Res Sci Educ (2014) 44:363–388
DOI 10.1007/s11165-013-9386-6

An Exploratory Study to Investigate the Impact of an Enrichment Program on Aspects of Einsteinian Physics on Year 6 Students

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Published online: 31 October 2013

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 paper was to explore the impact of an enrichment program on aspects of Einsteinian physics on year 6 (10 and 11 years 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 program. 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. The majority of students reported being interested and engaged in the program of activities and did not feel that they were too young to learn concepts related to Einstein's physics.

This manuscript was submitted to *Research in Science Education* (RISE), September 2013.

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Keywords Primary science · Curved space · Einstein's physics · Conceptual understanding · Attitudes · General relativity

Introduction

Despite Einstein's theories of general and special relativity now being known and celebrated by the science community for nearly 100 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 and 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 California public schools (California Department of Education 2000) 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" (p. 40). 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" (p. 41). Moreover, relativity is not mentioned anywhere in the California state standards 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 paper 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 et al. 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 paper 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 and Pella 1972), it is surprising that a search of the literature revealed very little research conducted in relation to school students' understanding of Einstein's concepts.

Purpose and Research Questions

The purpose of the research presented in this paper was to explore the impact of an enrichment program based on Einsteinian physics on a class of year 6 students' science knowledge and attitudes towards science. The enrichment program 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 program are provided later in the paper). The research was guided by the following two research questions:

1. What impact did the enrichment program 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 program 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 paper. 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 paper. 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 and 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 and 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 p. 39) 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.

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 paper begins to address this dearth of information by exploring the impact on year 6 students of a specially designed enrichment program on Einsteinian physics including the Theory of General Relativity. One important tool used by the professor in the program 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 and 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 and Kumar 2010; Baily and 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 (e.g. 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 and 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 and 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 and 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 and 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 et al. (2010, p. 337) reported that some factors that influence attitudes include "gender, support, teacher effectiveness, curricula, and the perceived difficulty of science". These findings were based on results over 3 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 program, such as the one that is the focus of this research, that addresses the novel ideas underpinning Einsteinian 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 and 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 program 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 are provided. This section concludes with more detailed information about the enrichment program 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
5. Communicating (ACARA 2012).

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). Following consultation, the senior secondary Australian Curriculum materials are in the final stages of development prior to publication. With public submissions now closed, it will be interesting to see how much modern physics is included in the new course.

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 and 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 80 km 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 programs 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 paper. 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 facilities at the GDC include a large public astronomy centre (Gingin Observatory), the robotic Zadko telescope, a 20-m pendulum tower, a 1-km scale model of the Solar System, the Leaning Tower of Gingin (a 45-m steel tower for students to do free fall experiments) and research laboratories (Venville et al. 2012).

The School Case Study

The program was initially conceived by a university physics professor who approached a year 6 classroom teacher in a local primary school and asked if he would be willing to allow his class to collaborate on the research project. 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 weeks) 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 programs at the school include environmental projects such as rural tree planting, a vegetable garden, solar energy generation and a chicken run.

The Enrichment Program

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

This enrichment program 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 program 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 program 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 program 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 1 provides an overview of the content and pedagogical approaches used during the 6-week period. Each weekly lesson took between 60 to 90 min 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 program 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 (Table 1).

Phase 2: Excursion to the Gravity Discovery Centre

The second phase of the enrichment program 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

Table 1 An overview of the classroom lessons conducted by the visiting physics professor

Week	Topic	Content	Pedagogical approach
1	Space–time diagrams	Your journey to school	Group discovery of answers: students contributing their ideas, joint work on a whiteboard.
		Falling objects	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	Group discovery of answers
		Speeds that connect space and time	Arbitrariness of human-invented units
		What speed do we use?	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	Storytelling using PowerPoint: people and their discoveries
		The story of Pi	Progressive discoveries over millennia and across cultures
		The story of Newton and Einstein	Proof and disproof of ideas
		Curved space	
4	Curved space geometry with balloons	Making "straight lines"[a]	Experiments in geometry
		Do parallel lines ever meet?	Concept of a straight line
		"The sum of the angles in a triangle is 180 degrees": true or false?	Geometry on balloons
5	Fun with black holes	Idea of a black hole	Classroom discussion and videos
		Movies of black holes	Black holes: what are they, where are they?
		Balloon black holes	Videos of black holes and Stephen Hawking
6	What is gravity?	What would it be like to live amongst the asteroids?	Classroom group discussion, videos and PowerPoint animations
		Matter always tries to follow straight lines in space-time	Einstein versus Newton
		Gravity is the force you need to bend the lines	Einstein's idea of gravity
7	*Free Float* play	Reinforcement of learning	Gravity Discovery Centre excursion
			Classroom play: *Free Float*

[a] Straight lines means shortest path, a geodesic

Table 2 The program of activities at the GDC

Exhibit	Description/activity
Lycra space and curved space landscapes	Experiments with curved space landscapes and multiple spheres representing the relative movements of astronomical bodies in space
Representing curved space	
The Time Coil	Use your ears to hear yourself in the past
The speed of sound in air	Comparison between the speed of sound and the speed of light
Time travelling into your past	
Navigating the curves of space	Using "black hole" exhibits to study the effects on orbiting objects
Toy cars on the black hole	
Floaters and fallers at the Leaning Tower of Gingin	Balloon drops from the Leaning Tower of Gingin
Free fall water balloons from the Leaning Tower of Gingin	Space–time plots for a falling balloon
Space–time diagrams for the water balloons	
Curved space whiteboard	Does the sum of the angles of a triangle always equal 180°
Curved space geometry with protractors	
Our planet is a time machine	Floating free vs free falling
	Space–time diagrams
Full Dome Projection in the Cosmology Gallery	Movie: Black Holes

by performing experiments. Table 2 provides an overview of the program that the students participated in at the GDC.

Phase 3: Free Float, a Scripted Play

The year 6 students who participated in this 6-week enrichment program performed a scripted play, *Free Float*, at the School of Physics, in the local university. This was the culmination of the program, 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 program on Einsteinian physics presented in the year 6 class in one primary school (Yin 2009). In order to explore the impact of the enrichment program 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 program is a member of the research team, different researchers observed the classroom lessons during the in-class phase of the enrichment program 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 paper because it did not contribute to answering the research questions.
2. Interview with the physics professor

   An open-ended interview was conducted with the physics professor after he had taught the enrichment program. The purpose of the interview was to ascertain his goals for the program, to clarify the content and pedagogical activities used during the program 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 1 and 2 for a summary).
3. Student pre/post-questionnaire

   The researchers developed a draft student questionnaire specifically for this program. 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 program 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). 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 program (Table 1). 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, one 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. We point out that the questionnaire did not cover all of the topics in the enrichment program because we developed the questionnaire prior to the delivery of the enrichment program and focused on what we know about students' misconceptions from the literature (Treagust and Smith 1989; Dostal 2005; Feeley 2007) and the new Australian Curriculum for year 7. Student responses to the questions were marked as in the following scheme 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 acknowledge 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 program.

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 program 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 and 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 this paper. 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 program were selected as quotations to include in the findings to exemplify the quantitative results.

Students' attitudes towards participation in the enrichment program were ascertained after completion of the program. First, students were asked to identify which parts of the program they found most enjoyable. The following questions also were 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 program. 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 Fig. 1 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 program, 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 (Fig. 1). The paired-samples *t*-test indicated that there was a statistically significant increase in science quiz 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

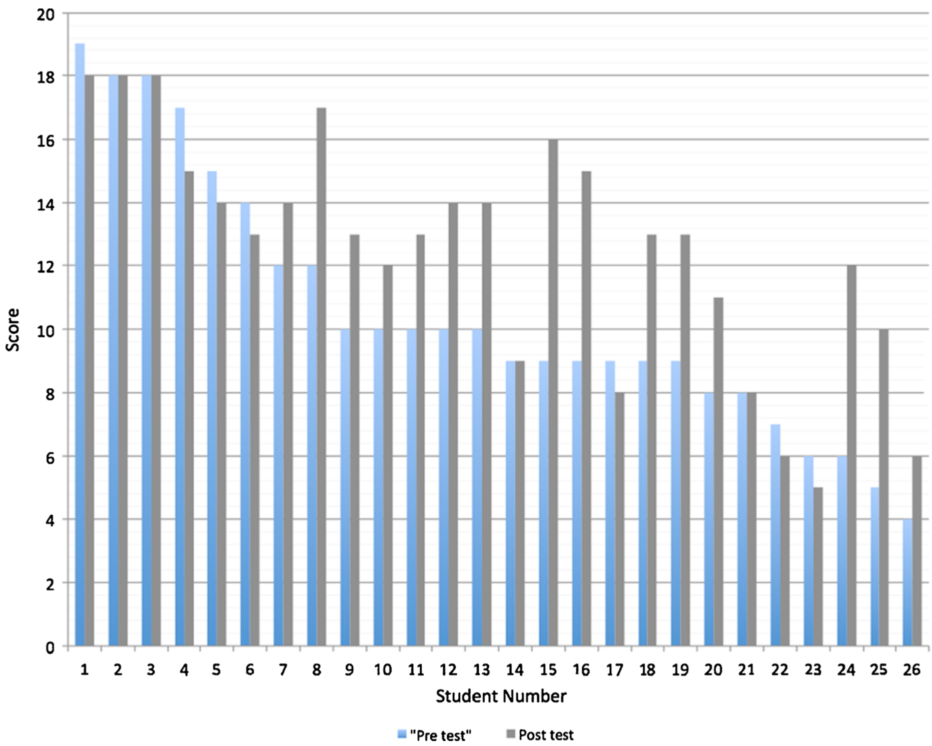

Fig. 1 The pre/post-questionnaire results from the 26 year 6 participants in the enrichment program

science quiz 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 1 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 program (a “ceiling effect”). This indicates that either the enrichment program 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 program. 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 program, 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 9) or “No, because it could be a different size” (student 25). 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 5) and “No because the angles are changed by the curve on the balloons [sic] surface” (student 1).

On the post-instruction questionnaires, 20 of the children said that the angles of a triangle add up to 180°, 5 said 90° and 1 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 24); “No because they’re different shapes” (student 12)). 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 20) 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 1). Provided below are examples of pre- and post-questionnaire explanations from a variety of students to question 2.

Student 4 (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 8 (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 15 (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 21 (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 3).

Questions 4 and 5 concerned black holes (see Appendix 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 spagetifies [sic] everything that gets too close, including light" (student 9).

On the post-instruction questionnaires, only one student responded “I don’t know” to questions 4 and 5 (student 24). 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 11). 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 4 (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 6 (pre-instruction score 18; post-instruction score 18 [no change]).

Table 3 Summary of student responses to question 2 of science quiz about the sum of the angles of a triangle (see Appendix)

Student responses	Pre-instruction	Post-instruction
Inconsistent	10	3
Partially consistent	13	10
Consistent	3	13

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 20 (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 21 (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 4).

In further analysing the pre/post-questionnaires, responses to question 7 relating to gravity on Earth (see appendix) showed that in pre-instruction, 23 out of 26 students chose the correct answer (D). Out of the three 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 17) did not choose the correct answer pre- or post-instruction (Table 5).

Question 9 relating to gravity on the Moon, adapted from Feeley (2007), has an astronaut dropping a feather and a hammer (see Appendix 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 program. As a result of the enrichment program, 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.

Table 4 Summary of student responses to questions 4 and 5 of science quiz about black holes (see Appendix)

Student responses	Pre-instruction	Post-instruction
Unsure	9	1
Inconsistent	14	0
Partially consistent	0	16
Consistent	3	9

Table 5 Summary of student responses to question 7 of science quiz about gravity on Earth (see Appendix)

Student responses	Pre-instruction	Post-instruction
Inconsistent	3	1
Consistent	23	25

Provided below are examples of pre and post-questionnaire explanations to question 9.

Student 15 (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 22 (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 6).

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

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 program 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 and 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 will cover these concepts explicitly for the first time at the year 7 level.

Students' Attitudes Towards the Enrichment Program (RQ 2)

Students were asked which activities in the program 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 2 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.

Table 6 Summary of student responses to question 9 of science quiz about gravity on the Moon (see Appendix)

Student responses	Pre-instruction	Post-instruction
Unsure	3	0
Inconsistent	13	13
Consistent	10	13

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

Mr B made it fun. (Student 3)
It was fun as well as educational. (Student 15)
I learnt a year's worth of information. (Student 24)

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–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 3 provides the students' responses to the post-instruction 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 (Fig. 3). 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 13)
It was very easy to get his ideas because of the way they were explained. (Student 25)
I find his stuff interesting. (Student 11)
Undecided
Some of his ideas I could understand, others baffled me. (Student 18)
I didn't really get it. (Student 22)
Some I can understand and some not. (Student 19)
Yes, too young
It can be confusing at times. (Student 26)
Some stuff is very complicated. (Student 17)

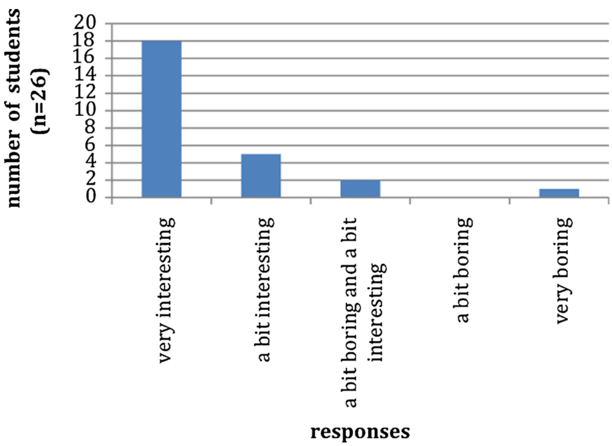

Fig. 2 Students' responses to the post-instruction item "Was it interesting to find out about space and time and gravity?"

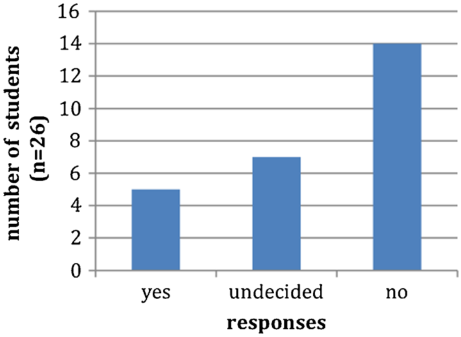

Fig. 3 Students' responses to the post-instruction questionnaire item "Do you feel you are too young to understand Einstein's ideas?"

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), but the data collection did not extend to ascertaining the activities and learning of individual students at the GDC. These findings are encouraging because many of the participating children were able to 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 program 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 and Skamp 2008). The positive responses from the majority of 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 et al. 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 5 is that they focussed on factual knowledge rather than allowing students to demonstrate their conceptual understanding.

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 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 and 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 and 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 program achieved learning objectives in the Science as a Human Endeavour strand and the Science Inquiry Skills strand of the new national 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 program 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 a number of limitations with regard to the approach used, and we explicitly outline these limitations here so that readers may interpret our 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 paper and we felt that detailed analysis would not enrich the findings. In our subsequent analysis of these data, we have not found any results that contradict the findings presented above, although we feel that the video data do provide more insight into the students' attitudes and we will present these findings in a later paper. We have already mentioned the problems aligning the questionnaire directly with the content presented in the enrichment program; however, we feel this problem is likely to have resulted in an underestimation of the impact of the enrichment program on the students' understanding of relevant concepts. Finally, we acknowledge the limitations with regard to the data collected on student attitudes. 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 program as we have assumed. Notwithstanding these limitations, we are encouraged by the findings of this exploratory case study that indicate the potential for teaching Einsteinian physics to upper primary school aged children.

Conclusion

The findings of this exploratory case study indicated that an enrichment program on Einsteinian physics could potentially enable year 6 children to comprehend relativity related concepts. Further, the enrichment program was found to be engaging for the majority of 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 program 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.

Acknowledgments This research was supported by a grant from the Australian Research Council, the Gravity Discovery Centre and the Graham (Polly) Farmer Foundation (LP100100640). The views expressed are those of the authors and not of the sponsor organisations. We would like to acknowledge the contribution of all the project team members and, in particular, the teacher and students who participated in this program on a voluntary basis.

Appendix

Science Quiz

1. What does the word *'speed'* mean to you?

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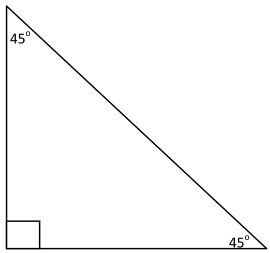


2. The sum of the angles of a triangle add up to _____________°. If we drew the above triangle on a balloon, would the angles add up to the same value?
   Please explain your answer.

....

....

3. What does the word 'parallel' mean?

....

....

   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?

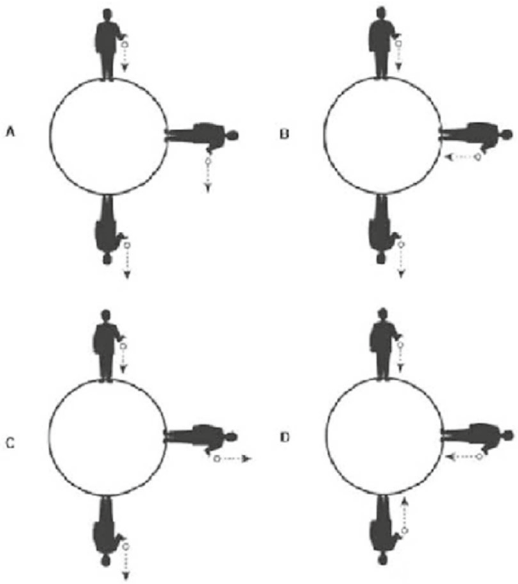
....

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?

....

....

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?

....

....

....

....

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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