the students that objects float on the Moon (Table 9).

Pre-instruction: The hammer and the feather would float in the air because gravity isn't [sic] there to let it drop.

Post-instruction: The [sic] will both float.

Table 9: Summary of student responses to Question 9 of science questionnaire about gravity on the Moon (see Appendix A)

<table>
<thead>
<tr>
<th>Student Responses</th>
<th>Pre-Instruction</th>
<th>Post-Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Inconsistent</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Consistent</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>

In summary, it is evident that most of the students in this class had a good understanding of the effects of gravity on Earth but had varying misconceptions about gravity on the Moon and in space. The enrichment programme only resulted in an additional three students being able to improve their understanding of gravity on the Moon. This is a very common misconception amongst students (Treagust & Smith, 1989; Dostal, 2005; Feeley, 2007).
After instruction, half of the students (13/26) were able to provide correct explanations for objects falling on the Moon. Other students continued to believe that objects would float away. It is interesting to note that the new Australian Curriculum now covers these concepts explicitly for the first time at the Year 7 level.

**Students’ Attitudes Towards the Enrichment Programme (RQ 2)**

Students were asked which activities in the programme they most enjoyed and the most frequent responses were that they enjoyed learning something new, conducting hands-on experiments by themselves, learning about black holes, rockets and space–time, as well as performing in the play. Figure 5 provides the students’ responses to the Likert scale item, “Was it interesting to find out about space, time and gravity?” The figure shows that 18 of the 26 students said that it was "very interesting" and another five said it was "a bit interesting". Only three students responded in a neutral or negative way.

Students’ hand written responses reflected the affective and educational benefits many of the students felt they had gained from the enrichment programme.

> Mr B made it fun. (Student A3)

> It was fun as well as educational. (Student A15)

> I learnt a year’s worth of information. (Student A24)

The university professor also thought that the Year 6 students easily grasped some of the ideas he presented to the class about Einstein’s physics, commenting that, “They learnt to think about space and time, they learnt to appreciate that falling from a tower and floating in a space station are really the same thing.” (“Deep Physics can be Child’s Play,” 2011, p. 6)
Figure 5: Students’ responses to the post-instruction questionnaire item “Was it interesting to find out about space, time and gravity?”

Figure 6 provides the students’ responses to the post-instruction questionnaire item, “Do you feel you are too young to understand Einstein’s ideas?” The majority of students responded negatively (14 of 26), five responded positively and seven children were undecided (Figure 6). Student responses to this item indicated that some of the students felt that the university professor had made the ideas more accessible, but other students were very clear that they still found the ideas presented confusing and difficult.

No, not too young

Mr B made it a lot easier. (Student A13)

It was very easy to get his ideas because of the way they were explained. (Student A25)

I find his stuff interesting. (Student A11)

Undecided

Some of his ideas I could understand, others baffled me. (Student A18)

I didn’t really get it. (Student A22)

Some I can understand and some not. (Student A19)
Yes, too young

It can be confusing at times. (Student A26)

Some stuff is very complicated. (Student A17)

![Bar chart showing responses to the post-instruction questionnaire item](chart)

Figure 6: Students’ responses to the post-instruction questionnaire item “Do you feel you are too young to understand Einstein’s ideas?”

Discussion

The findings from this exploratory case study conducted with one Year 6 class of 26 students, in one primary school in Australia, showed that there were measurable and statistically significant but modest improvements in the students’ understanding of aspects of Einsteinian physics. Students’ hand written responses to some of the items on the questionnaire indicated that at least some of them were able to respond in ways that showed that they not only had gained some knowledge, that is, they could recall ideas, they also showed a level of comprehension of these ideas (Bloom, 1956). For example, data from item two of the questionnaire about whether the angles of a triangle drawn on a balloon would still add up to 180° indicated that post-instruction, at least half of the children in this class could respond correctly and generate their own explanations for their answer in a way that is consistent with Einsteinian physics.

It is also possible that some students could apply the ideas they had learnt in a new context, for example, during the excursion to the Gravity Discovery Centre (GDC). However, the data collection presented in this chapter did not extend to ascertaining the activities and
learning of individual students at the GDC. This was the first research study involving students and the GDC and is an area for future investigation. The findings are encouraging because many of the participating children could comprehend the ideas and provide their own explanations consistent with Einsteinian physics about curved space and the way it affects the angles of a triangle, for example. This compares favourably with the findings of Haddad and Pella (1972) with Lebanese students in Years 4 to 8 who were able to demonstrate knowledge but were not able to provide their own explanations of relativity-based concepts.

Student responses to questions about their engagement during the enrichment programme showed that, even if they did not fully comprehend the ideas about Einstein's theory that were presented to them, they still enjoyed and were interested in the activities undertaken at school and especially at the GDC. The students were excited to experience the use of unusual equipment in experiments at the GDC. This finding is consistent with other research that also indicates that students enjoy a practical, hands-on approach to science, that they are stimulated by novel content and unusual equipment (Logan & Skamp, 2008).

The positive responses from many children indicated that they did not think they were too young to learn about Einstein’s ideas. This finding is consistent with other research that reports that one factor influencing students’ attitudes towards science is the perceived difficulty of science (Aschbacher, Li, & Roth, 2010; Wulf et al., 2010).

Today’s students are exposed to a wide variety of television shows and movies that provide a wealth of information and myth, but are able, with the aid of computer-generated imagery (CGI), to provide exciting, colourful and riveting entertainment. Students viewing these multimedia programs can bring a wealth of knowledge (both accurate and inaccurate) with them to the classroom.

Travel between galaxies using wormholes is a major theme in many movies and television shows and students may confuse these with black holes, especially when some shows are claiming to “tap” the power of black holes to enable wormhole travel. The Black Holes presentation at the Gravity Discovery Centre involved students lying on mats on the floor of the darkened Cosmology Gallery and then viewing the movie on the domed ceiling. This was a novel experience for the students, and they expressed their enjoyment of this activity in their feedback. A movie is not enough, though, as the
students’ responses indicated a need for a more systematic approach in addressing students’ conceptual understandings if this experience is to be of maximum benefit to student learning. One of the limitations of Questions 4 and 6 is that they focused on knowledge recall, rather than allowing students to demonstrate their comprehension of black holes and gravity.

Some participating students made comments that the university professor “made it a lot easier” and that “it was very easy to get his ideas because of the way they were explained”. These comments support the idea that the nature of the instruction and developmental appropriateness are critical to engaging students with science content. If ideas are presented at a level beyond the comprehension of the students, they will experience difficulty and will be less likely to engage with the material and achieve success. The teacher’s role is important in providing appropriate scaffolding and learning materials to facilitate student learning of complex content.

The findings also support research on learning in informal contexts, such as the Gravity Discovery Centre, that provides students with the opportunity to explore and learn in an enjoyable way without the pressure of being assessed or competing with other students. It seems that this type of learning is indeed intrinsically motivating for students (Rennie & Johnston, 2007).

An interesting question raised by the findings of this exploratory case study is whether 11 years of age, or the latter years of primary school, is a critical stage to capture students' interest in science and encourage positive attitudes towards science? Research indicates that many students seem to lose interest or disengage from science when they are teenagers (Bennett & Hogarth, 2009). If students come to high school enthused and keen to continue with science, will this "see them through" the middle years to upper secondary school where they can choose whether or not to continue with science subjects? Does early exposure to Einstein’s ideas capture students’ interest and challenge their thinking enough to open their minds to new possibilities for their futures? These are interesting questions for future research.

This enrichment programme achieved learning objectives in the Science as a Human Endeavour strand and the Science Inquiry Skills strand of the new Australian Curriculum: Science (ACARA, 2012). For example, students participated in a scripted play that
introduced the work of key scientists and their role in changing our understanding of space, time and gravity. Students also designed and conducted gravity experiments at the Gravity Discovery Centre. Conversely, the enrichment programme did not achieve the educational objectives of the Science Understanding strand of the Australian science curriculum (ACARA, 2012) because Einstein’s Theory of General Relativity and related concepts are not included for children from kindergarten to Year 10.

The findings of this exploratory case study highlight the paradox that a subject so rich in stories that demonstrate the history and philosophy of science with what seems to be intrinsically motivating subject matter is excluded from the Science Understanding strand of the Australian Curriculum.

Limitations
As an exploratory case study, there were several limitations regarding the approach used. These limitations are explicitly outlined here so that readers may interpret the findings with an appropriate degree of scepticism. First, the study was conducted with a small number of Year 6 students in one Australian classroom in one high socioeconomic primary school.

Although a range of data were collected, systematic analysis of the video and interview material were not included because these data were not specifically targeted at the research questions for this chapter and detailed analysis would not enrich the findings. In subsequent analysis of these data, results did not contradict the findings presented above, although the video data do provide more insight into the students’ attitudes. The problems in aligning the questionnaire directly with the content presented in the enrichment programme are likely to have resulted in an underestimation of the impact of the enrichment programme on the students’ understanding of relevant concepts.

Finally, the limitations regarding the data collected on student attitudes are acknowledged. This was a novel enrichment program that may have altered student attitudes in unforeseen ways that did not necessarily reflect their attitudes to the specific activities and/or content presented in the enrichment programme as has been assumed. Notwithstanding these limitations, the findings of this exploratory case study are very encouraging and indicate the potential for teaching Einsteinian physics to upper primary school aged children.
Conclusion

The findings of this exploratory case study presented in this chapter, indicated that an enrichment programme on Einsteinian physics could potentially enable Year 6 children to comprehend relativity related concepts. Further, the enrichment programme was found to be engaging for many participating children and enabled them to achieve learning objectives from the Science as a Human Endeavour and Science Inquiry Skills strands of the Australian Curriculum. The aspects of the enrichment programme that may have contributed to the learning and engagement of students were the developmentally appropriate explanations provided to the children by the visiting university professor, the hands-on nature of the in-class activities that related to the children’s everyday lives, an excursion to the Gravity Discovery Centre and participation in a scripted play about key moments and key scientists in the historical development of modern understandings of relativity. More research is needed to ascertain detailed information about ways that enrichment can enhance learning and engagement with this topic.

The next chapter, Chapter 4, presents an exploratory multiple case study of students’ understanding of the solar system during an experiential activity called the Solar System Walk at the Gravity Discovery Centre.
Abstract

The purpose of the research presented in this chapter was to explore students’ understanding of the solar system prior to, during and after participating in, a Solar System Walk exhibition at a science centre. The Solar System Walk exhibit was developed to allow students to learn about the size and scale and other factors about the solar system experientially by walking through a one kilometre long model of the Solar System at the Gravity Discovery Centre (GDC), north of Perth, Western Australia.

The design of the research was a multiple case study of Year 8, 9 and 10 high school students (ages 12 to 14) who participated in three separate and individually planned school excursions to the GDC that each included the Solar System Walk activity. Data collection included a pre-Solar System Walk quiz, observation and field notes and a post-Solar System Walk diagram. Quantitative analysis included descriptive statistics of each school group’s data from the pre-quiz and post-diagram and an ANCOVA to indicate any variation in impact of the excursion on the schools.
Introduction

This research focused on school students’ understanding of the solar system when they participated in an activity that included walking through a scale model at a science centre. While the ideas of ‘size’ and ‘scale’ are not generally considered ‘science content’ in the same way as ‘atoms’ or ‘genes’, they can be considered to be ways of thinking that are fundamental to understanding science concepts and also to scientific literacy. In this vein, Duschl (2012) outlined seven crosscutting concepts drawn from the US National Science Education Standards (NRC, 1996) and other documents that are different from the practices and core ideas in science. The crosscutting concepts are “themes or concepts that bridge the engineering, physical, life and Earth/space sciences; in this sense they represent knowledge about science or science as a way of knowing” (Duschl, 2012, p. 7). One of these crosscutting concepts is “scale, proportion, and quantity” (p. 6) which encompasses the ideas of size and scale which were the focus of this research.

The fundamental nature of the concepts of size and scale to science is reflected in curriculum documents internationally. For example, ‘scale and measurement’ is one of the six overarching ideas in the Australian Curriculum: Science that represent “key aspects of a scientific view of the world and bridge knowledge and understanding across the disciplines of science” (http://www.australiancurriculum.edu.au/science/the-overarching-ideas).

Tretter, Jones, Andre, Negishi, and Minogue (2006a) established the groundwork on existing cognitive frameworks students have with respect to conceptualisations of distinctly different sizes and scales and how they differ by age. As scientists deal with ideas and objects of increasingly large (and small) size and scale, Tretter et al. (2006a) argued that educators need to become more adept at developing school students’ capacity to understand and work with these magnitudes. “Students need to have the opportunity to enhance their conceptions of phenomena at different scales in order to grasp the scientific issues and solutions that have wide reaching impact on the human-scale world” (Tretter et al., 2006a, p. 310). One way of achieving this is to involve students in activities using scale models of the solar system.

There are a number of science organisations around the world that have scale models of the solar system with the purpose not just of helping students to learn about the Earth’s neighbouring planets, but also to help them understand something about the vast sizes and
scales that the solar system represents in comparison to the sizes and scales normally experienced by human beings in their everyday world. For example, there are scale models of the solar system in Washington D.C. at the National Mall, the Sagan Planet Walk in Ithaca, New York, at the University of Colorado in Boulder, as well as Kansas City and various other locations in the USA. The Mills Observatory in Dundee, Scotland has a planet trail and many European countries have various solar system walks. Assessment of the effectiveness of a guided walk through such a model for instruction of the relative sizes, scales and distances in the solar system shows that “actual student participation in such an activity is indeed worthwhile” (LoPresto, Murrell, and Kirchner, 2010, p. 236).

The study by LoPresto et al. (2010) indicated that students initially grossly underestimated the distance between planets in the solar system. Gains in post-test understanding of scale were significantly larger in the group that participated in the walk as opposed to those students who attended a lecture (LoPresto et al., 2010). These findings support the benefits of experiential learning.

The research reported in this chapter built on the work of Tretter et al. (2006a), Tretter, Jones, and Minogue (2006b) and Lo Presto et al. (2010) to empirically examine how an informal (out-of-school) excursion and participation in a Solar System Walk activity influenced students’ conceptualisations of the size and scale of planets in the solar system. In this way, the research drew together two important areas of science education, that of students’ conceptions of size and scale in the context of the solar system, and research on student learning in informal science institutions.

**Purpose and Research Questions**

The purpose of this research was to explore the educational outcomes from three different excursion experiences of Year 7 to Year 9 students (ages 12-14) from three different school groups during an excursion to the Gravity Discovery Centre. The study investigated the students’ understanding of astronomical distances through participation in walking a scale-model of the solar system at the Gravity Discovery Centre (GDC). The walk is approximately 1 km long, beginning at the model representation of the Sun and follows a path that leads to the other planets, their moons and other objects of interest in our solar system. More specifically the research questions were:

- What do Year 7, 8 and 9 students know about the solar system?
What impact did participation in the Solar System Walk activity at the GDC have on Year 7, 8 and 9 students’ science knowledge about the size and scale of the solar system?

The research was conducted within a conceptual framework that incorporated the relevant research traditions of understanding concepts in science and learning in informal science contexts. The literature related to each of the two research traditions: that of understanding concepts in science, particularly size and scale of the solar system; and that of informal science education, in particular learning by experience, is reviewed in the following sections.

Understanding Concepts in Science
The concepts of size and scale are important for students’ learning of size-dependent properties that are at the core of science. Students, however, have been shown to have considerable difficulty with these concepts, both at the K-12 (Tretter et al., 2006a) and undergraduate level (Drane, Swarat, Light, Hersam, & Mason, 2009). Trumper (2001) tested pedagogical methods that related the size of astronomical objects to different objects (e.g. basketball, grapes) and revealed that the majority of students underestimated distances. This shows that students have difficulty comprehending the vastness of our solar system, that is, how far apart the planets and the sun are from each other.

Tretter et al. (2006b) suggested that misconceptions in science understandings are a result of limited mathematical skills required for scientific reasoning. Importantly, Benchmarks for Science Literacy emphasise the need for students to develop their estimation skills and the habit of checking their answers against reality (AAAS, 2009). The study by Tretter et al. (2006b) demonstrated that students’ accuracy of scaling conceptions is dependent on these basic mathematical skills and they discuss the ability to unitize as “conceptualising a new unit from existing objects” and with this, a second mental operation of using the new unit for “comparative or calculation purposes” (p. 1063). They see this proportional reasoning as a “precursor skill to multiplicative thinking” (Tretter et al., 2006b, p. 1063). Their research tested and compared students in middle school, high school, and university with each other and with professionals to see how fundamental mathematical skills are manipulated to conceive of and calculate physics investigations beyond the scale of human perception.
Teachers may teach basic measurement skills but the results of the study by Jones and Taylor (2009) suggested that to develop increasingly sophisticated understanding of scale within their students, teachers may need to place more emphasis on visualising scale, learning how to move from one scale to another, as well as creating new scales. “It appears that there may be a gap between the critical role of scale as described by these participants and the current place of scale in science instruction” (Jones & Taylor, 2009, p. 472).

Research concerning size and scale reveals that students encounter difficulties in appreciating extreme scales and suggest that direct experiences play an important role in their conceptualisation (Tretter et al., 2006b). Tretter et al. (2006b) discussed how devices such as the telescope and the microscope have aided scientific understandings beyond the scope of human sense perception. Moreover, “the ability to mentally manoeuvre across many orders of spatial magnitude is increasingly necessary for a fundamental understanding of a number of scientific phenomena” (Tretter et al., 2006b, p. 1062). While the study by Tretter et al. (2006b) is not based on empirical work in the classroom, their theoretical findings have implications for formal and informal science education. These include “emphasizing unifying themes in science … as a strategy to minimize the curricular incoherence that exists in many current science curricula” (p. 1062).

The research conducted and reported in this chapter of the thesis directly addresses these ‘incoherencies’ in conceptual understandings by providing students with opportunities to use devices such as telescopes combined with their own sense perceptions in physical space. The real-world educational environment in which this research was conducted tests the hypothesis that students’ misconceptions about size and scale related to the solar system can be addressed through experiential learning.

Duschl (2012) draws attention to the shift in science learning from ‘What do we want students to know and what do they need to do to know it?’ to ‘What do we want students to do and what do they need to know to do it?’ The shift in emphasis has moved from knowing to doing. This notion is consistent with current research as presented in this chapter that shows students struggle comprehending science concepts when they are only presented in abstract form. Duschl (2012) identifies scale as a “crosscutting concept” that bridges disciplines of engineering, physical, life and earth/space sciences. He identifies scale in the US grade band progression descriptions as follows: Years K-2: relative scales e.g. fastest/slowest without units of measurement; Years 3-5: extend concepts of scale and
units to express quantities of weight, time, temperature and other variables; Years 6-8: estimate across scales and contexts by using algebra to predict changing variables; Years 9-12: apply more complex mathematical and statistical relationships to move back and forth between models at varying scales. Applying mathematics is a means for students to ‘do’ scientific investigations in order to gain understanding about spanning sizes from nanometres to billions of metres.

As research is undertaken to understand how students conceptualise different concepts, studies have been carried out on particular pedagogical materials used to teach them. For example, concerning size and scale, Jones et al. (2007), investigated the influence of the film Powers of Ten (Eames & Eames, 1977). Even though it was produced nearly 40 years ago, teachers still frequently use this and other similar films to approach spatial scales because these show students both macroscopic and microscopic scale. The film begins with a 1 m² picnic rug and zooms out by a power of ten every ten seconds continuing out from Earth to the edge of our solar system and to the outer edges of the Universe, where our own galaxy appears as a mere speck. The camera then zooms back to the picnickers and into their bodies, with ten times more magnification every ten seconds to the negative power of ten, and we journey inside a proton of a carbon atom within a DNA molecule in a white blood cell. The film demonstrates the relative size of things in the Universe and the effect of adding another zero.

American Science Standards recommend that by the end of Year 8, students should know that: “The Sun is many thousands of times closer to the Earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the nearest star takes a few years to arrive ... Some distant galaxies are so far away that their light takes several billion years to reach the Earth” (http://www.project2061.org/publications/bsl/online/index.php?chapter=4#A3).

The idea of using light to help students imagine these immense distances is a potentially helpful pedagogical strategy, but moving from minutes to years to billions of years, which is beyond the scope of human experience, is extremely difficult to conceptualise. Resources like the Powers of Ten film open the imagination to enhance these abstract understandings. Another pedagogical strategy teachers often use involves using analogies in which astronomical distances are scaled down to the size of common objects. For example, using a basketball as an analogy for the Sun, an apple seed used to represent the
Earth would be 30 metres away, and the nearest star beyond our Sun (almost 4.3 light years away) would be 7000 km from the basketball.

**Students’ Misconceptions about the Solar System**

Despite improved pedagogy in science education, misconceptions arise across the sub-disciplines of science and more specifically in astronomy. In this chapter, the term misconception is used to mean students’ expressed understandings that are different from accepted scientific explanations (Taber, 2015). These misconceptions can be present for students from primary school through university and into adulthood. For example, some primary school students hold a scientific view of planetary motion, others hold various misconceptions, such as the “inclusion of stars within the solar system” (Lelliott & Rollnick, 2010, p. 1789); that all stars are the same size; and that the brightness of a star depends on its distance from the Earth (Hapkiewicz, 1999). Some students believe that the Universe is very crowded and that the planets, moons and stars are closely packed together (Hapkiewicz, 1999). Miller and Brewer (2010) questioned US undergraduates and found that they “overestimated the distance from the Earth to the Moon...underestimated the distance from the Earth to the Sun, and dramatically underestimated the distances to the nearest star and the nearest galaxy” (p. 1549).

The Sun and its orbiting planets are often taught in terms of just the names and composition of the planets so it is not surprising that students’ understandings of space dimensions are inaccurate. Also, many students cannot explain the causes of the different seasons. They think summer results from the Earth moving closer to the Sun and being further away in winter, when actually the seasons are caused by the tilt of the Earth and the amount of sunlight reaching the Earth at different latitudes. Another common and widespread misconception is attributing the Moon’s phases to it being eclipsed by the Earth, with shadows cast by the Earth onto the Moon (Bailey & Slater, 2003; Brewer, 2008; Trundle, Atwood, Christopher, & Sackes, 2010).

Students’ misconceptions are deep seated and difficult to shift. Misconceptions are not a mere lack of knowledge but are “within a system of prior beliefs that make understanding certain concepts very difficult” (Miller & Brewer, 2010, p. 1550). Ritger and Hays Cummins (1991) argued that misconceptions in astronomical distances are similar to misconceptions about time encountered in students’ understanding of geological time scales.
Plummer (2009) conducted research into young students’ ideas about the Earth, Moon, Sun, and stars, and found that they constructed various frameworks to help them understand the world around them. Vosniadou and Brewer (1992) described student representations ranging from a flat Earth with a sky above, to a spherical Earth with gravity acting towards its centre. Between these, students expressed a range of alternative conceptions that combined aspects of the observable world with models presented at school and through the use of globes and maps. Student explanations about the day-night cycle included clouds obscuring the Sun, the Sun moving to the other side of the Earth, and that the Earth moves around the Sun. These studies suggest that while young students understand that the Sun is involved in the change from day to night, they may not be familiar with the apparent motion across the sky. Students also had difficulty representing the Sun's size compared to the Earth, as well as the apparent motion of the Moon (Plummer, 2009).

Osborne, Wadsworth, Black, and Meadows (1994) described a study involving young students in England, who completed an astronomy course. There were mixed results from within each age group and between the different age groups. Representing the scale of the solar system was challenging for all age groups, as well as distinguishing the differences between stars and planets and being able to name the planets in the solar system. Other studies involving interviews with primary school students, conducted by Sharp (1995, 1996), reported similar findings. Students in Years 1 and 2 had great difficulty producing drawings of the solar system. Their drawings were incomplete and the planets were arranged randomly. About 50% of older students in Years 5 and 6 were able to produce drawings of the solar system detailing the Sun and all of the planets, with varying degrees of accuracy and detail. Children's comments about the movement of the planets and the age and origin of the solar system also highlighted a lack of knowledge in these areas.

Sharp and Kuerbis (2006) described a 10-week study, involving 31 students aged 9 to 11, where one task involved drawing a map of the solar system and its components. When coding their maps, Sharp and Kuerbis (2006) identified aspects of the diagrams for the of purpose of scoring. Number of planets, names of planets, relative sizes and relative distances as well as planetary features were considered as important aspects to be included in the student maps.
Student misconceptions in science are sometimes derived from the mass media. For example, Duke University physicist, Mark Kruse, documented misconceptions that he found reported in the media about the Higgs boson particle (Yeager, 2012). Some science documentaries are educational, but many science fiction films use ad hoc science information as a basis for entertainment purposes. Science fiction films expose students to ideas such as wormholes, parallel universes, and time travel, but often these concepts are not portrayed accurately and are inconsistent with current scientific thinking. A blog provided by author and scientist Dan Koboldt (http://dankoboldt.com/space-travel-misconceptions/) documented on July 17, 2014 nine misconceptions about space travel frequently portrayed in science fiction movies such as the misconception that there are formal directions in space, that there is sound in space and that flying in space is like flying on Earth.

Very little formal research has been conducted on the science learning and misconceptions that students may acquire through the mass media; however, some studies indicate a strong relationship. For example, Donovan and Venville (2014) found a close correlation between the ideas that primary school aged children have about genes and DNA and the way these ideas are portrayed in the mass media, including both ideas consistent with current scientific thinking and misconceptions. The same may be the case with size and scale within the solar system and other astronomical-based concepts that are often portrayed in the mass media.

**Informal Science Education: Learning through Experience**

Rennie (2007) discussed the value of out-of-school science learning in terms of intrinsic motivation through pleasurable social experiences of incidental learning. “Effective learning occurs when a person is motivated to participate in the learning experience, the context is socially and physically supportive, and the linking of new learning into the person’s mental structures is facilitated” (p. 153-154).

One of the most rapidly expanding and popular informal science learning contexts is the digital sphere including web-based digital environments called virtual worlds. Bennett, Maton, and Kervin (2008) suggested that virtual environments show promise in the areas of science and engineering for modelling and controlling complex systems. Second Life (http://www.secondlife.com) is a well-known virtual environment, with many universities creating Second Life virtual classrooms and environments for distance learning. For school
students, multi-player game environments are being developed to support science, technology, engineering and mathematics learning.

Many students are proficient using immersive games that challenge their thinking and require strategy, in collaboration or in competition with other players (Cotten, Shank, & Anderson, 2014). Moonbase Alpha is one such game intended to inspire interest in science and astronomy. Students assume the role of an astronaut working to further human expansion and research (VirtualHeroes.com, 2010). Game play allows students to engage with learning that cannot be accessed from, or created in, a real classroom (Dede & Barab, 2009). Immersive environments are commonly web based, allowing students to participate from anywhere with an Internet connection.

Augmented reality mixes virtual elements with the real environment. As users move around a physical location, virtual features are displayed or superimposed on the real space, adding to or augmenting the experience of the location. Rather than positioning students within an entirely virtual, simulated world, augmented reality is designed to blur the line between the real world and the enhanced perceptions provided by technology. Examples of augmented reality have been used to add features such as virtual objects in museums (Harriman, 2012). An augmented reality game that has become popular with people of all ages since its release in July 2016 is Pokémon Go, a game that progresses according to a player’s location. Players are able to use their mobile phone’s GPS and camera to view the virtual world as they engage with virtual creatures that appear on the screen in each location.

The Gravity Discovery Centre (GDC) provides students with educational opportunities to learn science concepts by conducting experiments with equipment that is not available anywhere else. The GDC provided a unique context for the research that is presented in this chapter.

**Methodology**

An exploratory multiple case study research design was used, with mixed methods of data collection. Three year groups of students from three different schools that visited the Gravity Discovery Centre made up the three case studies in this multiple case study design. More detailed profiles of the case study schools are provided below. A case study “can test theory or build theory, incorporate random or purposive sampling, and include
quantitative and qualitative data” (Merriam, 1988 p. 2). “The opportunity to use multiple methods of data collection is a major strength of case study research” (Merriam, 1988, p. 69). A multiple case study enables a more complex and multi-layered picture to be developed about a phenomenon, in this study, the impact of participation in a Solar System Walk activity on students’ understanding of size and scale in the solar system (Stake, 2010).

The rationale for using a multiple case study was that it allowed the researcher to examine the impact of excursions to the Gravity Discovery Centre that were planned in different ways, with diverse activities for different groups of students. The study was conducted in situ and the researcher did not interfere with the planned educational experiences of the participating schools, teachers and students. This meant that the three groups had very different experiences. As documented in more detail below, students from one case study school had considerably more pre-excursion, classroom-based teaching on astronomy, two groups stayed overnight and visited the observatory before participating in the Solar System Walk, and another group arrived, walked the Solar System Walk and left within a few hours. This meant that controlling variables was impossible, and a multiple case study design the more suitable option for this exploratory study that would result in a more realistic examination of what actually occurs when schools and students visit this science centre. Mixed methods research also enables researchers “to address more complicated research questions and collect a richer and stronger array of evidence than can be accomplished by any single method alone” (Yin, 2009, p. 63).

Profiles of the Case Study Schools
The three year groups from the three schools that made up each of the case studies for the research presented in this chapter were given the pseudonyms School B, School C and School D. The teacher from the participating class at School B, a Perth metropolitan primary school, was a Physics PhD candidate with a vested interest in astronomy and university connections both in Australia and UK. She provided opportunities for the students to choose which part of the Moon they would like to see photographed through NASA technology, as well as link with other international students to observe astronomical events including a lunar eclipse and the transit of Venus. Tables 10 and 11 provide profiles of the participating schools based on information provided in the official Australian Government MySchool website (http://www.myschool.edu.au) in 2015. Table 10 indicates
that Schools B and C had an ICSEA well above and School D an ICSEA well below the national mean.

Table 10: Summary of each participating school’s ICSEA, and participants

<table>
<thead>
<tr>
<th>School</th>
<th>ICSEA</th>
<th>Year Group</th>
<th>Number of students who completed the questionnaire</th>
<th>Number of students who completed the solar diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>School B</td>
<td>1138</td>
<td>Year 7</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>School C</td>
<td>1128</td>
<td>Year 8</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>School D</td>
<td>900</td>
<td>Year 9</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
Table 11: Background information about the three participating schools from their official MySchool websites, 2015 (http://www.myschool.edu.au)

<table>
<thead>
<tr>
<th>School</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>School B Year 7</td>
<td>School B is a government, coeducational, metropolitan primary school from Year K to 7 with total enrolments of approximately 400 students. Sixty four per cent of students come from families in the top quartile of an Australian wide rating of socio education advantage. It is a vibrant primary school commanding an outstanding reputation consistently attaining high standards of achievement in science. Their motto is Motivate, Educate, Celebrate and 54 cultural groups are represented within the 400 highly motivated students. Students are supported by experienced staff, supportive parents and extensive facilities and grounds, which assist in providing students with rich, authentic learning opportunities. The school has received recognition at international, national and state levels for excellence, developing students’ thinking skills and environmental education. Waterwise Awards, Awards for Excellence and Innovation, Sustainable Cities Awards, Waste and Litter Reduction Awards and reaching state and national finals of the Future Problem Solving competition are examples of the diverse learning opportunities offered. Many of the senior students gain entry into Gifted &amp; Talented programs. This school has been a finalist in the WA Science School of The Year.</td>
</tr>
<tr>
<td>School C Year 8</td>
<td>School C is a government, coeducational, metropolitan secondary school from Year 8 to 12 with a student population of approximately 1700. ICSEA (1128). School C’s reputation is based on outstanding academic performance. Sixty one per cent of students come from families in the top quartile of an Australian wide rating of socio education advantage. Specialist language courses in German, French, Mandarin and Japanese plus extension programmes in Mathematics, Science, English and Society and Environment are fostered. This school is a leading school in music education, supporting a symphony orchestra and various ensembles and choirs. Challenging programmes in the performing and visual arts are open to all students. Volleyball school students compete at the highest levels. Other sports are catered for and developed to meet the needs of students, culminating in a variety of inter-school and State competitions. At School C there is a strong belief and commitment to success - whether in academic, cultural, vocational or sporting pursuits. The emphasis on self-discipline and opportunity to demonstrate responsibility are paramount. The school’s multicultural environment encourages tolerance and understanding of the global needs in today’s society. As a result a very positive and caring culture exists in which students enjoy and share their own achievements.</td>
</tr>
<tr>
<td>School D Year 9</td>
<td>School D is a government, coeducational, rural secondary school with a student population of around 750 students. This includes students from rural areas and around 100 Australian Aboriginal students. 9% of students come from families in the top quartile and 38% in the bottom quartile of an Australian-wide rating of socio education advantage. The school caters for the educational needs of a diverse student population. The school’s ethos of excellence sets the expectation that students will achieve to the best of their ability. It offers academic Gifted and Talented Education Programs in Mathematics/Science and Humanities; special programs in AFL Football, Netball, Dance and Music; intensive tutoring program for students experiencing difficulty with literacy and numeracy, an Education Support Unit, and has sophisticated ICT facilities for current learning styles. The engagement of Aboriginal students is a key priority and offers highly successful programs for these students.</td>
</tr>
</tbody>
</table>
A Description of the Gravity Discovery Centre Programme

The participating classes of all three case study schools visited the Gravity Discovery Centre (GDC) to participate in the Solar System Walk activity and other activities in an individually designed programme.

The Solar System Walk is about 1 km long and starts at the “Sun”, which is a large, paved circle to represent the huge size of the Sun. The path leads to all the other planets and their moons in our solar system. The Solar System Walk activity and the size and distances of the planets in the model for this activity are to scale to give an understanding of the vastness of our solar system. Prior to students’ participating in the activity, Solar System Walk Student Workbooks were distributed and the students were issued with a pedometer. Students made predictions about the distances between planets (in number of steps) and sizes of the planets and recorded their estimates. Actual observations were then recorded as the students completed the Solar System Walk activity. Students also recorded their pedometer readings at each planet and information about each of the planets.

The Year 7 class (School B) combined their visit to the GDC with a school excursion to the area and stayed in overnight accommodation nearby. This enabled the class to visit the Gingin Observatory at night, prior to completing the Solar System Walk the next morning. The Year 8 students (School C) travelled by bus to the GDC and were only able to spend four hours at the GDC before they had to travel back to school. The Year 9 class (School D) also stayed overnight on their excursion to the GDC, visited the Gingin Observatory and viewed a lunar eclipse during the night of their stay. All of the students that participated in the Solar System Walk completed a questionnaire prior to completing the actual walk and a post-walk diagram (more details about these methods of data collection are provided later in this chapter). A summary of activities for each school is provided in Table 12.
Table 12: A summary of excursion activities for each participating school

<table>
<thead>
<tr>
<th>School B – Year 7</th>
<th>School C – Year 8</th>
<th>School D – Year 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-visit instruction on this topic and questionnaire completion</td>
<td>Questionnaire completed pre-visit</td>
<td>Questionnaire completed pre-visit</td>
</tr>
<tr>
<td>GDC visit and overnight stay</td>
<td>Day visit to GDC</td>
<td>GDC, observatory visit and overnight stay</td>
</tr>
<tr>
<td>Diagrams completed post-walk</td>
<td>Diagrams completed post-walk</td>
<td>Diagrams completed post-walk</td>
</tr>
</tbody>
</table>

Students from School B stayed overnight near the Gingin Observatory and used the telescopes to view astronomical objects and a lunar eclipse. The detail they could see on the Moon’s surface was reflected in the detail that the students displayed in their drawings of the solar system. They asked meaningful questions, particularly in the cosmology gallery, after telescope viewing the previous evening. They were not rushed in the Solar System Walk, having risen with the Sun and had a leisurely breakfast on site. This meant they were relaxed and prepared (as opposed to hurried and confused) and thus more ready to learn.

The students from School C, a Perth metropolitan high school, were academically capable. These students were unfamiliar with bush settings and found the elements (flies, heat, kangaroo ticks and sand tracks) challenging. After a two-hour bus trip they completed four activities – the tour, the Cosmology Gallery, the Leaning Tower, and the Solar System Walk – in four intense hours. The learning, though tangible, was rushed. Some students were not able to complete the Solar System Walk due to time restrictions and were not given the experience of size and scale that telescope viewing provides.

The students from School D, a rural high school, were all indigenous Australians. They stayed the night and participated in a viewing night at the observatory. They were provided with one tutor per four students to assist them in completing their booklets. These students brought traditional knowledge of animal tracks, understanding bush surroundings, identifying plants and animals and interpretation of the solar system in relation to their traditional stories. This knowledge was reflected in the discussion during the Solar System Walk activity.
Procedure for Data Collection
A four-step procedure as outlined in Chapter 2, Figure 3 guided the data collection for each case study within the multiple case study design. Prior to the case study students’ visit to the Gravity Discovery Centre (GDC) the students completed a questionnaire to ascertain their prior knowledge of the solar system. During the GDC visit and solar system walk activity, the researcher observed the students and took field notes to record her observations. The students also completed a workbook related to the activity. After the GDC visit, all participating students completed their workbook and a solar system drawing.

Methods of Data Collection
As the main form of data collection, participating students were given a workbook that contained activities to be completed before, during and after the Solar System Walk activity at the Gravity Discovery Centre including a solar system questionnaire to indicate students’ general understanding of the solar system before participating in the solar walk, and a solar system diagram drawing task, where students were required to use data collected on their walk to create a scale drawing of the solar system.

Pre-Solar System Walk Questionnaire
Because this study is the first research to be conducted to ascertain students’ learning during the Solar System Walk activity at the GDC, a new pre-excursion questionnaire on the solar system was developed by the researchers to ascertain students’ pre-excursion knowledge of the solar system. A draft questionnaire was developed, consisting of 12 short answer questions designed to probe students’ general knowledge about the solar system. The draft questionnaire was given to two experienced physics education experts so they could comment on the validity of the items. The feedback indicated the experts were satisfied with the items suggesting only minor changes that were incorporated into the final version (see Appendix B – What Do You Already Know? section).

Field Observations
At the Gravity Discovery Centre, the students took part in a number of astronomy-based activities (including the Solar System Walk activity) that aimed to provide them with insight into the many different aspects that make up the solar system. The researcher and the classroom teachers completed the Solar System Walk with the participating students from each class. The researcher collected observational data through photographs and field
notes during the excursion and additional reflective notes after the excursion. The focus of
the field notes was the actions and conversations of students as they participated in the
Solar System Walk, in particular any actions or comments from students about their
perceptions of the size and scale of the solar system and the impact the solar system walk
had on their perceptions. While this was the focus of observational field data collection,
the researcher also noted students’ perceptions of the GDC in general and other actions and
comments that might have been relevant to their learning in science.

The qualitative aspect of the naturalistic setting of the solar walk, enhanced by immediate
feedback by the participants as they experienced the learning process was included as a
form of triangulation and to provide on-the-ground data with regard to students’
developing new understandings of size and scale in the solar system. The observations and
field notes also provided data on the nature of the Solar System Walk and the engagement
of the students. For example, it was noted that as this activity was outside the classroom,
the children were easily distracted by wildlife observed in the environment of the Gravity
Discovery Centre. The indigenous students were interested in marsupial and reptile tracks
in the sand; while younger students, distracted by kangaroos in the environment, lost track
of the purpose of the walk and sometimes forgot to record the pedometer reading at the
appropriate planet.

**Student Excursion Workbook**

On arriving at the start of the Solar System Walk, at the ‘Sun’, students were asked to
make predictions about the number of steps it would take to get to each planet on the Solar
System Walk from their starting point at the Sun. Students were provided, in their
workbook, with information about the approximate distance from the Sun to each planet in
millions of kilometres (e.g. Mercury is 58 million km and Jupiter 778 million km from the
Sun). They were told that on the Solar System Walk one average step is approximately
equal to 4 million kilometres and provided with a table showing how many million
kilometres up to 200 steps would represent. Students were then asked to predict
approximately how many steps it would take them to get to each planet along the walk.

This simple exercise only required students to divide the distances (provided for each
planet) by four to give them a realistic approximation of steps. It was apparent that some
students trusted their mathematical reasoning over their intuitive judgment about the
number of steps it would take them to reach each planet. Other students preferred to guess a value for the distance from the Sun on the Solar System Walk.

**Post-Excursion Solar System Diagram**

The student excursion workbook included space for the students to write down data about each planet, including the age, diameter, surface temperature, number of Earth masses, and composition of each planet. This information was provided at the station for each planet on the walk. Students also wrote down the number of predicted and the actual number of steps it took them to get to each planet along the Solar System Walk. Students were then asked to use this information to complete a labelled diagram of the Sun and planets of the solar system. The students were asked to “draw the planets to scale, in order of their distance from the Sun and to label each planet. This solar system diagram was used as data to indicate students’ post-excursion understanding of size and scale of planets within the solar system.

**Data Analysis**

Creswell (2013) summarised the process of data analysis in research with mixed methods as “organizing the data, conducting a preliminary read-through of the database, coding and organizing themes, representing the data, and forming an interpretation of them” (p. 179). He explained that the steps are all “interconnected and form a spiral of activities all related to the analysis and representation of the data” (p. 179). The general process of qualitative data analysis requires preparation and organization of the data, “then reducing the data into themes through a process of coding and condensing the codes, and finally representing the data in figures, tables, or a discussion” (p. 180).

The data analysis for this multiple case study included four major phases including:

1. development of two coding sheets for the solar system questionnaire and the solar system drawings; 2. pre-testing the coding sheets; 3. coding of raw data; and, 4. verifying the coded data (Kumar, 2011). The development of the coding sheets for the pre-excursion solar system questionnaire and the post-excursion solar system diagram was the first phase of data analysis. Creswell (2013) describes the process “that begins with the development of the codes, and then the organization of themes into larger units of abstraction to make sense of the data” (p. 187).
Coding is the foundation for “discovering regularities in the data” (Punch, 2009, p. 175). “The task is to compare one unit of information with the next in looking for recurring regularities in the data” (Merriam, 2009, p. 177). Preliminary coding sheets were developed to represent the process for the coding analysis. The coding sheets provided a set of rules for assigning numerical values to answers obtained from the students on the solar system questionnaire and the solar system diagram (Kumar, 2011).

The second phase of pre-testing the coding sheets involved selecting ten students’ sets of responses and coding the responses to check for any problems in coding. Cross checking (or “inter-coder agreement”) (Creswell, 2009, p. 191) was based on codes and themes in the analysis of the data and a second coder independently examined the students’ responses. Minor changes were made to the coding sheets after the two coders independently analysed the initial set of ten student responses to allow for greater clarity in how the students’ responses were to be coded. Final coding sheets and student examples are provided in Appendices D, F and G. The solar system questionnaire had a total possible score of 33 and the solar system diagrams a total possible score of 50.

The third phase of data analysis involved all raw data from the participating students being coded according to the coding sheets, with a different code sheet for each student. The fourth phase of the analysis involved a second set of ten students’ data being re-coded by a second researcher. The re-coding of the data showed that the process of analysis was effective with a high inter-coder agreement greater than 90%. As a consequence, no further changes were made to the coding sheets and the data were then entered into an SPSS (Statistical Package for the Social Sciences) database for statistical analysis.

Descriptive statistics for each case study school were generated for the solar system questionnaire and the solar system diagram including mean, median, maximum and minimum scores. Box and whisker plot graphs were generated so that comparisons could be made between the three case study schools with regard to central tendency as well as the spread of scores. A one-way analysis of covariance (ANCOVA) was used to compare the post-excursion solar system walk diagram scores of the participating students from the three different schools. The pre-excursion solar system questionnaire score was used as a covariate to partial out the effects of students’ pre-excursion knowledge of the solar system.
Findings

The findings for this study are presented in four sub-sections. The first section presents the data of participating students from the three schools on the pre-Solar System Walk questionnaire on their general knowledge of the solar system. The second section presents the data of participating students from the three schools' post-Solar System Walk drawings of the solar system. The third section presents the student drawings of the solar system and the themes that emerged. Codes are used to refer to individual students. The code includes a letter (B, C, D) to represent the student’s school and a random number to identify the individual (e.g. B12). The final section discusses results of the statistical analysis of variance.

Pre-Solar System Walk Questionnaire for Students

Table 13 provides descriptive statistics from the quantitative analysis of the students’ pre-Solar System Walk questionnaire that tested their general knowledge of the solar system prior to participation in the Solar System Walk activity. Figure 7 displays these data in the form of box plots so that comparisons between schools’ central tendency and spread can be made. Each box plot includes a dot (•) indicating the mean and a central line (-) indicating the median. The bottom of each box is the 25th percentile and the top is the 75th percentile and the end points of the whiskers show the maximum and minimum scores (or the range) from the cohort in each school.

The data from Table 13 and Figure 7 show that students from School B had the highest mean and median scores, as well as the highest overall score. These high scores were despite the students from this school being younger with fewer years of schooling than the students from the other two schools. This finding is perhaps not unexpected given that the teacher of these Year 7 students was a PhD candidate in science education at the time the research was conducted and was passionate about astronomy. Due to these factors, the students from School B had been provided with a stimulating classroom environment in astronomy and therefore had excellent general knowledge about the solar system. A limitation of the methodology is that data were not collected to verify this school environment.

The data from Table 13 and Figure 7 show that there is an inverse relationship between the year level of the students in each school and their scores on the solar system questionnaire. This is, at face value, surprising as usually we observe that students learn more at school
and, therefore, have higher general knowledge scores on average the higher their school level. However, when we take into consideration the socio-educational circumstance of each school that participated in this study as indicated by the school ICSEA (Index of Community, Socio-Educational Advantage) score, it is apparent that there is a positive relationship between socio-educational advantage and their solar system knowledge as indicated by their solar system questionnaire scores. School D has the lowest ICSEA score and students in School D had the lowest mean and median solar system questionnaire score.

Table 13: Descriptive statistics from the pre-Solar System Walk questionnaire on general knowledge about the solar system for students from each case study school

<table>
<thead>
<tr>
<th>School</th>
<th>Mean (•)</th>
<th>Median (-)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
<th>50th percentile range of scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>B – Year 7 (n=24)</td>
<td>26.83</td>
<td>27.00</td>
<td>31.00</td>
<td>20.00</td>
<td>26.00 - 28.00</td>
</tr>
<tr>
<td>C – Year 8 (n=25)</td>
<td>23.80</td>
<td>24.00</td>
<td>29.00</td>
<td>16.00</td>
<td>22.00 - 26.00</td>
</tr>
<tr>
<td>D – Year 9 (n=20)</td>
<td>17.75</td>
<td>17.00</td>
<td>25.00</td>
<td>12.00</td>
<td>14.75 – 21.25</td>
</tr>
</tbody>
</table>
Figure 7: Box plots comparing the central tendency and spread of scores for the pre-Solar System Walk questionnaire on general knowledge about the solar system for students from each case study school.

**Statistical Data Analysis**

Examination of the Shapiro-Wilk statistics and histograms for each group indicated that the ANCOVA assumption of normality was supported. Scatter-plots indicated that the relationship between the covariate (pre-knowledge scores from pre-excursion solar system questionnaire) and the dependent variable (post-excursion Solar System Walk diagram scores) was linear. Finally, the assumption of homogeneity of variance was supported by the absence of a significant IV-by-covariate interaction $F (2, 65) = 8.58, p < 0.05$.

The ANCOVA indicated that after accounting for the pre-knowledge scores from the solar system questionnaire, there was a statistically significant effect of the school experience at the Gravity Discovery Centre on the post-Solar System Walk diagram scores, as indicated by a large effect size (eta squared) of 0.52.
**Student Post-Solar System Walk Diagrams of the Solar System**

Table 14 provides descriptive statistics from the quantitative analysis of the students’ post-Solar System Walk diagrams of the solar system. Figure 8 displays these data in the form of box plots so that comparisons between schools’ central tendency and spread can be made. Each box plot includes a dot (•) indicating the mean and a central line (—) indicating the median. The bottom of each box is the 25th percentile and the top is the 75th percentile and the end points of the whiskers show the maximum and minimum scores (or the range) from the cohort in each school.

The data presented in Table 14 and Figure 8 show that students from School B have the highest post-Solar System Walk scores on the solar system diagrams. This is consistent with the pre-Solar System Walk questionnaire (Table 13 and Figure 7) that indicated these students had the highest general knowledge about the solar system. Table 14 and Figure 8 show an interesting trend that is different from the trend we found prior to the excursion activities as represented in Table 13 and Figure 7. The post-Solar System Walk diagram indicates that students from School D had a higher median and mean score than School C students. This indicates that the effect of participation in the Solar System Walk activity was greater on the students from School D than the students from School C.

Table 14: Descriptive statistics from the post-Solar System Walk drawings of the planets in the solar system by students from each case study school

<table>
<thead>
<tr>
<th>School</th>
<th>Mean (•)</th>
<th>Median (—)</th>
<th>Maximum Score</th>
<th>Minimum Score</th>
<th>50th percentile range of scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>B – Year 7 (n=24)</td>
<td>33.63</td>
<td>33.50</td>
<td>44.00</td>
<td>18.00</td>
<td>31.75 - 36.25</td>
</tr>
<tr>
<td>C – Year 8 (n=25)</td>
<td>25.78</td>
<td>26.00</td>
<td>33.00</td>
<td>17.00</td>
<td>23.00 - 29.00</td>
</tr>
<tr>
<td>D – Year 9 (n=20)</td>
<td>27.20</td>
<td>29.50</td>
<td>39.00</td>
<td>9.00</td>
<td>24.25 - 34.00</td>
</tr>
</tbody>
</table>
Figure 8: Box plots comparing the central tendency and spread of scores for the post-Solar System Walk drawing of the solar system for students from each case study school.

Themes in the student diagrams of our solar system

Student diagrams that were completed after the Solar System Walk activity, varied greatly in their level of detail. Basic drawings only had different sized circles drawn in a linear fashion, with no labeling or other details shown except minor details such as rings around Saturn. Some drawings had the first letter of each planet's name as the only detail added. More complex drawings included details such as the name of each planet, the number of moons and the composition of the planets. A few students added colour to their drawings, but most were completed in pencil only. Time was a critical factor in the level of detail shown in student drawings, with students who had more time during their visit producing more detailed diagrams. Major themes evident in the student diagrams are described below including: the Sun, the asteroid belt, the orbit of the planets, and the planets.
The Sun

Every student diagram included the Sun, which was represented as a large circle or semi-circle. Sunspots and solar flares were the most common labels on the Sun in student drawings. Rays, or prominences as drawn by Student B6 above, were featured in 50% of the Sun diagrams. The Sun was drawn much larger than the planets in 99% of student drawings. One student commented on their drawing that "The Sun is so large that a million Earths could fit inside yet it's only a middle sized star".

The Asteroid Belt

Fifty per cent of students drew the asteroid belt in their diagrams. Some drawings just had a single line to represent it. Most students drew many small circles densely packed together as their representation of the asteroid belt. An example of this feature is shown in Student B22's drawing above. The asteroid belt is actually very sparse and this was a common misconception that has been highlighted in the analysis of the student diagrams. One student noted "these guys love to rock" next to the asteroid belt on their diagram.
Orbit of Planets

Very few students produced drawings of the solar system with the planets shown in orbit around the Sun. Only one student (B11) drew the solar system with the planets shown in orbit around the Sun (Figure 11).

A few students (B4, B5, B6 and C16) drew partial lines to represent the planets orbiting the Sun, as shown in Figure 12.

Most students represented the solar system with the planets in a linear fashion. Student C1’s drawing is shown as an example in Figure 13.
**Planets**

The number, names and positions of the planets were each scored out of eight marks and 80% of students attained full marks for these categories. Most drawings had the correct number of planets shown. Only two students included Pluto in their drawings of the solar system. Two different students wrote on their drawings "Pluto has been demoted". One mark was given for each planet drawn and most students scored eight marks for this category. Most students correctly labeled the planets and also scored eight marks for this category.

Mercury and Venus, as well as Uranus and Neptune, were the most common planets drawn out of order in student diagrams. One student from School B used green glitter pen to represent the oceans on Earth and described our planet as "a green and white marble floating in space". Other drawings of Earth were coloured blue and green.

Most students differentiated between the inner and outer planets in terms of their size. Some drawings showed the inner planets all the same size. Some diagrams from School B had comments about Curiosity landing on Mars. Jupiter was shown as the largest planet in 90% of drawings. The rings of Saturn were the most common added feature in student drawings. Rings around Saturn were noted in 95% of drawings, even when no other labeling was shown. Comments next to Saturn on some drawings were "famous for its rings".

One student wrote "Big distance" between each of the outer planets, showing their awareness of the difficulty of the task to represent the correct size and scale on the same A4 drawing.

A few student diagrams showed stars in the solar system. This is another misconception that was noted during the analysis of the student diagrams. An example of a diagram showing stars in our solar system is Student B21's drawing shown in Figure 14.
Students who completed the solar system diagram were allocated marks up to a maximum of 50. Marks were awarded for their accuracy for the number of solar system characteristics drawn and were allocated as shown below:

- Sun 1
- Asteroids 1
- Number of Planets 8
- Names of Planets 8
- Position of Planets 8
- Size of planets 8
- Rings 4
- Moons 6
- Orbit 2
- Features 4

**Discussion**

The purpose of this research was to explore the educational outcomes from three different excursion experiences of Year 7 to Year 9 students (ages 12-14) from three different school groups during an excursion to the Gravity Discovery Centre. The first research question focused on Year 7, 8 and 9 students’ knowledge about the solar system and the second research question focused on the impact that participation in the Solar System Walk activity at the GDC had on the participating students’ science knowledge of the size and scale of the solar system. This discussion is structured to consider the findings related to each of the research questions and then to consider the limitations of the study.

**Year 7, 8 and 9 Students’ Knowledge about the Solar System**

The first research question was: What do Year 7, 8 and 9 students know about the solar system? This study provides interesting findings with regard to the students in the three case study schools that challenge what our expectations might normally be of students in Year 7, 8 and 9.
The maximum score for the pre-Solar System Walk questionnaire was 33 and the data showed that the mean score for the Year 7 students in School B was the highest at 26.83 of the three participating schools. Students in Year 8 from School C had a mean score of 23.80 and Year 9 students from School D had a mean score of 17.75 (Table 13 & Figure 7). These findings are interesting because they are inconsistent with an expectation we might have that the older students are, and the longer they have been at school, the more they will know about science concepts such as those related to the solar system. The youngest students from School B had the highest mean score on the pre-Solar System Walk questionnaire and the oldest students from School D the lowest mean score. There are a number of complex factors that may have contributed to this phenomenon including the expertise and passion of the classroom teacher in School B, and the socio-educational status of the schools involved in the research.

The high scores of the Year 7 students (School B) on the solar system questionnaire were consistent with an assertion that the class teacher was passionate about astronomy and provided a stimulating classroom environment focused on astronomy concepts. The impact of the classroom teacher may be one of the factors that contributed to the high pre-Solar System Walk scores of the students in this school. School B’s description on the official MySchool website also indicated the school’s commitment to science through awards for developing students’ thinking skills, for environmental education, problem solving and, in particular, being a finalist in the Western Australian state Science School of the Year awards (Table 11). Observations and discussions with teachers from the other two schools indicated that staff in those schools were committed science instructors, however, there was no indication that they had any particular passion for astronomy over and above other science topics.

Overall, Australian school students perform well in international studies of scientific and mathematics literacy as well as general academic performance (Thomson, De Bortoli, & Buckley, 2013). The results from this study showed that, prior to the excursion, most participating students could recall the names of the planets in the solar system, knew how many planets there are, the relative positions of the planets in the solar system, as well as facts such as the largest and smallest planets. The results presented in this study contrast with those presented by Osborne et al. (1994) who found that only about 50% of students in Year 5 and 6 in the UK were able to produce drawings of the solar system with the Sun and all of the planets.
Both School B and School C had an ICSEA (Index of Community, Socio-Educational Advantage) one standard deviation above the national average in contrast with School D’s ICSEA which was one standard deviation below the national average (Table 10). Moreover, in contrast with Schools B and C, both metropolitan schools, School D is a rural school with a comparatively high proportion of Australian indigenous students. The school’s description on the official MySchool website indicated that the engagement of Aboriginal students is a key priority (Table 11). Both the rural location of the school and the high proportion of Australian indigenous students in the school may have been factors that contributed to the comparatively low initial score of students on the pre-Solar System Walk questionnaire.

There is considerable data indicating that, in Australia, these factors impact negatively on students’ general academic performance including in science and mathematics. For example, the 2012 results from PISA (Programme for International Student Assessment), conducted by the OECD (Organisation for Economic Cooperation and Development), showed that students from low socio-economic backgrounds, students from rural and regional locations, and students of indigenous background were up to two and a half years behind their peers by the time they were in Year 10 (Thomson et al., 2013). These inequitable outcomes are mirrored in the Australian national school testing (NAPLAN) conducted in Years 3, 5, 7 and 9 (ACARA, 2015). Research by McConney, Oliver, Woods-McConney, and Schibeci (2011) describes how indigenous students “do not enjoy equal educational outcomes” (p. 2033). McConney et al. (2011) found, however, that despite lower educational outcomes attained by indigenous Australian students that “indigenous Australian students held interest in science equal to that of their non-indigenous peers” (p. 2033).

Analysis of the data provided by students before, during and after their participation in the Solar System Walk indicated that students held a number of misconceptions that are reported in the literature. Research conducted by Vosniadou and Brewer (1992) documented different models that young children use to describe their perceptions of the Earth. According to this research, young children almost always perceive that the Earth is flat and that the Sun either goes ‘up and down’ from the sky to below the Earth, or goes around the flat Earth. The findings reported above show that all participating Year 7, 8 and 9 students had more mature conceptions than the students reported by Vosniadou and Brewer (1992) that is likely to have developed as a result of formal and informal
schooling. All participating students represented the Sun, the Earth and planets as spherical in shape. It is difficult to ascertain, however, the degree to which students understood the dynamic and complex nature of the solar system. For example, most students represented the planets in a linear fashion and few indicated that they understood that the planets orbit the Sun.

The findings from this study support the literature related to students’ misconceptions about the solar system. The student drawings revealed that their alternative conceptions were consistent with findings from around the world. A common misconception as identified by Lelliott and Rollnick (2010), is the inclusion of stars in the solar system. This was demonstrated in participating student B21’s drawing (Figure 14). In addition, Hapkiewicz (1999) noted that some students thought that the solar system was densely packed. Drawings from participants in this study revealed that many thought that the asteroid belt is cluttered (Figures 9, 10, 12).

Furthermore, in agreement with Plummer (2009), students had difficulty representing the size of the Sun compared to the Earth (see drawings from students B22 and B11, Figures 10 and 11). The findings from this study on Year 7, 8 and 9 students’ knowledge about the solar system sheds light on the challenges for science centres and other informal educational providers such as the GDC to provide appropriate educational activities for groups of students from different schools. Formal schools have sustained relationships with students over several years and have the time and capacity to ascertain students’ prior knowledge and build on that prior knowledge during educational activities and programmes. In contrast, informal education providers have limited time and capacity to determine what knowledge students bring to the activities and lessons that they provide.

The findings from this study show that regardless of the year group that students are in at their school, their level of understanding of relevant concepts may vary enormously. The findings of this study indicate that the factors that impact on this understanding may relate to the passion and knowledge of their classroom teachers and other factors such as the socio-educational advantage including the location and proportion of indigenous students in the school. The findings from this study suggest that it is important for informal science centres to find out as much as possible background information about visiting schools, their teachers and students prior to their visit and also to ascertain students’ level of understanding of relevant concepts. This would better enable the informal science centre to
provide educational activities at an appropriate level to build on what the students already know and also to challenge any misconceptions that students may already have developed.

**The Impact of the Solar System Walk activity**

The second research question was: What impact did participating in the Solar System Walk activity have on Year 7, 8 and 9 students’ science knowledge about the size and scale of the solar system? The findings against this research question were also interesting and challenging in that while the students from School B which had the highest pre-excursion questionnaire scores, made the greatest gains, the students from School D with the lowest pre-excursion questionnaire scores, outperformed the students from School C (Figure 7 & 8). The ANCOVA statistical analysis indicated that there was a statistically significant effect of the different experiences that each school group had at the Gravity Discovery Centre on the students’ post-excursion understanding of the solar system as indicated by the scores on their solar system diagrams. Factors that may have contributed to this interesting finding are explored in the following paragraphs.

The information provided in Table 12 and in the descriptions of the different experiences the three groups had with their excursion to the Gravity Discovery Centre gives insight into the reasons why School B and School D seemed to learn better as a result of the excursion than School C. While School C is a high socio-economic school and a high academic performing school, the quality of the educational experience for the participating students seems to have been substandard compared with the other two schools. School C visited the GDC for only four hours due to the long bus trip required to get the students to and from the excursion site within the one day. In comparison, students from both Schools B and D stayed overnight in nearby accommodation and, as a result, they had much more time to participate in a number of activities at the GDC including the Solar System Walk activity. It is highly likely that the sustained contact students from Schools B and D had with the environment and activities at the GDC contributed to the students’ learning in a number of ways.

For example, the sustained period for the excursion may have indicated to the students the importance of the topics and concepts studied, provided them with more time to assimilate the concepts, and allowed for reinforcement of the learned concepts and ideas through participation in a greater number of activities and also through conversations with GDC and school staff and other students. These factors reinforce the literature that argues for the
importance of sustained, quality engagement between schools and informal science education providers, sustained time with specific exhibits and, in particular, pre- and post-exursion opportunities to prepare students for excursions and reinforce learning that occurred during the excursion (Rennie, 2007; Rennie & Johnston, 2007).

Focusing specifically on the data representing the participating students’ learning of size and scale in the solar system reveals a mix of what can be considered both positive and not-so-positive findings. On the positive side, the experience of standing inside the representation of the Sun at the start of the GDC Solar System Walk, and then walking past scale-models of the planets undoubtedly enabled the participating students to grasp the enormous differences in size of the Sun and the planets and the vast distances between them. During the activity students made many comments and noted their surprise with regard to how far they had to walk to reach each planet, for example. Moreover, almost all students drew the Sun much larger than the other planets in their post-exursion drawings, most students differentiated between the inner and outer planets in terms of their size and Jupiter was shown as the largest planet in 90% of drawings.

As documented by Tretter et al. (2006a, 2006b), Jones and Taylor (2009) and Osborne et al. (1994) students have difficulty comprehending the size and scale of the solar system. It is virtually impossible to represent the enormity of the solar system on paper or in textbooks. Though it is possible to use the latest virtual reality technologies to provide students with a simulation of the planets and the vast distances between them, the actual experience of walking through a scale-model of the solar system offers students a kinaesthetic and novel way to experience and visualise the system and its dimensions. It is possible that the kinaesthetic awareness that students can develop in activities such as the Solar System Walk, helps with student understanding of concepts such as size and scale. This hypothesis is supported by findings presented by LoPresto et al. (2010) that endorsed the value of experiential learning.

On the less positive side, students’ post-exursion drawings did not truly represent the scale of the solar system, the distances between the Sun and planets and the differences in size between the Sun and planets. Students were simply asked to make their drawings to scale, and the difficulty of doing this is a limitation of the method of data collection used in this study. Students may not have known what ‘to scale’ means, or may not have understood the importance of showing their understanding of the vast differences in size.
and distances between the Sun and planets. Moreover, the paper provided to students for making their drawings would have limited their ability to create truly to scale drawings in an accurate manner. As argued by Jones and Taylor (2009), teachers (and researchers) may not only need to place more emphasis on visualising scale, learning how to move from one scale to another, and creating new scales; but also place more emphasis on drawing and modelling scientific phenomena to scale. The researcher/observer noted that students from all three school groups experienced difficulty with the mathematics involved in the student activities. This is an important and relevant factor in relation to teaching students about size and scale (Tretter et al., 2006b). The GDC does not have appropriately qualified staff or student materials available on site that could address this issue.

Practical implications based on the findings of this study indicate that there is a need to enable students to capture the whole experience and have their own learning record. To facilitate this, new technologies could be incorporated, such as the use of tablets or smartphones. Students could then have access to camera and global positioning technologies, and use smart codes on each of the planet signs to access additional reference material. Students could record and calculate instantly using their electronic device, instead of using pedometers as they did in this study. At a later time, students, teachers and researchers could access any information captured on the Solar System Walk. The GDC experience could be captured and used as a virtual tour for students who were unable to make the trip or in follow-up activities at school. However, observations indicated that the participating students enjoyed the novel experience of being at the GDC and walking through the Australian bush and the scale model of the solar system.

Limitations of the Study
As noted in the discussion, the data collected only provided limited insight into the students’ understanding of facts related to the solar system and also size and scale of the solar system. The nature of the activities, the time constraints for students and teachers and the fact that this was an exploratory study conducted for the first time at the GDC, were limiting factors that affected this research and data collection. It is recognized that many other and more probing questions would have provided more insightful data. The questions were deliberately factual in nature due to the constraints mentioned above. Size and scale of the solar system and its components was ‘experienced’ by the students as they walked the 1 kilometre solar system walk. Data collection for the size and scale of the solar system consisted of student representations in their solar system drawings.
For example, asking students to draw the solar system with accurate size of the planets and to scale on the same diagrams was very difficult for them to represent with any great accuracy. This was a limitation and should be improved in future studies that investigate the impact of informal educational activities on students’ understanding of these concepts. It was important for the researcher to minimise the invasiveness of the data collection on the students and their teachers and, as such, data collection tools specifically designed to test students’ conceptions of size and scale were not employed.

The study would have benefitted from further qualitative data such as interviews to further assess student prior excursion understanding and post-exursion learning. This research was, however, an exploratory study to evaluate the usefulness of an informal learning programme related to the size and scale of the solar system. The students were not normally exposed to learning in an out-of-school setting like the Gravity Discovery Centre. The use of different data collection methods was due to constraints on access to the students at the GDC on the day of data collection. The real-world context of a school excursion controls and complicates any research undertaken. There is limited flexibility in when and how students can undertake particular activities, especially when combined with the need to collect data from them.

**Conclusion**

The findings of this exploratory case study indicated that the Solar System Walk activity at the GDC did enable the participating Year 7 to 9 students to better comprehend concepts about the size and scale of the solar system. Further, the results revealed that: prior knowledge is important; time spent at the GDC impacts student learning; and the kinaesthetic nature of the activity may support learning by indigenous students and those from low socio-economic schools. These findings also suggest that within the scope of the ages of participating students, age is not a barrier to learning about the solar system; and that learning is closely dependent on opportunities, exposure, learning environment and teaching expertise. More research is needed to ascertain exactly what aspects of the programme resulted in the learning.
Chapter 5: The Impact of a Science Centre Programme on Year 8 Students’ Conceptual Understandings of Gravity

Abstract
The aim of the research presented in this chapter was to investigate the effectiveness of educational programmes delivered through a science centre, specifically the Gravity Discovery Centre (GDC), in changing students' conceptual understandings of gravity. The GDC provides school students with access to science learning facilities, including a 45-metre tower known as the Leaning Tower of Gingin, where students can conduct gravity experiments. The case study involved three classes of Year 8 (12 - 13 years old) students from one school, who visited the GDC for an excursion as part of a science enrichment programme offered at that school.

Students conducted gravity experiments including dropping water filled balloons of different masses from the top of the Leaning Tower. Data collection for the case study included pre-exursion and post-exursion questionnaires that evaluated students' conceptions of gravity. Questions focused on problems such as the direction a fishing line would take when dropped into the water at different locations on the Earth and comparing a feather and a heavy hammer when dropped on Earth and on the Moon.

A range of scientific conceptions was observed amongst the students. Many students could state that gravity always acts towards the centre of the Earth. However, misconceptions included confusion between gravity and the Earth’s magnetic field. Students frequently tried to justify their pre-exursion misconception that a heavier water balloon would hit the ground before a lighter balloon when dropped from the Leaning Tower. Pre-exursion and post-exursion data show change in students' understandings of gravity. The results indicated a statistically significant improvement in students’ conceptual understanding of gravity on the pre/post questionnaire with a small effect size.
Introduction
Many secondary school students who can successfully solve numerical problems relating to gravity and vertical motion have qualitative misconceptions similar to those held by much younger students. For example, students who can quantitatively solve problems about gravity on the Moon, may still believe that a hammer dropped by an astronaut on the Moon will float away (Kavanagh & Sneider, 2007). The Australian Curriculum: Science describes change to an object's motion as caused by unbalanced forces, including Earth's gravitational attraction, acting on the object (http://www.acara.edu.au). In this regard, the Australian Curriculum is similar to curriculum documents worldwide that require students be taught about physics from a perspective consistent with Newtonian science. However, when students reach Year 12 Physics, the curriculum covers new concepts including the study of black holes, dark energy and dark matter, that are relevant in contemporary contexts. The scope for exploring new concepts in physics and astronomy is vast, including the Square Kilometre Array and newly discovered gravitational waves. Such contemporary contexts require understanding of physics from Einsteinian perspectives and are supported by Einstein’s theory of general relativity.

Concepts related to Einstein's physics are usually not taught until students are in university. The reason relativity is often ignored in the school science curriculum may be due to the abstract nature of Einstein’s explanations of gravity. This knowledge is possibly assumed to be too difficult for school students. Teachers and curriculum developers themselves may not have the knowledge and expertise to include relativity in the curriculum, and curriculum developers may prefer to include Newtonian explanations of gravity because they are seemingly more intuitive for students. However, research has shown that primary school aged students can learn abstract scientific concepts, such as "the nature and relationship of DNA, gene, allele and chromosome" (Donovan & Venville, 2014, p. 353) and understand some difficult concepts related to Einstein’s physics (Haddad & Pella, 1972; Pitts, Venville, Blair & Zadnik, 2013). Given that there is documented evidence that students can comprehend challenging ideas in science, there is no valid reason why abstract scientific concepts are not part of a twenty-first century science curriculum.

Purpose and Research Questions
The purpose of the research presented in this chapter was to investigate the effectiveness of educational programs delivered through the Gravity Discovery Centre (GDC) in changing Year 8 students' conceptual understandings of gravity.
The research questions were:

1. What are Year 8 students’ pre- and post-instructional conceptions of gravity?
2. How did the educational programmes delivered at the GDC impact on Year 8 students’ conceptual understandings of gravity?

Conceptual Framework

 Relevant themes and key findings from four main areas of the literature are presented in this section, providing a conceptual framework as follows:

- The history of gravitational theory
- Students’ alternative conceptions about gravity
- The role of out-of-school contexts in the learning of science; and,
- What the Australian Curriculum says about gravity and related concepts.

The History of Gravitational Theory

 Much of what is known about gravity comes from the written works of Aristotle. Ancient Greek theories were based on elements of substances: earth, fire, air and water. Aristotle saw that ‘heavier’ objects such as earth elements fall faster than ‘lighter’ objects such as fire and air. Moreover, Aristotle theorised that given the Earth is comprised of the earth element, objects fall towards it and thus Earth occupies the region closest to the centre of the Universe (Kavanagh & Sneider, 2007).

It wasn’t until the 16th century that Copernicus questioned ancient Greek theories of elements, providing a broader perspective of planetary impact on gravity. Astronomer Tycho Brahe recorded comets and planetary movements and put forward the idea that all planets are in motion. His student, Johannes Kepler, took these findings and developed laws governing planetary motion. Although these early scientists understood that objects fall to Earth, they were unable to accurately measure the speed and acceleration because the objects were moving too quickly and their tools were not accurate enough. Galileo Galilei experimented with balls rolling down a smooth ramp and, using a water clock to measure time, found that the ball travelled a quarter of the way down in half the time it took to travel the whole distance (Hewitt, 2015).

This led Galileo to see that there is a relationship between speed and distance travelled, namely that the distances traversed were proportional to time squared. From this he inferred that an object falling vertically would follow the same relationship and that bodies
did not fall toward the Earth at a fixed speed, but accelerated at a constant rate. These discoveries led Galileo to initiate contemporary theories about gravity, by quantitatively studying motion itself, rather than the causes of motion (Kennedy, 2012). Galileo advanced ideas about the law of inertia, stating that gravity is not intrinsic to the body, but rather is an external action exerted upon the body.

Galileo’s ideas of gravity as an external force rather than as a property of the body, were taken up by Isaac Newton and led to new understandings about physics relating to force, mass and weight. Newton laid the foundations for mechanics and gravity. Newton’s first law of motion describes objects moving with uniform velocity; his second law concerns objects that are accelerating and the third law states that the gravitational attraction between two bodies is equal and opposite. Newton’s laws provided an explanation of why objects of different masses fall with the same rate of acceleration. Newton also saw that planetary motion had an effect on gravity, with the Sun as the central gravitational force, yet he could not explain exactly the orbit of the planet Mercury (Hewitt, 2015).

In the early 20th century Albert Einstein, in his general theory of relativity, perceived a gravitational field as a geometrical warping of 4-dimensional space-time. It is helpful to use a waterbed as an analogy to explain the difference between Newtonian and Einsteinian perspectives of gravity. A large ball will make a dent in the bed (the more massive the ball, the greater the dent) towards which a marble will ‘gravitate’ in a curved motion. Without the larger ball, the smaller ball will roll in a straight line.

From a Newtonian perspective, the marble is attracted to the ball and we would surmise that due to this attraction, the marble would move in a straight line towards the ball. From an Einsteinian perspective, the path of the movement of the marble curves because the surface on which it is located is curved. That is, the first, Newtonian perspective is 2-dimensional; the second, Einsteinian perspective operates using four dimensions for space and time. Due to the difficulty in visualizing 4-dimensional space-time, a 3-dimensional analogy is useful. The use of a waterbed analogy can also aid students' transition to a new conceptualization (Einstein's) of previously taught concepts (Newton's).

The Gravity Discovery Centre has an exhibit that demonstrates this for students, helping them to learn about space-time and Einstein's physics. Space-time is viewed as a rubber
sheet, stretched flat when there is no matter present. Different sized balls are placed on the rubber sheet, pushing down and creating depressions (see Figure 15).

![Figure 15](image)

Figure 15: A photograph of a rubber sheet and balls being used as a demonstration to represent gravitational warping of space-time

In Einstein's general theory of relativity, differential field equations describe how the shape of space-time depends on the amount of matter or energy in a region of space. The breakthrough of Einstein’s theory of general relativity explained exactly the anomaly of Mercury’s precessing elliptical orbit, unexplainable until this time (see Figure 16). Instead of tracing an ellipse around the Sun, as predicted by Newton's laws, Mercury's orbit shifts slightly each time it rotates (Kennedy, 2012).

![Figure 16](image)

Figure 16: Precession of the perihelion of Mercury (adapted from Kennedy, 2012, p. 214)

Astronomical observations of planetary motion became more precise in the nineteenth century and the orbits of the planets were observed as being not "the perfect ellipses that one would expect if the Sun were the only gravitating body: the effects of the gravitational pull of the other planets caused slight but measurable deviations from ellipses" (Schutz, 2003, p. 48). Jupiter changes its position only slightly while Mercury orbits the Sun several times. The perihelion of Mercury’s orbit (its point of closest approach to the Sun) will
move forward and is said to precess forward. All planets have similar effects on each other’s orbits. As the closest planet to the Sun, Mercury experiences the greatest warping of space-time, explaining the slight deviation in its elliptical orbit. Thus, the slight variations in planetary orbits, previously seen as an anomaly, could now be explained by Einstein’s theory of general relativity.

**Students’ Alternative Conceptions about Gravity**

A key finding of studies on conceptual change is the persistent nature of some alternative conceptions and their effect on further learning, in spite of instructional efforts (Duit, 2009; Taber, 2009). These studies reveal that learners often present ideas relating to science topics that are at odds with the target knowledge presented in the curriculum (Taber, 2014). Resistance exists especially in such fields where pre-instructional conceptions are deeply rooted in daily life experiences and are continually supported by such experiences. Conceptions that are based on sense and motor experiences like thermal phenomena and conceptions of forces and motion are examples of such resistant preconceptions. These have been labelled ‘entrenched conceptions’ or ‘core ideas’ (Chinn & Brewer, 1993) and are based on common sense theory (Bliss & Ogborn, 1994), that presupposes no further investigation of anomalous concepts is required.

The literature is clear that the concept of gravity is one where students develop entrenched pre-instructional conceptions as a result of their ‘common sense theory’ or everyday experiences. A number of researchers in the 1980’s and 1990’s provided evidence to support students’ erroneous pre-instructional conceptions. For example, Noce, Torosantucci and Vicentini (1988) noted that students held the belief that you need air for things to fall. Treagust and Smith (1989) interviewed 24 tenth grade students and used a written instrument to test 113 other students and noted that there were a variety of misconceptions relating to gravity that were held by students. Bar et al. (1994) found that the youngest students in their sample thought all objects fall at the same rate. Older students thought heavier objects accelerate faster.

More recently, Feeley (2007) developed a survey to investigate student understandings about gravity concepts amongst undergraduate astronomy students and pre-service K-12 teachers. Survey questions were developed and modified from Berg and Brouwer (1991) and Dostal (2005). Students were asked open-ended questions about the behaviour of objects on the surface of the Earth and the Moon and asked to explain the causes of this
behaviour. Survey results revealed a variety of conceptions that students had about various aspects of gravity. These conceptions were similar to those found in earlier studies and included "the tendency to attribute gravity to the presence of an atmosphere, and the belief that a threshold amount of gravity, mass or weight is necessary for free-fall to occur" (Feeley, 2007, p. ii). Feeley (2007) also found that students believed that “… a planet’s gravity is related to its distance from the Sun, the Sun’s gravity influences the gravity of the planets that orbit it, [and] a planet’s rotation affects its gravity … " (p. 5).

A commonly held student misconception is that the Earth has a magnetic attraction and that the air is a connector of this force. Students’ views are not concerned with mutual gravitational interaction, but rather with the Earth attracting objects and the existence of air allows for the action of gravitation. Many students think that because a feather is lighter than another object such as a heavy rock, it will fall slower than the heavier object (Dostal, 2005). Dostal followed up research conducted on several continents including England, Italy and Canada with regard to students’ understanding of concepts of force. Middle school students were asked if an astronaut was on the Moon and released a feather from one hand and a spanner from the other, what would happen? Eighty percent of students thought that the spanner would not fall to the surface of the Moon, but that it would either remain stationary or float away. “Explanations commonly referred to the Moon having no gravity or no atmosphere and thus concluding that no force would be exerted on the spanner” (Dostal, 2005, p. 28).

Table 15 below summarises students' prior ideas found in the literature and the scientifically accepted conceptions about forces acting at a distance. This illustrates how difficult it is to introduce and teach complex ideas about gravity when they are contrary to students’ existing conceptual frameworks.
Table 15: A comparison of student conceptions vs scientifically accepted concepts (These student conceptions were recorded by researchers including Dostal, 2005; Feeley, 2007; Kavanagh & Sneider, 2007; Noce, Torosantucci & Vicentini, 1988; Treagust & Smith, 1989)

<table>
<thead>
<tr>
<th>Student Conceptions</th>
<th>Scientific Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Gravity is conducted by air</td>
<td>• Gravity does not need a conducting medium</td>
</tr>
<tr>
<td>• Gravity does not exist in space</td>
<td>• There is gravitational attraction in space between planets</td>
</tr>
<tr>
<td>• The Moon has no gravity</td>
<td>• Gravity does act on the Moon</td>
</tr>
<tr>
<td>• The Earth has magnetic attraction</td>
<td>• The Earth has magnetic north and south pole, but this does not affect gravity</td>
</tr>
<tr>
<td>• Speed increases with height</td>
<td>• Speed does increase with height, but g is constant at 9.8ms$^{-2}$</td>
</tr>
<tr>
<td>• Mass/weight affects falling speed</td>
<td></td>
</tr>
<tr>
<td>• Gravity only acts on heavy, slow or inactive objects</td>
<td></td>
</tr>
<tr>
<td>• Gravity acts upwards</td>
<td></td>
</tr>
<tr>
<td>• A planet’s gravity is related to its distance from the Sun</td>
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</table>

In devising an instructional method that will lead to conceptual change, the nature and construction of the pupils' prior (and sometimes entrenched) ideas need to be taken into consideration. A study conducted in California by Sneider, Bar and Martimbeau (1994) (as cited in Bar, Zinn & Rubin, 1997), with 12 year-old students, involved an experiment to explore students’ prior ideas that gravity is connected to air. Interviews were conducted; then the students completed pre-tests and discussed how a ball would travel as it rolled off a table. The results showed that, prior to the lesson, 65% of the students believed that it was necessary to have air in order for gravity to act. After the lesson only 20% of the students still held this mistaken belief. Not all of the others believed that gravity acts everywhere. Some of the students who had previously believed that gravity could not act beyond the Earth's atmosphere changed their minds to gravity acts 'only a little' in space, or 'just near planets like Jupiter'. The classroom activity conducted by Sneider et al. (1994) challenged a major preconception of students, that gravity needs air as a conducting medium, and caused a conceptual change in the ideas of some students. The findings point to the group work involving the experiment and group discussion as critical in facilitating assimilation of the new ideas (Driver et al., 1994; Hubber, 2005).
Taber (2014) explains the importance of understanding students’ pre-instructional conceptions to the processes of teaching and learning that also are relevant to informal learning contexts such as the GDC.

Research to understand the nature and characteristics of students' conceptions continues because understanding the precise nature and status of different types of reported conceptions is important in understanding how conceptual change may best be brought about e.g., by directly challenging student conceptions, by ignoring them and simply teaching the canonical ideas, or by seeing learners' conceptions as useful (or necessary) starting points that need to be modified over time through a multistage conceptual trajectory. (Taber, 2014, p. 40)

Taber’s (2014) comments raise questions that are important to the gravity exhibits at the GDC and whether students’ pre-instructional conceptions should be explicitly acknowledged, ignored, or utilized as a stepping stone to improved understanding.

The Role of Out of School Contexts to the Learning of Science
Dierking et al. (2003) define ‘informal science learning’ as “science learning that occurs outside the traditional, formal schooling” (p. 108). While this phrase might include the type of learning that is the focus of this research at the Gravity Discovery Centre (GDC), it is very broad and inclusive of a wide range of learning that occurs throughout a person’s lifetime and in a vast range of contexts and situations including during home life, through the mass media and through the natural environment (Tal, 2012). The term ‘informal science learning’ also suggests a considerable degree of freedom of choice about what, when and where the learner participates in the learning process (Rennie, 2007) that is not relevant to the type of programme in which the participants in this study were involved at the GDC. Tal (2012) preferred to use the term ‘out of school learning’ because it indicates the learners as being school students and because it also indicates the location of learning without being too restrictive, that is, not in school.

In this chapter the term, ‘out of school learning’ is adopted in a similar way to Tal (2012) because the research focused on school-aged students in Year 8 and the term is consistent with the nature of the event, a school excursion to a science centre or museum. Moreover, the term ‘out of school learning’ is consistent with the programme at the GDC that was determined by the GDC staff in consultation with the school teaching staff and the PhD
candidate and was well planned with limited ‘free choice’ on the part of the student participants.

Dierking et al. (2003) described three critical principles that underpin learning in out of school contexts and these are elaborated by Rennie (2007). First, learning is a personal process. Learning is different for each person depending on their background experiences and knowledge, their interpretation of the learning experience, and how the learner chooses to interact with the learning experience. Second, learning is contextualized in a social environment where the learner interacts with other people, including other students, friends, family members, teachers or museum staff. These people interact and influence the experience, each other’s thinking and learning and the nature of the learning that takes place. Rennie (2007) refers to Falk and Dierking’s (2000) Contextual Model of Learning that identifies three contexts relevant to learning in out of school settings including the personal context, the sociocultural context and the physical context of the learning experience. Third, learning takes time. The time dimension of learning is also represented in Falk and Dierking’s Contextual Model of Learning and reflects the “cumulative, iterative process of learning” (p. 130). Learning is rarely completed in a short lesson or out of school experience, but evolves over time and multiple experiences, sometimes leaps forward or slides backwards and organically develops knowledge and conceptual understanding often in a non-linear manner.

Braund and Reiss (2006) strongly argue that school science teaching needs to be complemented by out of school science learning activities including programmes offered by science centres, botanic gardens, zoos, science museums, and those provided at the Gravity Discovery Centre. Braund and Reiss outline five ways that out of classroom contexts can contribute to learning including: 1. improved development and integration of concepts; 2. extended and authentic practical work; 3. access to rare material and to ‘big’ science; 4. improved attitudes to school science, thus improving science learning; and, 5. social outcomes including collaborative work and responsibility for learning.

Lelliott (2014) described a framework to examine knowledge construction processes of Years 7 and 8 students learning about gravity at a science centre in South Africa, based on personal learning framed within the theory of human constructivism. From a constructivist viewpoint, meaningful learning is considered to be a cognitive process in which individuals make sense of their world in relation to the knowledge they have previously
constructed. Lelliott and Rollnick (2010) argued that gravity is a concept that most people find difficult to understand and explain and that thoroughly planned interventions were the most likely to successfully result in conceptual change. Falk and Dierking (2000) make the common sense point that single exhibits are not likely to impact participants’ understanding of gravity because of the complexity and strongly held nature of the misconceptions. Rennie’s (2007) review of the literature points to studies that show the importance of interactivity of exhibits and activities. That is, participants need to be involved in doing something, receiving feedback and being invited into further interaction. Interactive exhibits allow visitors to conduct activities, gather evidence, select options, think of conclusions, test and provide input (Rennie, 2007).

Gravity and Related Concepts in the Australian Curriculum

As this research was conducted in Australia, it is important to consider the curricular context in this country. Australia has only recently introduced a national curriculum that was being implemented at the time the research was conducted. The Australian Curriculum: Science has three interrelated strands: Science Understanding, Science as a Human Endeavour and Science Inquiry Skills (http://www.australiancurriculum.edu.au/science/curriculum).

Science Understanding includes four sub-strands: Biological Sciences; Chemical Sciences, Earth and Space Sciences; and, Physical Sciences. The Physical Sciences sub-strand for kindergarten to Year 10 outlines that students should be taught concepts including: how an object's motion (direction, speed and acceleration) is influenced by a range of contact and non-contact forces such as friction, magnetism, gravity and electrostatic forces. While the curriculum states that students should appreciate that concepts of force, motion, matter and energy apply to systems ranging in scale from atoms to the universe itself, it does not allow for the geometry of curved space and the quantum reality of the universe with concepts that reflect quantum ‘weirdness’.

The curriculum offers elaborations in areas relating to this study on gravity. Table 16 below provides information about the content descriptions and elaborations in the Australian Curriculum (http://www.australiancurriculum.edu.au/science/curriculum) that are relevant to the research presented in this chapter.
Table 16: Australian Curriculum: Science content and elaborations relevant to student learning about gravity

<table>
<thead>
<tr>
<th></th>
<th>Year 5 to 6</th>
<th>Year 7 to 9</th>
<th>Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Earth and space sciences</td>
<td>• The Earth is part of a system of planets orbiting around a star (the Sun)</td>
<td>• Predictable phenomena on Earth, including seasons and eclipses, are caused by the relative positions of the Sun, Earth and the Moon</td>
<td>• The universe contains features including galaxies, stars and solar systems and the Big Bang theory can be used to explain the origin of the universe</td>
</tr>
<tr>
<td>• Physical sciences</td>
<td>• Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object</td>
<td>• Exploring how gravity affects objects on the surface of Earth</td>
<td>• The motion of objects can be described and predicted by using the laws of physics</td>
</tr>
<tr>
<td>• Elaborations</td>
<td>• Considering how gravity keeps planets in orbit around the Sun</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is important to note that the Australian Curriculum: Science focuses on Newtonian perspectives of gravity. Yet it is Einstein’s theories of relativity that are studied at university and are the basis of contemporary exploratory research in physics. Teachers may not have the expertise though, to teach Einsteinian physics.

If students were introduced to some of these fundamental Einsteinian concepts at a younger age, they could gradually build up a knowledge base to cope with these complex...
concepts in senior secondary school years. In addition, it is possible they would be more motivated to pursue science as a field of study in senior school because the understanding of Einsteinian concepts provides the tools to explain more complex science. Moreover, teaching science as a human endeavour where scientific knowledge changes over time with new discoveries and the development of theory is consistent with the Australian Curriculum: Science. It is possible that both Newtonian and Einsteinian perspectives on gravity could be taught and explanations given to students about when these two theories are useful for understanding observations and empirical data, and their limitations. This is a developing area for future research and an international collaborative study is in the initial stage of planning.

Research Context
Information about the research context is provided in this section including details of the participating school. One of the key aspects of the enrichment programme was that it included an excursion to the Gravity Discovery Centre (GDC). Background information about this centre was presented in previous chapters and to avoid repetition is not included here. The Learning Tower of Gingin, a 45-metre steel tower where students conducted free fall experiments was the main focus for this study.

The participating Year 8 students attended a government-funded secondary school that caters for 1721 students from Year 7 to Year 12. The school is located in a high socio-economic status suburb 12 km from the Perth central business district. The school Index of Community Socio-Educational Advantage (ICSEA) value is 1138. The average school ICSEA value in Australia is 1,000 with a standard deviation of 100 points. The official school website (part of the Australian Government MySchool website, www.myschool.edu.au) explains that the school’s reputation is based on outstanding academic performance. There is a strong belief and commitment to success - whether in academic, cultural, vocational or sporting pursuits.

Method
An excursion to the Gravity Discovery Centre provided the students with an opportunity to participate in an enrichment programme that involved conducting gravity experiments from the Leaning Tower of Gingin, a platform 45 metres above the ground. The aim was to expose students to ways of looking at gravity and to provide the opportunity to test their
ideas through experimentation. More details of the programme are provided later under the heading, Student Excursion Workbook.

The research design was an exploratory case study delineated by the enrichment programme on gravity presented to the Year 8 students from one secondary school (Yin, 2009). The participants were seventy-five students from three classes at the secondary school. In order to explore the impact of the enrichment programme on the students, mixed methods of data collection and analysis (Creswell, 2009) were used. Creswell and Plano Clark (2007) explain that mixed methods research includes both the collection and analysis of quantitative and qualitative data. That is, closed-ended information and statistical analysis as well as open-ended information, for example, that allow participants to use their own words, is used to answer research questions. Creswell and Plano Clark argue that by mixing the data, researchers can provide “a better understanding of the problem than if either dataset had been used alone” (p. 7). The strategies used for data collection in this case study included a student pre- and post- excursion questionnaire; workbooks used by the students to record their experiments and results; and participant observation of the excursion activities by the researcher and a research journal. Each of these data collection strategies is explained in more detail below.

**Student Pre- and Post-Excursion Questionnaire**

A questionnaire was initially developed to determine Year 8 students’ pre- and post-exursion conceptions of gravity by the doctoral researcher. The questions were drafted with consideration of the research questions and information gleaned from the background literature review.

The first two questions included in the questionnaire focused on students’ understanding of gravity on Earth. Previous research showed that young children sometimes have very different views of the Earth to adults and it was important to ascertain the general pre-instruction conceptions of the Earth in the participating Year 8 students. Many young children, up to at least Year 3 and sometimes older, view the Earth as a flat object (Tao, Oliver & Venville, 2013). Even if they have developed the scientific understanding that the Earth is spherical, they may have misconceptions about gravity, for example, that gravity is something to do with the Earth’s magnetic field and pulls objects towards the North and South poles; or, that gravity pulls everything ‘down’ towards the ‘bottom’ of the spherical Earth (Tao et al., 2013). The first two questions in the questionnaire were drawn from
items developed and released by the Trends in Mathematics and Science Study (TIMSS) that are rigorously validated for delivery in a variety of countries and cultural contexts (Olson, Martin & Mullis, 2008).

The first question asked students to draw a picture of the Earth with people fishing at different points on the Earth. Students were then asked to draw the direction that the fishing line would take for each person. The second question asked students to explain what they drew. These questions were designed first to show whether participating students had developed a spherical concept of the Earth and also to identify any students with misconceptions about gravity, for example, caused by confusion between gravity and the magnetic field of the Earth. Previous research (Tao et al., 2013) showed that while many Year 3 Australian and Chinese children held these misconceptions, by Year 6, most know that the Earth is spherical and understand that gravity acts on objects by pulling them towards the centre of the Earth.

Questions 3 to 6 focused more specifically on students’ understanding of gravity and probed for misconceptions in relation to gravity as a universal attractive force between all objects with mass. In particular, these items probed students for misconceptions related to how the mass and distance between objects and the presence of air affects the gravitational force. Gravity is a universal attraction between any two objects with mass. Every object in the Universe is affected by gravity. The two factors that affect the magnitude of the force of gravity are the mass of the attracted objects and the distance between them. The greater the masses, the greater the gravitational force between two objects. The greater the distance between two objects, the less the gravitational force between them. Each object with mass in the Universe is attracted to all other objects, regardless of size or distance. Whether on the Earth, Moon, or in outer space, gravity is present. Air or an atmosphere is not required for gravity.

Question 3 and Question 6 of the questionnaire asked students to compare a feather and a heavy hammer if they were dropped on the Earth (Q 3) and on the Moon (Q6) (NASA, 1971 or see YouTube video http://www.youtube.com/watch?v=PE81zGhnbo0w&feature=related).

These questions were included in the questionnaire because they probed the participating students’ science knowledge to see if they understood the effects of gravity on objects of different mass (i.e. a light feather compared to a heavy hammer). Gravity is complex
because students may intuitively know that the stronger gravitational force on the heavier masses such as the hammer should speed it up more quickly. In fact, the stronger pull on the greater mass is cancelled out by the extra effort required to speed up this greater mass. As a consequence of this cancelling out effect, the rate at which free-falling objects fall on the Earth is always $9.8\,\text{ms}^{-2}$, regardless of their mass. However, on Earth, because objects are falling through the air, the air exerts an upward force on them as they fall. This force can differ depending on an object's size, density and speed. Air resistance has a considerable effect on objects such as a feather or a flat piece of paper, normally resulting in them falling at a slower rate than objects such as a heavy hammer.

Question 3 and 6 were also included because they were thought to be useful in determining if students recognise gravity as being universal or confuse it with ideas such as air needing to be present for gravity to have an effect. Even though students may quantitatively understand gravitational force, they may still hold on to preconceived ideas about air being necessary, especially if they confuse air pressure with gravity. Question 6 had an additional factor in that the objects are dropped from a three metre high platform, further probing students for the misconception about distance between objects and gravity.

Students' ideas about air being necessary for gravity may be related to their view of weight as a force. Studies by Ruggiero, Cartelli, Dupre and Vicentini-Missoni (1985) demonstrated that some students think air is the force that results in weight. The idea that air must be present for gravity to act was widespread among middle school students in their sample (Ruggiero et al., 1985). Relating gravity to air provides insight into students' ideas about gravity being something that resides outside of objects rather that all objects exerting gravitational pull (Driver et al., 1994).

Some students describe a "holding" idea that an atmosphere holds gravity in, and other students describe Earth's magnetism and spin as the cause of gravity (Driver et al., 1994). Terms used in the media like weightless and zero gravity may perpetuate the idea that there is no gravity in some places. Students also learn about moons that lack an atmosphere or have a very thin atmosphere, and hear references to astronauts being weightless in space. Questions 4 and 5 of the questionnaire asked why astronauts don’t float off the Moon (Q4) and what would happen to a pen if an astronaut on the Moon released it (Q5). These questions were included to further explore students’ conceptions of gravity and if they may have been influenced by socio-cultural factors such as movies that suggest weightlessness.
for astronauts (Q4). Question 5 further probed students’ conceptions related to mass and gravity with a pen being a small mass and considerable evidence in the mass media showing small objects ‘floating’ in space or on the Moon (see YouTube video https://youtu.be/o8TssbmY-GM).

**Item validity**

Two experienced physics teachers and two Australian university physics professors were provided with the draft questionnaire and asked to provide feedback on the validity of the items with regard to the planned enrichment programme and the appropriateness for Year 8 students. The experts suggested minor changes to the initial draft items, which were incorporated into the final version (see Appendix C). For example, the order of questions was changed so that similar ideas were presented in a developmental way and the wording of specific questions was altered to be less confusing for the students. The final pre- and post-questionnaire consisted of six items that focused on the students’ understanding of gravity on the Earth and the Moon. The majority of questions were open-ended to better capture any change in the students’ conceptions in their own words rather than forced response items that used the words of the researcher. Moreover, open-ended items are more likely to demonstrate comprehension of ideas rather than lower level knowledge demonstrated by recall (Bloom, 1956).

The panel of experts agreed that the test items would give an indication of participating students' understandings of gravity; however, they acknowledged the limitations of the test and the difficulties of developing a suitable instrument for 12- and 13-year-old students on this topic. The difficulty of developing a suitable test were exacerbated by the informal nature of the enrichment excursion to the GDC where activities are less structured than in a classroom and may change depending on a number of variables on the day of the excursion. Some of these variables include the weather, the interests of the participating students and teachers, and the direction taken by GDC staff during the activities.

The questionnaire was administered to the seventy-five Year 8 students prior to and after the enrichment programme involving three experiments on the Leaning Tower of Gingin. A marking rubric with a total score of 30 points was developed to score the students’ responses to the questionnaire and shared with the group of researchers who suggested minor modifications. Students’ hand-written responses to the six questions in the questionnaire were marked using the marking rubric that was consistent with a broad
scheme with increasing marks up to a maximum of five for each question. Examples of the students' responses to questions are provided in the Findings section of this chapter.

All scores were entered into the Statistical Program for the Social Sciences (SPSS) software package and descriptive statistics generated. A paired samples t-test was used to ascertain if there was any statistical difference in the students’ mean scores over the period of the enrichment programme and an eta squared effect size statistic was calculated as suggested by Pallant (2011). The guidelines (proposed by Cohen, 1988, pp. 284-287) for interpreting this value are: 0.01 = small effect, 0.06 = moderate effect, 0.14 = large effect (Pallant, 2011, p. 247).

Once the quantitative analysis of the questionnaire responses had been completed, the answers to the questionnaire items were scrutinised a second time to find responses to use for more detailed scrutiny and presentation in this chapter. Student samples that exemplified particular conceptions that were both consistent with and not consistent with scientific views, as well as those that did and did not demonstrate a change over the period of the enrichment programme were selected as qualitative excerpts to include in the findings to exemplify the quantitative results.

**Student Excursion Workbook**

All students attending the excursion were provided with a workbook that guided them through three experiments on the Leaning Tower of Gingin and provided them with space to record their predictions and observations with regard to these experiments (see Appendix C for the Leaning Tower of Gingin student workbook, including pre- and post-excursion questionnaires and experiments).

**Dropping Balloons (Experiments 1 and 2)**

The purpose of the first two experiments was to elicit students' ideas about falling objects. The task was designed to find out if students think the mass or weight of an object affects its rate of fall. The first experiment involved dropping two water filled balloons of the same mass from the top of the tower and observing the time they took to hit the ground. The second experiment was similar to the first experiment but one balloon contained more water than the other. The student workbooks prompted students to predict what they thought would happen in each experiment and then record their observations after the experiment.
The ‘cancelling out effect’ (i.e. that stronger pull on greater masses is cancelled out by greater masses accelerating more slowly [described above]) means that, regardless of their mass, all free-falling objects on the Earth always fall at the same rate of $9.8\text{ms}^{-2}$. The experiments conducted during the excursion to the GDC were done so with the assumption that the effect of air resistance on the balloons was negligible. If the air could be removed and the balloons dropped in a vacuum, they would always hit the ground at exactly the same time.

At the secondary school level, students move from understanding gravity as a general universal force to understanding more of the details and mathematics of gravitational forces. At this level, students should be better able to engage in more abstract thinking involved with mathematical representations, such as the acceleration of a falling object, and also to learn of the many contexts in which gravity plays an important role. Secondary school students also move from qualitative descriptions of motion towards quantitative ones. Students do not always identify a force to account for falling objects. They think objects ‘just fall naturally’ or that the person letting go of the object has caused it to fall (Driver et al., 1994). Studies as early as that conducted by Osborne (1984) confirm that students often think heavier objects fall faster. Students, including university students, tend to think that heavier objects fall to Earth faster because they have a bigger acceleration due to gravity (Driver et al., 1994).

**Water in the Cup (Experiment 3)**

In this experiment, students made a small hole in the centre of the bottom of a polystyrene cup. They then placed a finger over the hole and filled the cup with water. This experiment was also conducted from the top of the tower and the students dropped their cups by pulling their finger downwards to release the cup as smoothly as possible.

In this experiment, students were asked, "What do you think will happen to the water in the cup?" The students wrote their predictions and then dropped the cups.

The water stays inside the cup even though there is a hole in the bottom of the polystyrene cup, until it hits the ground. On the Earth, if something isn't being held up it will accelerate downwards due to gravity. So if you hold onto a cup with a hole in it, the water will be pulled downwards through the hole and end up on the floor. Galileo worked out that if you let something fall towards the Earth, it would accelerate towards the ground at the same
rate whatever it is. This is true of both the water and the cup and they would both hit the ground at the same time (if air resistance is ignored) (The Naked Scientists, 2008).

**Researcher Participant Observation and Research Journal**

The researcher played an active role as a participant observer (Merriam, 1998) while the students were on the excursion to the GDC. At all times the regular classroom teacher retained control of the students and the excursion activities, and the researcher played a supporting role by interacting with students, reiterating directions given by the teacher, asking students questions and answering their questions when they arose. The researcher reflected on the excursion that evening by adding notes to her research journal about her observations and interpretations of events that occurred during the excursion. The notes were analysed by categorising text as ‘observation,’ ‘inference,’ or ‘reflection’. An annotation was considered an ‘observation’ if it was directly observed by the researcher and recorded in her notes. An annotation was considered an ‘inference’ if it used any observations and involved some kind of logical reasoning by the researcher to make another statement, usually an explanation for the observation. An annotation was considered a ‘reflection’ if it recorded additional, extrapolated thoughts of the researcher related to observations but not a direct explanation of the observation.

An example of annotated notes including an observation, inference and reflection follows:

The historical example of Galileo's famous experiment with falling objects was discussed with students at the tower [observation]. Students found dropping two balloons in exactly the same way and at the same time was difficult, especially in the conditions at the top of the tower which were windy and required the students to ‘let go’ of the balloons down two tubes that were over a metre apart [observation]. This made it hard for some students to reproduce the expected results [observation]. Consequently, student investigations may have reinforced incorrect student ideas, e.g. that the balloons would fall at different rates [inference] because the students observed them hitting the ground at different times.

Students could be shown videos of this situation performed under highly controlled conditions [reflection]. A film of an astronaut dropping a hammer and feather together on the Moon is especially interesting [reflection]. However, this film may
cause students to think that something special about being on the Moon, such as less gravity, causes the objects to drop together [reflection].

The notes from the researcher’s journal were used to critically reflect on the students’ experiences and responses to the activities at the outreach centre.

**Findings**

The findings from the quantitative analysis of the students’ pre/post-instruction questionnaires are presented in Table 17 and in graphical form in Figure 17. Table 17 shows that in four of the six questions there was an improvement in mean scores over the period of the enrichment programme (Questions 1, 2, 4 and 6), and in Question 3 the mean score remained the same indicating no overall improvement in students’ responses to this question. Question 5 showed a decrease in the mean score from pre-test to post-test. The paired-samples *t*-test indicated that, overall, there was a statistically significant increase in student scores on the sum of all six items on the questionnaire from time 1 (pre-test) (*M* = 24.59, SD = 3.40) to time 2 (post-test) (*M* = 26.00, SD = 3.33), *t*(74) = 3.409, *p* = 0.001 (two-tailed). The mean increase was 1.41 points with a 95% confidence interval ranging from 0.59 to 2.24. A Cohen’s *d* of 0.42 was calculated, indicating a small, meaningful effect size.

Table 17: Summary of mean scores for each of the six questions on the student pre- and post-exursion questionnaire (n=75)

<table>
<thead>
<tr>
<th></th>
<th>Q1 Fishing Line</th>
<th>Q2 Diagram Reason</th>
<th>Q3 Earth Feather</th>
<th>Q4 Astronaut</th>
<th>Q5 Floating pen</th>
<th>Q6 Moon Hammer</th>
<th>Q1 Fishing Line</th>
<th>Q2 Diagram Reason</th>
<th>Q3 Earth Feather</th>
<th>Q4 Astronaut</th>
<th>Q5 Floating pen</th>
<th>Q6 Moon Hammer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-Test (n=75)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4.63</td>
<td>4.53</td>
<td>4.72</td>
<td>4.08</td>
<td>3.68</td>
<td>2.95</td>
<td>4.84</td>
<td>4.81</td>
<td>4.72</td>
<td>4.61</td>
<td>3.65</td>
<td>3.36</td>
</tr>
<tr>
<td>Max</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Min</td>
<td>3.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>2.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>StDev</td>
<td>0.77</td>
<td>0.91</td>
<td>0.51</td>
<td>1.19</td>
<td>1.23</td>
<td>1.28</td>
<td>0.57</td>
<td>0.71</td>
<td>0.63</td>
<td>0.79</td>
<td>1.21</td>
<td>1.39</td>
</tr>
<tr>
<td>Median</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>4.00</td>
<td>3.00</td>
<td>2.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>
In order to answer the research questions about the Year 8 students’ pre- and post-excursion conceptions of gravity, in the following sections specific responses from students to the questions on the questionnaire, prior to and after the excursion, are explored in more depth.

**Students’ Pre- and Post-Excursion Conceptions about the Direction Gravity Acts on Earth (Questions 1 & 2)**

Questions 1 and 2 on the pre- and post-excursion questionnaire probed the participating students’ understanding about the direction of gravity on Earth by asking them to draw a diagram with people fishing in different positions around the Earth. The students were asked to indicate which direction the fishing line would take when dropped into water. Prior to the excursion, the majority of the participating Year 8 students could correctly explain that regardless of the position on Earth, “gravity pulls the fishing lines towards the centre of the Earth” (Student E17). Figure 18 shows typical diagrams from students who provided correct responses. There were, however, a number of misconceptions identified among the students, for example, confusion about gravity and the Earth’s magnetic field. One student said: “The gravity and magnetic pulling down to the centre of the Earth” (Student E49), and another student said that a fishing line is pulled “in the direction of each
pole” (Student E45). There were small improvements on Questions 1 and 2 after the programme at the GDC (Figure 17) indicating that some of these misconceptions were addressed.

Figure 18: Samples of correct student responses to Question 1 and 2 about the direction gravity acts on Earth (pre-excursion)
Students’ Pre- and Post-Excursion Conceptions about the Effect of an Object’s Mass and Gravity on Earth (Question 3)

Question 3 on the questionnaire asked students to compare a feather and a heavy hammer if they were dropped on the Earth. Most students could explain that air resistance would affect how quickly the feather dropped (Figure 19). Student E1’s initial response below "...gravity pulls the hammer down more quickly due to the weight of it..." reflected a pre-excursion misconception amongst the students that heavier objects will fall quicker than lighter objects. The statistical analysis (Figure 17) indicated that the programme at the GDC did not on average improve the ideas of the small proportion of students who held this misconception and it persisted despite their experiments from the tower.

Figure 19: Student response to Question 3 (feather and hammer drop)

Table 18 provides qualitative insight into three students’ pre- and post-excursion responses to Question 3. Student E1 refers to the weight of the hammer and feather prior to the excursion programme but not after. It is not clear whether this student retains the weight misconception after the excursion. Student E11 seems to confuse ‘wind’ with air resistance both before and after the programme of activities and student E23 expresses a view that the weight of the hammer overcomes whatever it is that causes the feather to ‘swish side-to-side’. It may be that E23 has a conception about air resistance but lacks the vocabulary, even after the GDC programme, to adequately explain his/her thinking.
Table 18: Student written responses to Question 3 (feather and hammer drop)

<table>
<thead>
<tr>
<th>Question 3. A person stands on a three metre high platform. He drops a feather from his right hand and a heavy hammer from his left hand at exactly the same time. What will happen to each object?</th>
</tr>
</thead>
</table>
| **Student E1**  
Pre- Question 3. The feather will float down slowly, but the hammer will drop quickly. This happens because the gravity pulls the hammer down more quickly due to the weight of it. The feather is also pulled by the gravity, but not as quickly.  
Post- Question 3. Each object will either float or plummet to the ground because gravity is pulling them down. |
| **Student E11**  
Pre- Question 3. The gravity would pull both the hammer and the feather at the same speed and both objects would hit the ground at the same time unless there is wind to slow the feather down.  
Post- Question 3. As for the hammer it will go down very fast and for the feather it depends on the weather. If it's very windy then the feather will go off track and if it's calm it will slowly come down. |
| **Student E23**  
Pre- Question 3. The feather will slowly swish side-to-side taking a long time to hit the ground while the hammer will fall at a rapid time because of the weight of the hammer.  
Post- Question 3. The hammer will smash down at a rapid speed because of its weight and the feather will swish side to side at an extremely slow speed. |

**Workbook: Experiments 1 and 2 Findings**

Due to logistics, students worked in groups while performing the three experiments for this activity. The students made predictions about what would happen when balloons filled with different amounts of water were dropped at the same time from the top of the Leaning Tower of Gingin. When they were at the GDC, students tested their predictions by dropping water filled balloons of different sizes from the top of the Leaning Tower (Experiments 1 and 2). The students timed and digitally recorded their experiments providing them with data for in-depth analysis. Students then explained what they observed based on the evidence.

Data from the workbook showed that students frequently tried to justify their misconception that a balloon filled with more water would hit the ground before a balloon
filled with less water when dropped at the same time from the Leaning Tower. For example, Student E7 believed that “an object is heavy the faster it will hit the ground”. When this student conducted an experiment from the Leaning Tower, he recorded that the two balloons hit the ground at the same time. He tried to explain the experiment by saying that, “maybe because the person in charge filled the water in the two balloons too close to each other”. Even though he observed and had digital data from his experiment that should have helped him correct his misconception, his incorrect belief persisted.

Post-excursion, students E13 and E15 noted the following in their workbooks:

- I learnt that two objects falling from the same height will impact the ground at the same time.
- When you drop balloons off the tower, no matter what size the balloon is it will hit the ground at the same time as the other one.

Unlike student E7, for students E13 and E15 their direct observations at the top of the tower appear to have impacted on their ideas about gravity and its effect on objects of different mass. The majority of students predicted that the water would fall out of the cup in Experiment 3. The researcher noted in her research journal, that due to windy conditions, it was difficult for some students to successfully drop the cup in an upright position and this may have contributed to persistence of misconceptions about gravity.
Students’ Pre- and Post-Excursion Conceptions about the Effect of Gravity on Astronauts on the Moon (Question 4)

Students expressed varying ideas about astronauts and their movement on the Moon. Table 19 provides examples of students' pre- and post-excursion views on the effect of gravity on astronauts from Question 4. This question had the biggest improvement in correct responses from before to after the GDC programme (Figure 17).

Table 19:  Student written responses to Question 4 (the effect of gravity on astronauts on the Moon).

<table>
<thead>
<tr>
<th>Question 4. Between July 1969 and December 1972 there were six Moon landings. Twelve astronauts spent a total of over 80 hours exploring the lunar surface. Why didn't the astronauts float off the lunar surface?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student E31</strong></td>
</tr>
<tr>
<td>• Pre- Question 4. The astronauts didn't float away because the moon has its own gravity, strong enough to hold heavy objects.</td>
</tr>
<tr>
<td>• Post- Question 4. The moon has its own small amount of gravity, just enough to hold two astronauts.</td>
</tr>
<tr>
<td><strong>Student E7</strong></td>
</tr>
<tr>
<td>• Pre- Question 4. Because before astronauts go into space, they need to do a hard exercise so they don't become very weak in space because you will become very light.</td>
</tr>
<tr>
<td>• Post- Question 4. Before the astronauts lift off they work out very hard to increase weight and because the suit is heavy, as well as there are gravity in the moon.</td>
</tr>
<tr>
<td><strong>Student E2</strong></td>
</tr>
<tr>
<td>• Pre- Question 4. The moon has a gravity field that keeps them on it, it's like saying why don't planets just float away the exact same thing. Plus they have magnetic boots.</td>
</tr>
<tr>
<td>• Post- Question 4. It's like saying why we don't float off earth - gravity holds us on the planet, so the same would happen on the moon.</td>
</tr>
</tbody>
</table>
Student E24

- Pre- Question 4. The astronauts [sic] did not float off the lunar surface due to the fact that the moon has a small amount of gravity so there would still be a minute gravitational pull towards the centre of the moon.
- Post- Question 4. The astronauts [sic] didn't float off the lunar surface because the moon has a small amount of gravity which would be just enough to pull the astronauts [sic] into the moon, however, because it is far weaker than earth, you can conduct many experiments that is unable to do on earth.

Student E31 appears to have a correct conception of gravity on the Moon prior to the GDC programme; however, after the programme, this student indicates his/her idea that gravity on the Moon gets used up and can only work with a certain number of objects, i.e. "Just enough to hold two astronauts." Student E7 confounds knowledge about muscle strength in astronauts and weight and gravity both prior to and after the GDC programme. Both students E2 and E24 seem to have reasonably good conceptions of gravity on the Moon before and after the GDC programme. However, student E2 adds a comment about magnetic boots prior to the excursion that contradicts his/her initial statement about a gravity field. Moreover, student E24 may confuse the lack of atmosphere on the Moon that allows gravity experiments to be more easily conducted with gravity that is "far weaker than earth".
Students’ Pre- and Post-Excursion Conceptions of Whether Gravity Acts on the Moon (Question 5)

Figure 20 and Table 20 provide examples of students’ responses to Question 5 on whether gravity acts on the Moon. The quantitative analysis (Figure 17) showed little difference in the mean scores from pre- to post-participation in the GDC programme.

Figure 20: Student response to Question 5 (pen drop on the Moon)

Table 20: Student written responses to Question 5 (pen drop on the Moon)

<table>
<thead>
<tr>
<th>Question 5. Imagine an astronaut standing on the surface of the Moon, is holding a pen. If the pen is dropped, what will happen? Why? Compare this answer to how you answered Question 4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student E1</td>
</tr>
<tr>
<td>• Pre- Question 5. The pen will float because it is small and light. Light objects are not pulled by gravity as easily as heavy objects.</td>
</tr>
<tr>
<td>• Post- Question 5. The pen will float away, because the moon's gravity isn't strong enough to hold two astronauts and a pen.</td>
</tr>
</tbody>
</table>
Student E25

- Pre- Question 5. Due to the small gravitational pull towards the centre of the moon, I think the pen will slowly fall and land on the surface of the moon. Because the gravitational pull is so little, it will take a lot longer to fall on the moon then it would on the earth.
- Post- Question 5. Because the pen is lighter than humans, the pen would not have enough weight to fully harness the moon's gravity. It would either stay where it is or slowly float upwards, due to the small levels of gravity.

Student E11

- Pre- Question 5. The pen would float gently down because there is very less or no gravity to pull the pen and everything will become lighter or heavier depending on the planet's gravity.
- Post- Question 5. I would think the pen would float and go down very slow because the moon has less gravity than Earth.

Student E2

- Pre- Question 5. It would float away because there is nothing magnetic about a pen therefore it will float away.
- Post- Question 5. All the objects would float away into space because it has nothing to hold it there.

Similar to Question 4, student E2 considered that magnetism (or lack of it) was involved with the pen falling to the surface of the Moon. Students expressed various ideas about the pen floating instead of falling on the Moon.

Student E1 expressed two misconceptions, first that "light objects are not pulled by gravity as easily as heavy objects" and second, that the Moon's gravity can only act on a certain number of objects. This second misconception was noted in the same student's response to Question 4. Student E25's response to this question prior to the programme seemed to be more correct than his/her response after the programme when the "floats upward" misconception was expressed. Student E11 improved his/her explanation after the programme by removing any reference to "no gravity" on the Moon. Finally, student E2 expressed the "float away" misconception both before and after the GDC programme but attributes this to "nothing magnetic about a pen" prior to the programme and "nothing to hold it there" after the programme.
Students’ Pre- and Post-Excursion Conceptions about Gravity on the Moon with No Air Resistance Present (Question 6)

Figure 21 and Table 21 provide examples of students' responses to Question 6 about gravity on the Moon with no air resistance present.

Figure 21: Sample of student responses about gravity on the Moon with no air resistance present (Question 6)
Table 21: Student written responses to Question 6 (feather and hammer drop on the Moon)

<table>
<thead>
<tr>
<th>Question 6. An astronaut is standing on a platform three metres above the surface of the Moon. He releases a feather from his left hand and a heavy hammer from his right hand at exactly the same time. What will happen to each object? Why?</th>
</tr>
</thead>
</table>

**Student E1**
- Pre-Question 6. Each object will float away because 3 metres above the moon is out of the moon's gravity range.
- Post-Question 6. They will both float away, because 3 metres is above the gravity level of the moon.

**Student E28**
- Pre-Question 6. Due to the fact that there is no air in space and that weight does not change the speed at which things fall, I think that both items will fall at the same time.
- Post-Question 6. The hammer will very slowly float to the centre of the moon. However the feather will do the same as the pen and either stay where it is or slowly float upwards. It is more likely to float upwards than the pen.

**Student E11**
- Pre-Question 6. The hammer and the feather will float gently because the moon is many times less gravity than earth therefore the gravity in moon is approx 0.1 and takes a long time to pull it down.
- Post-Question 6. The hammer would come down, but slower and the feather would come down slower because the moon has less gravity than Earth.

**Student E2**
- Pre-Question 6. A feather would float away same as question 5 as the hammer might hit the moon or just float away too.
- Post-Question 6. Both would float away into space because it has nothing to hold it there. Meaning gravity so no metal products.

Question 6 had the lowest mean score of all the questions on the quantitative results (Table 17 and Figure 17). Some students understood that the hammer and feather would fall at the same time (Figure 21 top picture); other students expressed misconceptions that the hammer and feather will float (Figure 21 middle and bottom pictures) and that this was due to a "lack of gravity in space" (Figure 21 bottom picture). Table 21 shows that some students provided appropriate responses both before and after the excursion (student E11);
some students held the same misconception before and after the excursion (students E1 and E2); and others developed misconceptions after the programme (student E28).

**Student Perceptions of the GDC Experience**

Students had the opportunity to write about what they had learnt on their visit to the GDC and what they would like to know more about. Some examples of student responses follow.

I want to know more about:

- Gravity in space (Student E5)
- The way that gravity works on different objects (Student E13)
- Is gravity the same on other planets? (Student E57)
- How things can defy gravity? (Student E74)
- Is there another life source on a different planet? (Student E68)
- How many galaxies there are? (Student E64)

Students were also asked to comment on what they found difficult.

- Getting the balloons to the same size and dropping them at the same time. (Student E74)
- I do not understand how two items of different sizes land at the same time. I don't understand how that works. (Student E65)

Student comments about their visit to the GDC highlighted the positive aspects of the excursion.

- The highlight was climbing the Leaning Tower of Gingin. This 45 metre tall structure is on an angle of 15 degrees, and is as tall as a 13-storey building. We climbed all 222 steps to reach the top and perform some experiments. We dropped water balloons out of the tower and watched them smash into the ground, recording how long it took for them to fall. (Student E13)
- My favourite activity was the tower because I had a fear of heights that high but I did it anyway. (Student E23)
- The most enjoyable part of the excursion was dropping water bombs off the top of the tower and testing if our theory was right or wrong. I would have liked to have more time to try out more experiments on the Leaning Tower of Gingin. (Student E65)
Discussion

Meeting the needs of a school science curriculum is not simply about providing generic resources with Australian Curriculum links. Successful use of the GDC by school science departments depends on identifying windows in the curriculum that will allow teachers the space to build confidence in regularly using outreach centres. Time is precious within any school science curriculum. With pressure to cover all content in order to ensure students are adequately prepared for assessments, it is impossible to ignore the restrictions upon teachers as a result. It also requires the provision of support to schools and teachers in translating generic pre-prepared resources into context-specific ones. "If students are to experience and observe key scientific phenomena and ideas in rich learning environments, then each strategy must be carefully designed and planned by the teacher" (Woolnough, 2005, p. 25). Teachers involved in this study had a range of purposes and motivations for taking students out of the classroom, from those who wanted to add variety, to those who identified specific science learning outcomes thought to be best achieved through learning at this outreach centre.

The findings from the case study presented in this chapter clearly show that the educational outreach programme at the GDC that involved the three experiments from the Leaning Tower of Gingin did have an overall positive impact on participating students’ conceptual understanding of gravity. The quantitative findings from the student pre- and post-programme questionnaire showed a statistically significant improvement of 1.41 points from a mean of 24.59 points to 26.00 points out of a total possible score of 30 points. The effect size is small but meaningful. Table 17 and Figure 17 show the quantitative impact of the programme on each question of the questionnaire from before to after the excursion to the GDC and the associated activities.

The more detailed qualitative data presented with regard to each question on the questionnaire indicated that the majority of the participating students from this high socio-economic school had a reasonably good understanding of gravity on Earth. There were a few students who held some misconceptions, for example, they confused gravity and the Earth’s magnetic field. Questions 3, 4 and 5 of the questionnaire and the student workbooks revealed a number of other misconceptions in these students relating to gravity including that: heavier objects fall faster than lighter objects; gravity needs an atmosphere to have an effect; and, that there is no gravity on the Moon. These misconceptions have been reported in the literature as discussed in the introduction to this chapter and outlined
The impact of the programme of experiments at the GDC affected different students in different ways. Some of the students were able to change their erroneous conceptions of gravity, as indicated by the findings. For example, Student E2 (Table 19) let go of their ‘magnetic’ misconception in his/her post programme questionnaire response. Some students did not change their views. For example, Student E1 (Table 20) was of the view before and after the excursion that a pen will ‘float away’ on the Moon. Some students even showed a reversal of conceptions and the adoption of misconceptions over the period of the GDC programme. These effects on the students are not surprising and are consistent with the time dimension of Falk and Dierking’s (2000) Contextual Model of Learning.

Learning takes time, it is cumulative and iterative. While the impact of the GDC activities may have been less than desirable with some of the students who participated in this study, it may be that they remember the experiments they conducted and when they are learning about gravity in a different time and place, they will think back to the experiments at the GDC and take into consideration their observations. This may impact on their way of thinking and influence their learning at a later date as is the case with many experiences in museums and out of school learning contexts (Rennie, 2007).

Braund and Reiss (2006) argued that there are five ways that out of classroom contexts can contribute to learning. It is helpful to reflect on the GDC gravity experiments programme with regard to the Braund and Reiss framework. First, these authors argued that out of school contexts can improve development and integration of concepts. The findings and the discussion above affirm that the GDC activities did indeed improve the participating students’ conceptual development of the concept of gravity in a modest but significant way. Braund and Reiss said that out of school contexts can extend authentic practical work and provide students with access to rare material and to ‘big’ science. It is evident that the students would not normally have access to a venue with a tower from which gravity experiments such as those conducted at the GDC could be incorporated into a school-learning programme. Conducting such experiments from facilities at school creates safety concerns and challenges that are difficult to overcome.
Braund and Reiss (2006) also claimed that out of school learning contexts and experiences can help to improve student attitudes to school science, thus improving science learning. While changes in student attitudes towards science were not an explicit aspect of the purpose of the study presented in this chapter, some data reflecting students’ attitudes was collected and presented in the findings. Students comments, for example, that they want to know more about “gravity in space” and “the way that gravity works on different objects” and questions such as “is gravity the same on other planets?” indicated that the students were switched on to the conceptual complexities of gravity and were possibly aware of their lack of understanding as a result of their participation in the programme. Students also indicated that they enjoyed the activities with comments such as: “My favourite activity was the tower…”

Finally, Braund and Reiss (2006) stated that social outcomes including collaborative work and responsibility for learning can also be an important outcome from out of school learning. The students who participated in the gravity activities at the GDC did so in groups and supported and helped each other with setting up and conducting the experiments, collecting the data and analyzing the results. While data were not collected specifically about the social outcomes of the GDC activities, the doctoral candidate noted that there was a lot of discussion happening during the experiments and much of this discussion was focused on the practical and conceptual aspects of the experiments. All of these things are indeed encouraging and indicate the educational value of the GDC programme.

**Limitations**

As an exploratory case study, there were some limitations with regard to the approach used, and these limitations are outlined here so that the findings may be interpreted with an appropriate degree of scepticism. Firstly, the study was conducted with Year 8 students from one high socioeconomic Australian secondary school.

Secondly, limitations with regard to the data collected are acknowledged. Although a range of data were collected, systematic analysis of the material used for the student experiments was not included because these data were not specifically targeted at the research questions for this chapter. Enrichment activities may have altered student attitudes in unforeseen ways that did not necessarily reflect their attitudes to the specific activities nor the content presented in the enrichment programme.
Group safety at the GDC posed a different set of challenges to those in the classroom. The tower activities described in this study were reported as being the most exciting part of the excursion for most of the students and staff. However, the tower activities were also the most challenging for a significant number of students and staff due to a fear of heights and the physical effort required to reach the top of the tower.

Other limitations include the informal nature of the excursion, less structured activities compared with school, prevailing weather conditions, student interest, teacher participation and supervision and the directions provided by GDC staff during the activities. Further, due to time constraints, student observations and misconceptions were the main focus of the study (what did they think) and theoretical instruction was not undertaken at this time.

Notwithstanding these limitations, the findings of this exploratory case study at a science outreach centre are encouraging and indicate the potential for teaching gravity to Year 8 students via experiments at an outreach centre. Follow-up by the teacher is required to ensure that students' various alternative conceptions are addressed and to avoid introducing possibly new alternative conceptions. For example, Student E47 wrote on their booklet "I do not understand how two items of different sizes land at the same time. I don't understand how that works." In this case, it is important that the teacher can respond to these comments to reinforce aspects of learning about gravity back at school.

**Conclusion**

The findings of this exploratory case study indicated that an enrichment programme including gravity experiments at the GDC could potentially enable Year 8 students to comprehend gravity concepts. Further, the enrichment programme was found to be engaging and enabled students to achieve learning objectives from the Science as a Human Endeavour and Science Inquiry Skills strands of the Australian Curriculum.

The aspects of the enrichment programme that may have contributed to the learning and engagement of students were the novelty and hands-on nature of activities at the Gravity Discovery Centre, the use of analogies and discussion about key moments and scientists involved in the historical development of modern understandings of gravity. Students must understand Newtonian gravity before they can attempt to understand challenging abstract Einsteinian gravity concepts. It is not just about doing experiments, it is the whole experience of the visit. At the GDC, they are not just students, they are researchers on a
voyage of discovery. Every student had the opportunity to participate in the experiments at the Leaning Tower of Gingin and many students overcame their initial fear of heights to climb to the top. The students were exposed to learning about gravity in ways not necessarily possible in the classroom.

Teamwork was essential to successfully carry out the three experiments described in this study. Preston and Mussone (2013) described how students that worked "... as part of a small team meant they weren’t solely responsible for the outcomes, and this gave them the confidence to share their knowledge more freely" (p. 65). Excursions are perhaps most supportive of learning when they are connected to school experiences via pre- and post-visit activities. More research is needed to ascertain detailed information about ways that enrichment at a science outreach centre can enhance learning about gravity.
Chapter 6: Conclusions and Implications

Introduction
This chapter draws together a final analysis of the findings of the research about engaging school students in science at the Gravity Discovery Centre (GDC), located near Gingin in Western Australia. The research involved in-depth investigation of three educational programmes delivered at the GDC in enhancing middle school aged students’ understanding of science. Recommendations for how student engagement at the GDC specifically and science outreach centres more generally, are offered, based on the findings of the three case studies.

Science expertise will be needed in the future for jobs that currently don't exist. A growing economy will be one that can adapt to global changes in the environment, technology, farming and business. Scientific and mathematical knowledge will be essential. “They all require a conversation informed by evidence, and evidence interpreted with understanding. Which business will not harness technology, manage and utilise data, grasp complex financial arrangements, anticipate the changes of the future?” (Chubb, 2015, para. 11).

Chubb (2015) cited:

The US National Bureau of Science released a paper examining its indicators for the science workforce. About 5 million Americans held positions that would traditionally be classified as "science and engineering"; but more than 16 million workers reported that their jobs required at least a bachelor's degree level of science and engineering training. Many of these individuals worked in fields such as sales, marketing and management – reflecting, as the report noted, "the pervasiveness of technology throughout our economy". The science workforce was not simply growing in importance: it was also growing in size and complexity. (para. 18).

In addition, Chubb (2015) cites a 2012 survey by the Australian Council of Deans of Science of 800 science graduates about their experience in the workforce. Ninety seven per cent of the respondents said their scientific skills were useful in their work, namely problem solving skills, effective teamwork, critical questioning and adaptability to change. Foundation skills in science equip a future workforce with knowledge and understandings that are useful across a broad spectrum of sectors including law, medicine, mining,
economics, government and education. For this reason, it is essential that science in high school be a captivating, educational and rewarding learning experience.

Summary of the Research
The question that guided the research presented in this thesis was:

What were students’ experiences of the educational programmes delivered at the GDC and what effect did these programmes have on students’ scientific understanding of astronomy?

This overarching research question was addressed through three case studies. The three case studies were all related to educational activities at the Gravity Discovery Centre.

- Case Study 1: An investigation of the impact an Einsteinian based enrichment programme has on Year 6 students’ science knowledge and attitudes towards science
- Case Study 2: Are we there yet? An exploratory study examining middle school students’ understanding of our place in the solar system
- Case Study 3: The impact of the Gravity Discovery Centre programs on Year 8 students’ conceptual understandings about gravity

The next section includes a summary of the three case studies and the findings.

Case Study 1
Chapter 3 provided an exploratory case study of one class of 26 students who participated in six in-class lessons as well as an excursion to the Gravity Discovery Centre (GDC) where they explored curved space geometry with balloons, black holes and gravity. This study explored the impact of an Einsteinian-based enrichment program on participating students’ understanding of relevant science concepts and attitudes towards school science. Concepts related to Einstein’s theory of general relativity are usually not taught until students are in university denying younger children access to this powerful way of understanding space, time and gravity.

Considerable research has shown, however, that complex and abstract scientific ideas can be presented in age appropriate ways that result in measurable learning. The purpose of this study was to explore the impact of an enrichment programme on aspects of Einstein’s theory of general relativity on Year 6 children’s understanding of, and attitudes towards
this topic. Mixed methods of data collection included pre/post-instruction questionnaires and classroom observations through formative assessment.

The results indicated a statistically significant improvement in children’s conceptual understanding on the pre/post questionnaire with a small effect size. Analysis of individual items on the questionnaire indicated variable results regarding certain concepts. For example, after the enrichment programme students were better able to understand curved space, but little improvement was observed in their understanding of gravity on the Moon. The students drew triangles on balloons and traced the paths of parallel lines. They also explored the history of ideas about space, from Pythagoras to Einstein and learnt about observations of the curvature of space. At the Gravity Discovery Centre, the students had the opportunity to experience some of the physics concepts that had been discussed in class, through guided interaction with the exhibits and by performing experiments on the Leaning Tower of Gingin. Most students reported being interested in the programme of activities and engaged in the challenge of learning concepts related to Einstein’s physics.

Factors that may have contributed to the learning and engagement of students were the details provided by the professor, the classroom experiences, the excursion to the Gravity Discovery Centre and the role-play activity about the development of modern understandings of relativity. "Not only does learning require prior knowledge, appropriate motivation, and a combination of emotional, physical, and mental action; it also requires an appropriate context within which to express itself" (Falk & Dierking, 2000, p. 32). With reference to the Contextual Model of Learning (Falk & Dierking, 2000), a network of novel, real world activities that linked school students with the outreach centre in a collaboration with a local university, provided the interaction between the personal, sociocultural, and physical contexts over time, in order for students to make meaning of their experiences and find connections

**Case Study 2**

This study explored students' understanding of astronomical distances, size and scale. Students were involved in an activity that consisted of walking a scale-model of the solar system at the GDC. The Solar Walk is over a distance of one kilometre, beginning at the 'Sun' and following a path that leads to the other planets, their moons and the asteroid belt. The research design was a multiple case study, involving three classes of students on an excursion to the GDC. A mixed-methods approach involved the collection of qualitative
and quantitative data, including a solar system questionnaire and a post-exursion solar system diagram drawn by students, to document the changes in student understanding of the solar system.

The findings of this study indicated that participation in a Solar System Walk activity enabled students in Years 7 to 9 to comprehend concepts about the size and scale of the solar system. However, the student diagrams revealed that they more readily learned the relative sizes of the planets than the distances between the planets. The findings also suggested several implications for the teaching and learning of scale and size through models at a science centre. First, prior knowledge of the solar system is likely to be an important factor when students are learning about size and scale from a walk through a model of the solar system. Second, time spent at the science centre is likely to impact students' learning of size and scale. Finally, the kinaesthetic nature of the activity may support student learning. The results of this study showed that student participation in a solar system walk enhanced their understanding of size and scale, beyond their experiential knowledge.

These findings also suggest that within the scope of the ages of participating students, age is not a barrier to learning about the solar system; and that learning is closely dependent on opportunities, exposure, learning environment and teaching expertise. "Appropriately designed exhibitions are compelling learning tools, arguably one of the best educational mediums ever devised for facilitating concrete understanding of the world" (Falk & Dierking, 2000, p. 139).

Case Study 3
The third case study presented in Chapter 5 included 75 Year 8 students conducting gravity experiments including dropping water filled balloons of different masses from the top of the Leaning Tower of Gingin at the GDC. The balloon drops were timed, videoed and analysed by the students. Data collection for the case study included pre-exursion and post-exursion questionnaires and workbooks that quantitatively and qualitatively evaluated students' conceptions of gravity. Students were able to consider Galileo's thought experiments when he discussed free fall from the Leaning Tower of Pisa and how acceleration due to gravity is constant.
The findings indicated that participation in this activity enabled the participating Year 8 students to better comprehend gravity. Key aspects that may have contributed to the learning and engagement of students were the novelty and hands-on nature of activities on the Leaning Tower of Gingin and the use of analogies and discussion about key moments and scientists involved in the historical development of modern understandings of gravity.

Excursions are perhaps most supportive of learning when they are connected to school experiences via pre- and post-visit activities. The findings of this exploratory case study indicated that an enrichment programme including gravity experiments at the GDC could potentially enable Year 8 students to comprehend gravity concepts. Further, the enrichment programme was found to be engaging and enabled students to achieve learning objectives from the Science as a Human Endeavour and Science Inquiry Skills strands of the Australian Curriculum.

The aspects of the enrichment programme that may have contributed to student learning about gravity were the novelty and hands-on nature of activities at the Gravity Discovery Centre. The students were exposed to learning about gravity in ways not necessarily possible in the classroom. "However, the specifics of what is learned varies from person to person, depending upon the individual's unique personal and sociocultural contexts. This understanding can and must be applied to designing ever more effective assessment strategies" (, p. 174). The Contextual Model of Learning (Falk & Dierking, 2000) should also be considered in the design of learning experiences to better meet the needs of students.

Every student had the opportunity to participate in the experiments at the Leaning Tower of Gingin and many students overcame their initial fear of heights to climb to the top. The gravity experiments revealed misconceptions, including confusion between gravity and the Earth's magnetic field, and the effect of air resistance and acceleration due to gravity. Interestingly, these results matched global research findings that show students have alternative conceptions, indicating misconceptions about gravity are common in students around the world (Dostal, 2005; Feeley, 2007; Kavanagh & Sneider, 2007; Treagust & Smith, 1989).
Significance

This research added to previous studies, particularly with regard to science education in informal contexts, student learning through scientific investigation and student understanding of astronomical concepts.

The major significance of the research presented in this thesis is that each of the case studies presented in Chapters 3, 4 and 5 indicate that the educational programmes at the Gravity Discovery Centre under investigation made an educationally relevant and positive impact on participating students. This is the first educational research conducted at the GDC and it clearly indicates that the programmes make a worthwhile contribution to student learning. The findings from each of the case studies strongly support Braund and Reiss’ (2006) assertion that school science teaching should be complemented by out of school science learning activities offered by science centres, and museums such as those offered by the GDC. In particular, this research has demonstrated three areas of significance of the educational programmes at the GDC.

Firstly, this study showed that GDC programmes can provide students with access to rare material and to ‘big’ science (Braund & Reiss, 2006). It is difficult for teachers, especially those who are not science specialists, to teach science topics that are not mainstream for many reasons. Teachers are constrained by the school curriculum, by their own knowledge and the facilities available for use to teach rare or ‘big’ science topics. The GDC programmes enabled the participating teachers and schools to provide to their students, exciting, cutting edge curriculum on ‘big’ science topics, access to state of the art facilities and importantly the knowledge and expertise to allow the students to participate in learning activities related to topics that they were unlikely to have experienced in a formal school environment.

For example, the first case study presented in Chapter 3 on Year 6 children learning about Einsteinian physics resulted in a novel and engaging programme of teaching and learning that clearly enabled the students to learn aspects of Einsteinian physics, a ‘big’ science topic and content that would not normally have been taught to these students.

The collaboration between a local primary school and nearby university allowed the physics professor with content knowledge expertise to work with the primary school teacher to provide novel, real world activities for the students involved. The programme
was innovative and cutting edge and stimulated learning and positive attitudes in the participating students. It would be highly unlikely that such a programme would have been available to students without the Gravity Discovery Centre.

The second area of significance is that this study showed that the educational programmes at the GDC supported students’ conceptual learning of science. All three case studies presented in Chapters 3, 4 and 5 provided data that students’ understanding of relevant concepts improved significantly. This is quite a remarkable result given that it has been documented in the literature that it is difficult to demonstrate learning over the short period of most science centre programmes (Rennie, 2007). Case Study 1, presented in Chapter 3 was of an extended period of several weeks, and it is apparent that the learning that resulted during this case study was probably the most substantial.

The multiple case study presented in Chapter 4 on the Solar System Walk showed the importance of prior learning on students’ excursion experiences and the learning that happens as a result of the experience. The findings from the multiple case study also showed that the longer the student engagement with an outreach programme, the more likely they would learn from the experience. The gravity case study presented in Chapter 5, showed that the GDC activities may reveal and potentially address entrenched misconceptions, for example, that gravity is related to magnetism, or that heavy objects fall faster than lighter objects.

The third area of significance is that the research presented in this thesis showed that the educational programmes at the GDC may have a positive impact on student learning (Braund & Reiss, 2006). All three case studies provided data that supported positive student engagement with science content. There appeared to be multiple factors about the GDC activities that engaged the students, for example, the unusual and interesting content about Einstein and the innovative pedagogies employed in the first case study, such as involving students in a historical play about Einstein and other scientists. The novelty of conducting experiments from the Leaning Tower of Gingin in the third case study in Chapter 5 was a point of considerable excitement for the participating students. The outdoor venue and the kinaesthetic nature of the Solar System Walk activity appeared to motivate and engage many of the participating students from the multiple case study presented in Chapter 4, especially the Indigenous Australian students who seemed to benefit considerably from the learning experience.
Implications of findings

The first proposition that underpinned the research was that science education in Australia is facing several challenges that need to be addressed. Informal education, experiential learning taking place outside the classroom, can be a means to re-engage students’ interest in science. Science centres are valuable, but need to go beyond merely exhibitory, ‘doing’ and ‘tinkering’. They need to allow students to experiment, create, collate and test data.

In December 2015, the Australian Prime Minister, Malcolm Turnbull, announced a $1.1 billion investment in innovation to direct the future of Australia towards a knowledge economy through an ‘ideas boom’ (Australian Government, 2015). The package includes a $48 million investment in a science, technology, engineering, mathematics (STEM) literacy program and $14 million to encourage girls in the STEM sector. In particular, support will be provided to expand community engagement initiatives, including inspiring Australia and citizen science initiatives.

Consistent with these new initiatives in the UK and Australia, the second proposition underpinning the research presented in this doctoral thesis was that science centres have a responsibility to be key drivers of science education innovation. An opportunity exists for science centres to become innovators in the education space where educational norms are questioned and cutting edge curriculum and pedagogies are developed and evaluated. This study was limited to one particular science outreach centre, the GDC, but all science outreach centres have the potential to provide similar experiences to student participants. It is important that the nature of the activities provided are relevant and appropriate for today’s science students.

Astronomy piques students’ interest because they can observe the night sky. Australia is renowned in astronomy with projects such as the International Square Kilometre Array and the Australian International Gravitational Observatory. In relation to the third proposition, that astronomy is an ideal discipline for conducting research on engaging students to learn science, for an outreach centre to maximise student learning potential, there is a need for strong links between curriculum and schools.

A Model of Student Outreach Centre Engagement

The Falk and Dierking model (2000) was used as a foundation (see Chapter 2) for the development of the following Model of Student Outreach Centre Engagement (Figure 22).
This new model takes the three overlapping contexts described in the Falk and Dierking (2000) model and relates them to student learning. The contexts of the Falk and Dierking model (2000) specifically relate to student entry into the new model and to the final post-activities involving interaction with the students to ensure reinforcement of experiences. The Model of Student Outreach Centre Engagement (Figure 22) begins with students (to the left of the diagram) and follows them as they progress through the school/learning process involving the school system, curriculum, teachers and outreach centre experiences. Finally, post-outreach experiences are consolidated by the teacher in the classroom.

At each step in the process, the Model of Student Outreach Centre Engagement (Figure 22) aims to show the effects on the student using various colours and shading. Students (on the left of the diagram below) come to school with varying prior knowledge resulting from their sociocultural context (Falk & Dierking, 2000). Other influences (listed top left of the model) affecting students could include students’ experience, motivation and personal context (Falk & Dierking, 2000). The findings from Chapter 4 are an interesting example of these influences because even though School B’s students were younger and had less years of schooling, their teacher was passionate about astronomy and engaged the students in class, before visiting the GDC. The youngest students from School B had the highest mean score on the pre-Solar System Walk questionnaire (see Figure 7) and the oldest students from School D achieved the lowest mean score. There are many factors that may have contributed to this phenomenon including the expertise of the classroom teacher in School B, and the socio-educational status of the schools involved in the research.

These results are inconsistent with an expectation we might have that the older the students are, and the longer they have been at school, the more they will know about science concepts such as those related to the solar system. For the curriculum to build on student prior knowledge, teachers can use a combination of the school system, the curriculum and outreach centre experiences to accommodate individual learning needs of students. Students from School B (Chapter 4) were motivated prior to their visit to the GDC and this influenced what they learnt during the excursion, as well as their extended overnight stay to visit the observatory and view a lunar eclipse.

When considering the impact of the Solar System Walk activity on participating students' science knowledge about the size and scale of the solar system, the findings were interesting and challenging in that while the high performing students from School B had
the greatest gains, the students from the lowest performing School D outperformed the students from School C (Figures 7 & 8).

Though it is possible to use the latest virtual reality technologies to provide students with a simulation of the planets and the vast distances between them, the actual experience of walking through a scale-model of the solar system offered students a kinaesthetic and novel way to experience and visualise the system and its dimensions. It is possible that the kinaesthetic awareness that students can develop in activities such as the Solar System Walk, helps with student understanding of concepts such as size and scale. The GDC bush setting was especially engaging for the indigenous students from School D. These students demonstrated confidence and knowledge about the plants and animals that were observed during the Solar System Walk, as well as sharing their cultural awareness of the stars through their Dreamtime stories.

The model shows that interaction between teachers (top centre of the model) and outreach centres is essential in providing relevant experiences that will engage student interest in science. This collaborative link between teachers and outreach centres is in line with the literature regarding previous research findings (Anderson, Lucas & Ginns, 2003). In Chapter 3, a partnership between a local university and a nearby primary school allowed the development of an enrichment programme that provided an opportunity for the early exposure of Year 6 students to concepts related to Einsteinian physics. A major aim of the programme was to present the physics in a novel and stimulating way by initially providing the students with real world examples to which they could relate (see Table 4). The primary school teachers involved in this partnership were open to ‘interpret, modify and present the school system and curriculum to students'. This resulted in an opportunity to present a curriculum to Year 6 students that is probably unique in Western Australia. Ideally, student interest, knowledge and perceptions have been enhanced due to positive interaction with appropriate learning activities at the outreach centre.
A Model of Student Outreach Centre Engagement

Teachers
Interpret, modify and present the school system and curriculum to students
Provide a varied, stable and challenging classroom environment that can facilitate student learning
Engage with students on a personal level
Plan, participate and co-ordinate formal and informal learning activities to enhance student learning
Provide post-exposure activities to check and reinforce student understanding of concepts

Outreach Centre Experience
Planned formal experiences related to relevant topics of study that have been covered or will be covered in the near future (introduction or culmination to school-based learning)
Teachers and students engage with novel activities to enhance existing individual skills, knowledge and interest
Using ‘real-world’ activities, ideas are tested to ‘cement’ learning or to correct misconceptions
Interesting activities provide motivation that may increase student retention of learned concepts and may therefore lead to continued interest in science

Students (pre-outreach)
Varied experiences of the school system
Online and theoretical experience of curriculum concepts
Have knowledge, perceptions and misconceptions

Students (post-outreach)
Outreach experiences have provided ‘proof’ of ideas and have dispelled misconceptions
Students have a factual understanding of concepts and are able to retain the knowledge they have gained through their experiences
Post-exposure interaction with teachers has allowed reinforcement of appropriate concepts and understandings
Student interest, knowledge and perceptions have been enhanced due to positive interaction with appropriate learning activities

Curriculum
Externally controlled but integral to the school system
Aims to provide necessary learning according to ‘norms’ of prevailing educational theory
(one size fits all approach)

School System
Aims to present a multitude of experiences to students with highly varied skills, knowledge and interest to enable student interaction with society

Students
Present with a varied mix of
Experience
Prior Knowledge
Motivation
Socio Cultural Context
Personal Context

Other Influences

Figure 2: A model of student outreach centre engagement (adapted from Falk and Dietkong, 2000)
Outreach centres can play a key role in addressing misconceptions in science. Evidence presented in the case studies in this thesis indicate the students enjoyed the novel experience of being outside and walking in the bush. This captured their interest and ensured it was a memorable experience. Students were out of their comfort zone.

The findings from Case Study 1 revealed that young students could learn aspects of Einsteinian physics. The Gravity Discovery Centre can provide experiences that contribute to student learning and it provides a flexible learning environment, where the learning activities can be adjusted in response to changing knowledge. The GDC is also a working research facility and students had the opportunity to talk to researchers about their work in the search for gravitational waves, which have now been detected (see Chapter 1). The nature of the outreach centre means that the learning activities are not necessarily linked to the curriculum. For example, aspects of general relativity are not part of the Western Australian science curriculum, but students that visited the Gravity Discovery Centre were exposed to learning about Einstein and his theories.

As part of Case Study 2, students had the unique opportunity to walk a scale model of the solar system, which would not have been possible at their school. The results presented in Chapter 4 showed that students gained more with extended time spent at the outreach centre revealing that prolonged engagement increases student understanding. In addition, it was seen that pre-engagement (at school before excursion) and post-excursion (at school follow up) impacted students’ understanding of key concepts in relation to size and scale of the solar system and gravity. The data suggests that Indigenous students that participated in the Solar Walk particularly benefitted from the experiential nature of the learning in an Australian bush setting.

Aubusson, Griffin and Kearney (2012) outline how "school science needs to take more account of young people's out-of-school science learning experiences and develop greater consistency to synthesise learning across formal and informal domains" (p. 1130). Tal (2012) describes how "the balance between well-defined and ill-defined tasks, between scaffolding, structuring, and freedom, and between student-centered and task-centered activities is subtle" (p. 1119). Tal (2012) describes how "research is necessary especially in outdoor settings that are rarely studied, where diverse sensual experiences and physical challenges could affect students' engagement, and safety issues can determine the
arrangement of the field trip" (p. 1120). Climbing the Leaning Tower of Gingin was the most challenging and exciting part of the outreach centre visit for many of the students.

The findings of Case Study 3 revealed that experiments could aid conceptual change. This is especially relevant for outreach centre staff, to take into account students' prior knowledge. Students should be able to work collaboratively to find complex answers to questions. To enable students to capture the whole experience and have their own learning record, new technologies could be incorporated, such as the use of iPads, enabling students to have a camera available and smart codes could be used for additional reference material, such as video/sound and eBook access. Students could record and calculate instantly and then retrieve any information at home or school at a later time.

An outcome of the excursions has been an ongoing Einsteinian physics group now meeting with teachers to research the benefits and feasibility of revising school science with the early introduction of Einsteinian physics. The project involves developing deep understanding of the concepts of Einsteinian physics: special and general relativity and quantum physics, plus knowledge of international research in teaching Einsteinian physics. When this study began, researchers were searching for gravitational waves. This study was timely, as gravitational waves have now been found. It is imperative that education systems, especially physics curricula, are updated to reflect contemporary knowledge.

Outreach centres such as the GDC have an important role to play in promoting science education and provide an opportunity for students to learn science in exciting and innovative ways that are not possible in the classroom. There are, however, challenges and difficulties in accessing remote outreach centres and in the development of high quality educational materials to be used by students. Evaluation of the long-term impact of outreach centres such as the GDC in enhancing student attitudes to science and science knowledge is an important consideration for the future. Further research into how informal science learning at outreach centres can complement formal science learning at school will impact science teaching and learning in the future.
References


Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students’ identities, participation and aspirations in science, engineering, and medicine. *International Journal of Science Education, 45*(5), 564-582.


Australian primary school children’s understandings of genes and DNA. *Science and Education*, 23(2), 325-360. DOI: 10.1007/s11191-012-9491-3


Appendix A - Science Questionnaire

1. What does the word ‘speed’ mean to you?

.................................................................

.................................................................

.................................................................

2. The sum of the angles of a triangle add up to \( \text{__________}^\circ \). If we drew the above triangle on a balloon, would the angles add up to the same value? Please explain your answer.

.................................................................

.................................................................

.................................................................

3. What does the word ‘parallel’ mean?

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Do you think that parallel lines ever meet? Circle Yes or No. Please explain your answer.

.................................................................

.................................................................

.................................................................

4. What is a ‘Black Hole’?

.................................................................

.................................................................

.................................................................
5. If the Sun was a Black Hole, what would happen to the Earth?

Please explain your answer.

6. Does the Earth’s spinning motion cause gravity? Circle Yes or No.

7. The diagram below shows a person holding a ball standing at three different places on Earth. If the person drops the ball, gravity will make it fall. Which of the following diagrams best shows the direction the dropped ball will fall at the three different positions. Please circle the letter next to the correct diagram.

Please explain your answer.
8. A person stands on a three metre high platform. He drops a feather from one hand and a heavy hammer from his other hand at exactly the same time. What will happen to each object? Why?

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9. An astronaut is standing on a platform three metres above the surface of the Moon. He releases a feather from one hand and a heavy hammer from his other hand at exactly the same time. What will happen to each object? Why?

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10. Imagine an astronaut standing on the surface of the Moon, is holding a pen. If the pen is dropped, what will happen? Why?

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...............................................................
...............................................................

Gravity Discovery Centre
Solar System Walk

Walk to the Edge Of the Solar System
Today, you are about to simulate a walk through our Solar System. One average step equals approximately 4 million kilometres. The table below provides some information you can use to work out how far you will need to travel in order to reach each Solar System object.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Distance (millions of kilometres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>60</td>
<td>240</td>
</tr>
<tr>
<td>70</td>
<td>280</td>
</tr>
<tr>
<td>80</td>
<td>320</td>
</tr>
<tr>
<td>90</td>
<td>360</td>
</tr>
<tr>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>200</td>
<td>800</td>
</tr>
</tbody>
</table>
Introduction

The “Walk to the Edge of the Solar System” is a self-guided walk that simulates travelling through our Solar System. As you “fly” along the path, you will meet up with some of the many objects that make up our Solar System.

In this workbook, you will be able to perform some simple calculations and record details of your travels. Along the way, you will reach information stations for various objects within our Solar System. The table below gives approximate distances to each solar system object. Use these distances and the information at each object you reach, to fill in the appropriate sections in this workbook.

Complete the table below

<table>
<thead>
<tr>
<th>Object</th>
<th>Distance (Million Km’s)</th>
<th>Number of Steps (Predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Venus</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>228</td>
<td></td>
</tr>
<tr>
<td>The Asteroid Belt</td>
<td>Approx 400</td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td>778</td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td>1427</td>
<td></td>
</tr>
<tr>
<td>Uranus</td>
<td>2870</td>
<td></td>
</tr>
<tr>
<td>Neptune</td>
<td>4497</td>
<td></td>
</tr>
<tr>
<td>Pluto (no longer a planet)</td>
<td>5900</td>
<td></td>
</tr>
</tbody>
</table>
What Do You Already Know?

How many planets are there in our Solar System?

What are the names of the planets in our Solar System?

Which is the largest planet?

Which is the smallest planet?

Which two planets are closest to Earth?

Which planets have moons?

Which planets have rings?

Scientists have talked of setting up a base on a moon of Saturn. Why not on Saturn itself?

Which planet has a surface that is frozen solid?

Apart from planets and moons, what other objects are there in the Solar System?

Which planet moves through phases just like our moon?

Apart from the Sun, what is the name of our nearest star?
Solar System Diagram

Draw a diagram of the Sun and planets of our Solar System. Draw the planets to scale, in order of their distance from the Sun. Label each planet.

The Sun
Age: ..............................................................................................................................
Diameter: ..........................................................................................................................
Surface Temperature: ........................................................................................................
Number of Earth masses: ..................................................................................................
Made up of: ......................................................................................................................

Mercury
Distance from the Sun: .................................................................................................
Diameter: ..........................................................................................................................
Surface Temperature: ........................................................................................................
Length of Year (Earth years): ..........................................................................................
Length of Day (Earth Days): ............................................................................................
Number of Moons: ..........................................................................................................
Number of steps (Predicted): ..........................................................................................
Number of steps (Actual)
**Venus**
Distance from the Sun: .................................................................
Diameter: ...................................................................................
Surface Temperature: .....................................................................
Length of Year (Earth years): ...........................................................
Length of Day (Earth Days): ..............................................................
Number of Moons: .........................................................................
Number of steps (Predicted): ............................................................
Number of steps (Actual): ............................................................... 

**Earth**
Distance from the Sun: ....................................................................
Diameter: ....................................................................................
Surface Temperature: .....................................................................
Length of Year (Earth years): ............................................................
Length of Day (Earth Days): ..............................................................
Number of Moons: .........................................................................
Number of steps (Predicted): ............................................................
Number of steps (Actual): ............................................................... 

**Mars**
Distance from the Sun: .....................................................................
Diameter: ....................................................................................
Surface Temperature: .....................................................................
Length of Year (Earth years): ............................................................
Length of Day (Earth Days): ..............................................................
Number of Moons: .........................................................................
Number of steps (Predicted): ............................................................
Number of steps (Actual): ...............................................................
Asteroid Belt
What are asteroids?
Why are many asteroids shaped like potatoes?
How big is the largest asteroid?
What is the main difference between the two sections of the asteroid belt?
What are Trojan asteroids?

Jupiter
Distance from the Sun:
Diameter:
Surface Temperature:
Length of Year (Earth years):
Length of Day (Earth Days):
Number of Moons:
Number of steps (Predicted):
Number of steps (Actual):

Saturn
Distance from the Sun:
Diameter:
Surface Temperature:
Length of Year (Earth years):
Length of Day (Earth Days):
Number of Moons:
Number of steps (Predicted):
Number of steps (Actual):
### Uranus
Distance from the Sun: -----------------------------------------------
Diameter: -----------------------------------------------------------
Surface Temperature: -----------------------------------------------
Length of Year (Earth years): ---------------------------------------
Length of Day (Earth Days): -----------------------------------------
Number of Moons: --------------------------------------------------
Number of steps (Predicted): ----------------------------------------
Number of steps (Actual): -------------------------------------------

### Neptune
Distance from the Sun: -----------------------------------------------
Diameter: -----------------------------------------------------------
Surface Temperature: -----------------------------------------------
Length of Year (Earth years): ---------------------------------------
Length of Day (Earth Days): -----------------------------------------
Number of Moons: --------------------------------------------------
Number of steps (Predicted): ----------------------------------------
Number of steps (Actual): -------------------------------------------

### Pluto?
What happened to Pluto?
Why is Pluto no longer classed as a planet? ---------------------------

Distance from the Sun: -----------------------------------------------
Diameter: -----------------------------------------------------------
Surface Temperature: -----------------------------------------------
Length of Year (Earth years): ---------------------------------------
Length of Day (Earth Days): -----------------------------------------
Number of Moons: --------------------------------------------------
Number of steps (Predicted): ----------------------------------------
Number of steps (Actual): -------------------------------------------
Astronomical Distances

What have you discovered on this journey through the Solar System?

Proxima Centauri is our closest star (apart from the Sun). Using our scale of 1 step to 4 million kilometres, you would have to walk across Australia to travel there!

Light travels at 300,000 kilometres per second. It takes 8.5 minutes to reach Earth from the Sun (8.5 ‘light minutes’). Use this information to calculate how many light minutes each planet is from the Sun and write your answers in the table below.

<table>
<thead>
<tr>
<th>Object</th>
<th>Distance (Million Km’s)</th>
<th>Number of Light Minutes from the Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Venus</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
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</tr>
<tr>
<td>Neptune</td>
<td>4497</td>
<td></td>
</tr>
<tr>
<td>Pluto (no longer a planet)</td>
<td>5900</td>
<td></td>
</tr>
</tbody>
</table>

The distance light takes to travel in one year is called a ‘light year’ (about 9.5 million million kilometres). Light leaves our Sun and passes Earth 8.5 minutes later. It leaves our Solar System after 5.5 hours and does not encounter another thing for 4.3 years.

The fastest outward-bound spacecraft yet sent, Voyager 1, has covered 1/600th of a light-year in 30 years and is currently moving at 1/18,000th the speed of light. At this rate, a journey to Proxima Centauri would take 72,000 years.
(We need your name to cross match the pre-excursion survey with the post-excursion survey but we will not use it for any other purpose)
The following experiments will require some teamwork, as people will be on the ground and at the top of the tower. To ensure accurate timing, the person on the ground should control when objects are released using a countdown (“5, 4, 3, 2, 1, drop”). Please ensure the safety of all concerned by moving sensibly on the tower and only dropping objects when it is appropriate to do so.
Gravity Discovery Centre
Pre-excursion Survey
Gravity Discovery Centre Pre-exursion Survey

Date: ..........................

Name ...................................... School ..........................................

(We need your name to cross match with the post-survey but we will not use it for any other purpose)

Please circle your Year Group

8  9  10  11  12

Please circle your gender

Female            Male

1. In the picture below, children are fishing in different locations on the earth. There is no wind or water current to affect the line. Draw an arrow to show the direction the fishing line will travel as it is dropped into the water.
2. In the diagram above, why did you indicate the fishing line direction(s) that you have?

.......................................................... ..........................................................
.......................................................... ..........................................................
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.......................................................... ..........................................................

3. A person stands on a three metre high platform. He drops a feather from his right hand and a heavy hammer from his left hand at exactly the same time. What will happen to each object? Why?

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4. Between July 1969 and December 1972 there were six moon landings. Twelve astronauts spent a total of over 80 hours exploring the lunar surface. Why didn’t the astronauts float off the lunar surface?

.......................................................... ..........................................................
.......................................................... ..........................................................
.......................................................... ..........................................................
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5. Imagine an astronaut standing on the surface of the moon, is holding a pen. If the pen is dropped, what will happen? Why? Compare this answer to how you answered the question above.

.......................................................... ..........................................................
.......................................................... ..........................................................
.......................................................... ..........................................................
.......................................................... ..........................................................

6. An astronaut is standing on a platform three metres above the surface of the moon. He releases a feather from his left hand and a heavy hammer from his right hand at exactly the same time. What will happen to each object? Why?

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.......................................................... ..........................................................
.......................................................... ..........................................................
.......................................................... ..........................................................

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Gravity Discovery Centre

Leaning Tower of Gingin Experiments
Experiment 1 - Different coloured water balloons of same size/weight

Choose two balloons, each of a different colour. Answer questions 1 to 4 and then fill the balloons with the same amount of water. At the top of the tower ensure that the balloons are dropped at the same time (Perhaps one person can drop both balloons). Record your results in the space provided.

Colours chosen .................................................................

1. How long do you think it will take for the first balloon to hit the ground?

........................................................................................................

........................................................................................................

2. Why did you choose this length of time?

........................................................................................................

........................................................................................................

3. Which balloon will hit the ground first?

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........................................................................................................

4. Why did you pick this balloon?

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........................................................................................................

Do the experiment now!

5. Describe what actually happened

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6. How long did it take before a balloon hit the ground?

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7. Is this what you predicted? Please explain why/why not.

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........................................................................................................
Experiment 2 - Different coloured water balloons of different size/weight

Choose two balloons, each of a different colour. Answer questions 1 to 4 and then fill the balloons with different amounts of water. At the top of the tower ensure that the balloons are dropped at the same time (Perhaps one person can drop both balloons). Record your results in the space provided.

Colours chosen ...............................................................

1. How long do you think it will take for the first balloon to hit the ground?
...........................................................................................................
...........................................................................................................

2. Why did you choose this length of time?
...........................................................................................................
...........................................................................................................

3. Which balloon will hit the ground first?
...........................................................................................................
...........................................................................................................

4. Why did you pick this balloon to hit the ground first?
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...........................................................................................................
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...........................................................................................................

Do the experiment now!

5. Describe what actually happened
...........................................................................................................
...........................................................................................................
...........................................................................................................
...........................................................................................................
...........................................................................................................

6. How long did it take before a balloon hit the ground?
...........................................................................................................

7. Is this what you predicted? Please explain why/why not.
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...........................................................................................................
...........................................................................................................
Experiment 3 - Cup of water

Select a Styrofoam cup from the experiment table. Answer questions 1 to 3. Place one finger over the hole in the bottom of the cup and then half-fill the cup with water. At the top of the tower ensure that the cup is dropped in an upright position. Record your results in the space provided.

1. How long do you think it will take for the cup to hit the ground?

2. Why did you choose this length of time?

3. What do you think will happen to the water in the cup? Explain why?

Do the experiment now!

4. Describe what actually happened

5. How long did it take before the cup hit the ground?

6. Is this what you predicted? Please explain why/why not.
Gravity Discovery Centre Post-exursion Survey

Date: 

Name ........................................ School ..........................................................

(We need your name to cross match with the pre-survey but we will not use it for any other purpose)

Please circle your Year Group

8 9 10 11 12

Please indicate your gender

Female Male

1. Three new things I have learnt today are?
   a..............................................................................................................................
   ..............................................................................................................................
   b..............................................................................................................................
   ..............................................................................................................................
   c..............................................................................................................................
   ..............................................................................................................................

2. Two things I want to know more about?
   a..............................................................................................................................
   ..............................................................................................................................
   b..............................................................................................................................
   ..............................................................................................................................

3. What did you find difficult?
   ..............................................................................................................................
   ..............................................................................................................................

4. What did you find confusing?
   ..............................................................................................................................
   ..............................................................................................................................

5. The most enjoyable part of this excursion was:
   ..............................................................................................................................
   ..............................................................................................................................
   ..............................................................................................................................
Let’s revisit your pre-excursion survey questions.

Based on any new information you have gained from today’s excursion, please make any changes to your answers to the pre-excursion survey questions.

1. In the picture below, children are fishing in different locations on the earth. There is no wind or water current to affect the line. Draw an arrow to show the direction the fishing line will travel as it is dropped into the water.
2. In the diagram above, why did you indicate the fishing line direction(s) that you have?

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3. A person stands on a three metre high platform. He drops a feather from his right hand and a heavy hammer from his left hand at exactly the same time. What will happen to each object? Why?
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4. Between July 1969 and December 1972 there were six moon landings. Twelve astronauts spent a total of over 80 hours exploring the lunar surface. Why didn’t the astronauts float off the lunar surface?
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5. Imagine an astronaut standing on the surface of the moon, is holding a pen. If the pen is dropped, what will happen? Why? Compare this answer to how you answered the question above.
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6. An astronaut is standing on a platform three metres above the surface of the moon. He releases a feather from his left hand and a heavy hammer from his right hand at exactly the same time. What will happen to each object? Why?
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Do you have any other comments you would like to make about your visit to the Gravity Discovery Centre?
## Appendix D – Chapter 4: Solar Student Coding Sheet

<table>
<thead>
<tr>
<th>School/Group</th>
<th>StudentID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>No attempt</th>
<th>Don’t know</th>
<th>Attempt Incorrect</th>
<th>Attempt mostly correct</th>
<th>Attempt correct</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance Calculation</strong></td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>General knowledge Questions</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Solar System Diagram</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall Diagram</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Number of Planets</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Planets in order</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Planets to scale</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Planet Descriptions from stations</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Astronomical distances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>What have you discovered?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Light minute calculations</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Other comments on paper</strong></td>
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## Appendix E – Chapter 4: Solar System Questionnaire - Coding Sheet

<table>
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<tr>
<th>Question</th>
<th>No answer</th>
<th>Incorrect</th>
<th>Some correct</th>
<th>Nearly correct</th>
<th>Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many planets are in our Solar System?</td>
<td></td>
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</tr>
<tr>
<td>What are the names of the planets in our Solar System?</td>
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</tr>
<tr>
<td>Which is the largest planet?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which is the smallest planet?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which two planets are closest to Earth?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which planets have moons?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which planets have rings?</td>
<td></td>
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</tr>
<tr>
<td>Scientists have talked of setting up a base on a moon of Saturn. Why not on Saturn itself?</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Which planet has a surface that is frozen solid?</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Apart from planets and moons, what other objects are there in the Solar System?</td>
<td></td>
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</tr>
<tr>
<td>Which planet moves through phases just like our Moon?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apart from the Sun, what is the name of our nearest star?</td>
<td></td>
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</tr>
</tbody>
</table>

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207
Appendix F – Chapter 4: Solar System Diagram - Coding Examples

School A

A7 correct/planet features

Comment

- Stereotype sun
- correct number of planets
- planets named
- correct order
- OK planet size
- Earth, Jupiter planet features shown
- rings on Saturn, Uranus
- Jupiter largest planet, Mercury smallest
- asteroid belt

<table>
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School A

A8

Comment
- incorrect number of planets
- planets named
- incorrect order
- incorrect planet size
- no planet features shown
- rings on Saturn
- Mercury smallest

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School A

A22

Comment

- Stereotype sun
- correct number of planets
- planets named (spellers)
- correct order
- incorrect planet size
- Jupiter planet features shown
- rings on Saturn
- Jupiter largest planet, Mercury smallest
- asteroid belt
- orbits indicated

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Comment

- Stereotype sun
- correct number of planets
- planet names indicated (Initial)
- correct order
- incorrect planet size
- Earth, Mars planet features shown
- rings on Jupiter, Saturn, Neptune
- Jupiter largest planet, Mercury smallest
- asteroid belt
- Stars indicated within solar system

<table>
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<tbody>
<tr>
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School A

A20

Comment
- correct number of planets
- planets named
- correct order (numeric)
- incorrect planet size
- no planet features shown
- rings on Saturn

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School B

R1

Comment

- correct number of planets
- planets are correctly named
- planets are in correct order
- a good effort at differentiating planet size
- planet features shown
- rings on Saturn, Uranus
- Jupiter largest planet, Mercury smallest

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<tr>
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## Appendix G – Chapter 5: Gravity Student Coding Sheet

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<th>StudentID</th>
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<tbody>
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<table>
<thead>
<tr>
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### Pre-exursion

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### Points of interest

### Reasons for diagram

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<table>
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### Feather versus hammer (Moon)

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