Design Principles, Implementation and Evaluation for Inquiry-Based Astronomy: An Investigation of the Issues Surrounding Sufficient Teacher Professional Development in Large-Scale Astronomical Initiatives

Michael T. Fitzgerald

BA., BSc.(Hons), MEd.

A thesis submitted to Macquarie University in accordance with the requirements of the degree of Doctor of Philosophy

Department of Physics and Astronomy

Faculty of Science

Macquarie University

NSW 2109, Australia

TABLE OF CONTENTS

Statement of Candidate *1*

Acknowledgements *2*

Abstract *3*

Statements of Co-Authors *5*

Part A: Introduction, Context and Background *17*

1. ***Students Perceptions of High School Science: What has Changed Over the Last Decade?***
   Danaia L., Fitzgerald, M., McKinnon, D. *23*
   Research in Science Education, 2013, Vol. 43, Issue 4, 1501

2. **A Review of High School Astronomy Student Research Projects over the last 20 years.**
   Fitzgerald, M., Hollow, R., Rebull, L., Danaia, L., McKinnon, D. *39*
   Publications of the Astronomical Society of Australia, 31, e037

3. **Space to Grow: LCOGT.net and Improving Science Engagement in Schools.**
   Danaia, L., McKinnon,D., Parker, Q., Fitzgerald, M., Stenning, P. *63*
   Astronomy Education Review, 11, 010106, 2012

Part B: Teacher Demographics, Blocking Factors, Perceptions and Change. 77

4. **Blocking Factors Inhibiting Inquiry-based Science Teaching and Potential Solutions: Perceptions of Positively-inclined Early Adopter Science Teachers.**
   Fitzgerald, M., Danaia, L., McKinnon, D. *79*
5. **Differences in perception of high school science: Students and Teachers views.**
   Fitzgerald, M., Danaia, L., McKinnon, D. *107*

Part C: Educational Design and Emerging Student Achievement. *133*

6. **Inquiry-based educational design for large-scale high school astronomy projects using real telescopes.**
   Fitzgerald, M., McKinnon, D., Danaia, L. *135*
7. **A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science.**
   Fitzgerald, M., Danaia, L., McKinnon, D., Deehan, J. *167*

8. **RR Lyrae Stars in the Globular Cluster NGC6101**
Fitzgerald, M., Criss, J., Lukaszewicz, T., Frew, D., Catelan, M., Woodward, Danaia, L., McKinnon, D.
193
Publications of the Astronomical Society of Australia, 2012, 29, 1, 72

9. **Photometric and Proper Motion Study of Neglected Open Cluster NGC2215**
Fitzgerald, M., Inwood, L., McKinnon, D., Dias, W., Sacchi, M., Scott, B., Zolinkski, M., Danaia, L., Edwards, R.
199

Part D: Conclusion and Recommendations *209*

Appendix: Human Ethics Clearance Documentation *215*

Statement of Candidate

I certify that the work in this thesis entitled “Design Principles, Implementation and Evaluation for Inquiry-Based Astronomy: An Investigation of the Issues Surrounding Sufficient Teacher Professional Development in Large-Scale Astronomical Initiatives” has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis.

The research presented in this thesis was approved by Charles Sturt University Ethics Review Committee, reference number: CSU 2009/025 on 7th February 2011.

MFitzgerald

Michael Fitzgerald (40224643)

2nd of February 2015

ACKNOWLEDGEMENTS

Firstly, thanks must be given to my main supervisors, Associate Professor David McKinnon and Dr Lena Danaia at Charles Sturt University, Bathurst for far too many factors that can fit into one thesis acknowledgement section but in general for the support, advice, trust and encouragement throughout. Thanks to Quentin Parker and the Department of Physics and Astronomy for giving me the opportunity to be involved in such an important project and the financial support to do so. Appreciation also is given for Mark Wardle for his supervision and wise advice at Macquarie in the second-half of the candidature.

David Frew deserves thanks for numerous contributions, not least significant conversations on observational astrophysics of stars while they are alive but also during their death throes. Carolyn Dow also helped out significantly undertaking a lot of organisational and administrative work in support of teacher visits and professional development workshop days for which I am indebted. Rob Hollow is noted for guidance and support on the long journey to discovery of similar astronomy education projects, many of which he was involved with himself.

Thank you to all of the administrators, teachers and students involved in the Space to Grow project whose contributions made this PhD possible. To single out individual teachers for the many dimensions of thanks necessary would definitely exceed the allowed word count for a PhD Thesis. Not least among this list though would be Paul Stenning and Anne Marceau for their staunch support of the project.

Appreciation is also held for the support provided by Las Cumbres Global Telescope Network, in particular Wayne Rosing, for their telescope time in support of this project as well as their accommodation for a week in Santa Barbara during my USA conference travel. Thanks also to the countless people who made my conference, talk and visit tour to the USA in the middle of 2013 able to happen.

My fellow comrades in the AAAstro room. Arik, Borja, Ivan, Andreas and Travis for helping me keep hydrated and laughing at times of need (or anytime that an excuse could be wrangled). Niyas for helping me keep my undefeated record (0-0) at Go and being the best deskmate that ever was. Stacey for tutoring me in the delights of American candy, Dimitri for being ninja caretaker of both rooms and code (although little trust I will put in him with cookies). Elaina for helping me with 2df but moreso for mandatory munchkin moments. Iza for never letting me fall prey to serious periogi addiction. And of course thanks to the whole host of other co-habitors of the astronomy phd room over the years.

Unique and unpredictable thanks to Jarrah Kingshott-Small for the excessive use, and company upon, the stress-relieving giant trampoline, as well as his parents, Cath and Matt Kingshott-Small, for being so accommodating (and buying him such an awesome Christmas present), during the final writing stages of the PhD. Thanks to Fin McCarthy for Robot Heart. Thanks to Theresa Rowe for persistently reminding me how close I was continually until this last moment composing the acknowledgements. And finally, thanks to my parents, Jim and Aileen Fitzgerald, whose numerous levels of support and encouragement have allowed me to actually get to this point at all.

Design Principles, Implementation and Evaluation for Inquiry-Based Astronomy: An Investigation of the Issues Surrounding Sufficient Teacher Professional Development in Large-Scale Astronomical Initiatives

ABSTRACT

Astronomy, as a human endeavour, allows us to explore and understand our place in the universe, both in time as well as in space. This field of practice forms an indispensable component of any endeavour to understand the nature and purpose of our existence. Astronomy also presents us with access to seemingly boundless aesthetic beauty as well as the potential for a lot of fun! While this is the case, these apparently appealing aspects of astronomy are being lost on the majority people in the modern developed world. Interest in science in general as a vocation as well as a general interest area is experiencing decline at all levels of education. This is occurring despite the necessity of science in the broad functioning of our societies, the necessity of scientific skills in most modern occupations and the continual calls for, and attempts at, reform of the nature of science education.

This thesis is situated in the context of an Australian high school level astronomy intervention project. This project focuses on enabling students to undertake real science with professional grade 2-metre class telescopes in order to provide an authentic experience of the nature, beauty and fun of astronomy. It was intended that this approach would positively affect students' perceptions of astronomy and science as well as what influences their subject choice in later years. The thesis takes three separate but interlinking pathways towards understanding the problems and issues involved with this endeavour as well as identifying potential solutions.

The first pathway starts by placing the intervention within a historical context. The history of student perceptions of high school science over time are explored showing that little has changed to shift student perceptions over the last decade. In turn, the intervention project itself is compared to other similar astronomy education projects. It is shown that while there are many differences amongst these projects, there are a number of common themes that can make or break such interventions and which must be addressed if success is the aim. The intervention project itself is then outlined in detail in a summary paper.

The second pathway explores the nature of the context within which the project operates and in which the teacher is the key actor. It is they who eventually direct what occurs in the classroom and hence what impacts student activity, motivation and learning. While this is the case, their autonomy is restricted by multiple factors which serve to block true inquiry-based learning in the classroom. Through semi-structured interviews with the teachers involved, the perceptions of these blocking factors are explored. Respondents claimed issues such as the lack of time, curriculum limitations, inadequate or poor-quality training and professional learning, poor resources and lack of supervisor support, amongst others, were identified as key factors.

The very stark differences in perception between teachers and students are then explored in a quantitative manner. Globally, teachers see their classroom actions and approaches in a much more positive light than their students do. Furthermore, it is shown that there is little relationship between the students' perceptions of their classrooms and their individual teacher's perception. This leads us to make the important qualifier presented in this thesis that in any endeavour accurate and effective project evaluation must be undertaken at the level of the student.

In the third pathway, the educational design principles and methodology used to guide the development of materials are outlined and investigated. This educational design goes beyond simple curriculum material creation to one which incorporates solutions to known, potentially tractable, issues identified in the previous research. Turning the traditional design approach on its head, student learning is perceived as having a lower priority than other concerns. Learning is theorised to emerge naturally, given both sufficient quality in the materials and in the teaching, when blocking factors have been removed. The design is also flexible and extensible, able to be presented concisely within a limited time span or able to take an advanced student all the way to a scientific publication. It is also continually adaptable and updated based on actively solicited feedback from teachers and students. The design also draws on multiple well-tested inquiry-based pedagogies as well as focusing on backward mapping from firmly defined goals.

The evaluation results of student gains, both cognitive and affective, who have experienced the implementation of this design is then examined. It is clearly shown that this educational design can have a dramatic impact on student learning and on their perceptions of science. It is also apparent from these data that the impact is heavily dependent upon the teacher and their *actual* implementation in the classroom. For those who have approximated the intended implementation, the gains in both dimensions tended to be much higher than those who did not. Finally, two examples of work are presented that have taken students to present their work for scientific publication using this design, a study of RR Lyrae variables in the Globular Cluster NGC6101 and a study of the previously neglected open cluster, NGC2215.

One of the major outcomes of this work has been to illustrate that with careful design, inquiry-based astronomy can feasibly be undertaken in the high-school classroom to dramatic effect**.** While there are still fundamental limitations set by outside concerns, this research shows that it is possible within the current state of school science to undertake inquiry-based science (rather than inquiry-based *school* science) within the everyday classroom. Within this project, powerful characteristics have been identified that all actors must take into account for a successful inquiry-based implementation whether they are teachers, principals or external project personnel. The most important implications that emerge from this research are for the nature of teacher training, both pre-service and in-service, for educational jurisdictions, and for the indispensable role that evaluation plays both during and after the implementation of external projects.

The nature of this intervention is that the teachers involved with this study were generally the keener and more independent teachers at their school. It remains to be seen what changes will need to be made as the design adapts to the less interested or less capable teachers as time goes on. One of the strongest aspects is the nature of the design outlined in this thesis and its ability to react strongly and effectively to the needs and requirements of the teachers who use it. If the approach is more widely adopted, the outlook for success is promising.

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper One

As co-authors of the paper entitled "Students Perceptions of High School Science: What has Changed Over the Last Decade", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

MFitzgerald

20/02/14

Michael Fitzgerald

Date

Danaia

17/02/14

Lena Danaia

Date

David H. McKinnon

17/02/14

David McKinnon

Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Two

As co-authors of the paper entitled "A Review of High School Astronomy Research Projects over the last 20 years", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

M Fitzgerald

20/02/14

Michael Fitzgerald Date

18/02/14

Rob Hollow Date

20/02/14

Luisa Rebull Date

L Danaia

17/02/14

Lena Danaia Date

David H. McKinnon

17/02/14

David McKinnon Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Three

As co-authors of the paper entitled "Space to Grow: LCOGT.net and Improving Science Engagement in Schools", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

M Fitzgerald

20/02/14

Michael Fitzgerald Date

L Danaia

17/02/14

Lena Danaia Date

David H. McKinnon

17/02/14

David McKinnon Date

P. Stenning

Paul Stenning Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Four

As co-authors of the paper entitled "Blocking Factors Inhibiting Inquiry-based Science Teaching and Potential Solutions: Perceptions of Positively Inclined Early Adopter Teachers", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

MFitzgerald

20/02/14

Michael Fitzgerald — Date

Danaia

17/02/14

Lena Danaia — Date

David H. McKinnon

17/02/14

David McKinnon — Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Five

As co-authors of the paper entitled "Differences in perception of high school science: Students and Teachers views." we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

M Fitzgerald

20/02/14

Michael Fitzgerald

Date

Danaia

17/02/14

Lena Danaia

Date

David H. McKinnon

17/02/14

David McKinnon

Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Six

As co-authors of the paper entitled "Educational Design for Large-Scale High School Astronomy Projects using Real Telescopes", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

M Fitzgerald

20/02/14

Michael Fitzgerald Date

David H. McKinnon

17/02/14

David McKinnon Date

L Danaia

17/02/14

Lena Danaia Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Seven

As co-authors of the paper entitled "A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science." we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

MFitzgerald

20/02/14

Michael Fitzgerald		Date

David H. McKinnon

17/02/14

David McKinnon		Date

LDanaia

17/02/14

Lena Danaia		Date

James Deehan

22/02/14

James Deehan		Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Eight

As co-authors of the paper entitled "RR Lyrae Stars in the Globular Cluster NGC6101", we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

MFitzgerald

20/02/14

Michael Fitzgerald Date

JCriss

20/02/14

Josh Criss Date

David Frew.

17/02/14

David Frew Date

19/02/14

Marcio Catelan Date

L Danaia

17/02/14

Lena Danaia Date

David H. McKinnon

17/02/14

David McKinnon Date

Statements from Co-Authors

Confirming the Authorship Contribution of the PhD Candidate

Paper Nine

As co-authors of the paper entitled "Photometric and Proper Motion Study of Neglected Open Cluster NGC2215" we confirm Michael Fitzgerald has made the following contributions:

* Conceptualisation of the paper

* Analysis of the data

* Review and Interpretation of the Literature

* Writing, editing and revision of the manuscript.

Furthermore, we agree to the inclusion of the paper in this doctoral research submitted for examination.

MFitzgerald

20/02/14

Michael Fitzgerald Date

Lauren Inwood

16/02/14

Lauren Inwood Date

David H. McKinnon

17/02/14

David McKinnon Date

15/02/14

Wilton Dias Date

Mariana Sacchi Gomes

17/02/14

Mariana Sacchi Date

LDanaia

17/02/14

Lena Danaia Date

PART A: INTRODUCTION, CONTEXT AND BACKGROUND

Introduction

> *A grasp of scientific method and the appreciation and critical faculties which go with it is an essential ingredient of an educated person in this century. People cannot understand the world as known today without such a grasp, and without some knowledge of the sciences and their applications, adequately fulfil their position as citizens – Bennett (2001)*

The early 21st century has been an era of explosive growth in scientific discovery and technological development. The rate of accumulation of scientific knowledge and understanding is skyrocketing. While this may be the case in the background, interest levels in undertaking science at all levels of education are dropping constantly, even if for literacy or simple interest rather than vocation (American Association for the Advancement of Science (AAAS) 1990; Committee for the Review of Teaching and Teacher Education (CRTTE) 2003; Drury and Allen 2002; Goodrum et al. 2012; International Bureau for Education 2001; Lyons and Quinn 2010; Millar and Osborne 1998). In Australia, enrolments in science subjects in senior high school have been steadily dropping for decades (Ainley et al. 2008), as shown in Figure 1. These issues are especially true for most developed countries, although not so much true in developing countries where interest in science is actually still quite high (Sjoberg 2005)

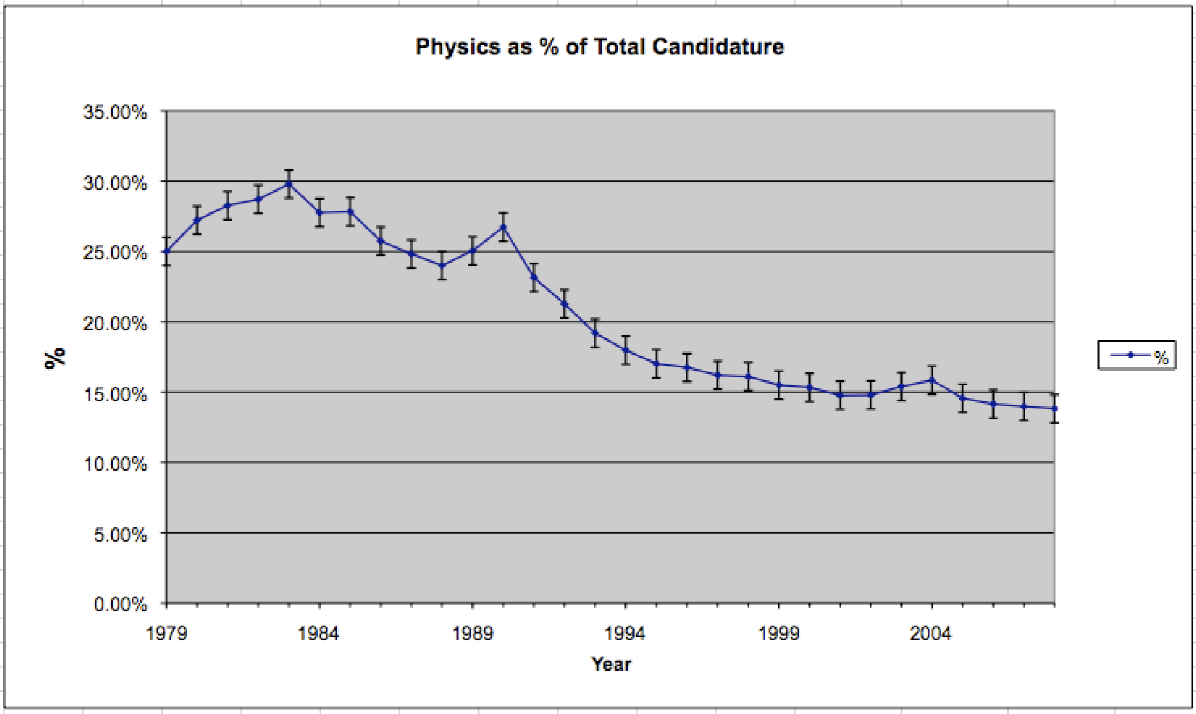


Figure 1. Enrolment in physics in Australian High-schools over time. (Ainley et al. 2008)

This story on the face of it appears to be a new story, a story symptomatic of our postmodern world. However, the quote at the beginning of this section did not initially originate in 2001 as the reference suggests, but rather was updated in Bennett (2001) from a much earlier quote from Archer Vassall in 1921. The only essential changes made were to update the gendered nature (he, him, man) of the earlier language to the modern accepted gender neutral form. Bennett takes this as a stepping stone to point out that the concern that students are not interested in science at the school level, are not continuing onto further education or scientific careers, and have a general low opinion of science is not a new phenomenon and has been known for a long time. This is not at all a peculiarly modern issue, it has been a noted trend for bordering on a century. Even though there are indications the situation is becoming worse, these problems of school science have a long history.

This lack of interest in school science is contrasted by the very high value that is generally placed in school systems and university entrance requirements of Science, Technology, Engineering and Mathematics (STEM) related subjects. But what is the source of this value? Perhaps it is that these subjects, more than any other, can provide some sort of objective performance 'measurement' in the form of a standardised test to rate, compare and sort teachers, schools and their students, whether it would be for an individual's university entrance score, as a performance indicator by jurisdictions or governmental bodies to rate teachers or schools or as a research tool to compare countries performance. This is seen as the case, even though such simple problem-based instruments is a very problematic proxy for actual scientific, academic, vocational or life potential.

> *''The trouble with school science is that it provides uninteresting answers to questions we never asked''* (Osborne, 2006).

But this value is imparted by various interest groups on the school system from the exterior. What about the interests of the actual 'consumers' of education; the students and parents? In this case, the current situation does not seem to be serving their wants and needs either. in large scale focus group interviews (Osborne 2000), students commonly felt that they were being marched across all of the concepts in science with no time to fully absorb any of the concepts while, at the same time, note-copying formed large parts of the curriculum. Both teachers and students tended to see science, in comparison to other subjects as content-dominated and as a particular body of knowledge that emphasized facts with answers that were known to be right or wrong in advance. Teachers did not necessarily hold this view of science in general, but accepted this perception as the inevitable result of a content-dominated and overloaded curriculum.

> *"Yeah, you're writing things down from the overhead projector .... you haven't had time to read it while you're copying it down. It's only when you come back to revision that you think 'I didn't understand that and I wish I'd asked him". But then you remember that you didn't have a chance to ask because you were that busy trying to copy it down you weren't reading" - Quote from student (Osborne 2000)*

There is a larger problem than just this general lament of the flagging interest in school science. The broad focus of aspects of science education has remained largely unchanged for at least half a century in the developed world. Scientists interviewed by Tytler (2006), showed concern that their children's textbooks looked much the same as the ones they used when they were at school, even though the landscape of modern science has changed dramatically. The nature of the workforce and the demands of life in general outside of the scientific sphere have also been radically shifted over the course of the last century (Gilbert 2005).

The changes impacting the demands of school science that were identified and discussed at a 2006 Australia Council for Educational Research (ACER) conference were of such magnitude that Tytler (2007) later called for an entire reimagining of science education.

> "*We need to re-imagine science education, accepting a shift that is occurring and must occur in the way we think of its nature and processes. The implication of this is that any moves towards a national agenda for science education needs to be premised on this re-imagining rather than refinement of the existing curriculum and assessment."* (Tytler 2007)

The industrial approach of trying to force into students as much factual knowledge and raw skills as possible to ready them for the workplace where they will largely undertake repetitive tasks is no longer relevant. Such occupations are slowly on the way out as they become increasingly mechanised or dealt with via robotics or artificial intelligence. The reality of the world that we increasingly live in is that factual knowledge is available nearly on demand and the focus of new workplaces and new occupations is tending more towards the synthesis of new knowledge rather than reproduction of the old (Gilbert 2005). Knowledge in this new world is also a verb not a noun, is about acting upon and producing new things rather than the storage of facts and hence requires entirely different intended outputs from school science than typical curriculums account for. (Fensham 2011)

> *"Isn't it just — it's, it's school, right? So — I mean, school sucks, right? I mean, you do what you can to improve it, but it's not — it's, in the end there's a limit, because it's school. And school sucks. Remember?" - Louis CK*

If the students are not being served by the current education and neither are the teachers, who is actually being served and why? If school science is giving the wrong picture of actual science to students then students are been given the wrong idea about science in the real world and making erroneous life choices based on this information, regardless of whether it is towards or away from science?

The first step is to identify our ideals behind what we are aiming for with school science education. A variety of large reports and reviews from around the world, as referenced earlier, have attempted to undertake this and they tend to largely overlap in their findings as well as their recommendations. One of the largest reports calling for reform in the Australian context was the Department of Education, Training and Youth Affairs commissioned report - "Status and Quality of Teaching and Learning of Science in Australian Schools" (Goodrum et al. 2001). Through a multiple method approach, involving quantitative surveys, qualitative interviews and focus groups of teachers, students and educational experts, this report endeavoured to set out what should be considered the 'ideal' picture of science that we should be aiming for. This was contrasted in the same report with the 'actual' picture of science that they extracted from their research.

The difference between the 'actual' and the 'ideal' picture was quite disappointing and many recommendations were made to redress the gap. Many endeavours in Australia following a variety of approaches were put forth to address many of these recommendations, such as ASISTM (Tytler et al. 2008), Scientists in Schools (Rennie 2012) and Science by Doing (Goodrum et al. 2008). However, as we will explore in the earlier parts of this thesis, the sum of these endeavours have seemingly had a disappointingly small large-scale impact over the last decade (Danaia et al. 2013).

From the perspective of the large-scale national reports, some of the details preventing high quality science in the grassroots classroom may be hidden. With their focus on science in general, some of the issues that affect one broad content strand and not another can be ironed out and disappear in the data. Also, some of the major issues in one of the major states or jurisdictions may not be apparent when the data is taken as a whole. In the context of a smaller intervention project such as that within which this thesis is based with a limited geographic it is possible to explore deeper more contextually dependant issues that may be invisible at larger scales.

The majority of this research was undertaken with relation to the Space to Grow astronomy education intervention project based in NSW, Australia (Danaia et al. 2012). The project was based on a 3 year funded Australian Research Council Linkage grant run through Macquarie University and Charles Sturt University with the cooperation of four partner organizations. Three of the four partners were educational jurisdictions, the Department of Education and Communities (DEC) Western Region, Catholic Education Office (CEO) Paramatta, as well as CEO Bathurst, while one, Los Cumbres Observatory Global Telescope Network (LCOGT) provided access to the Faulkes Telescopes. While initially the claimed scope of the project was to include approximately 40 schools, 200 teachers and 9000 students in Grades 9-12, the actual rate of implementation was much lower for reasons we explore in this thesis.

The focus of the project was to attempt to inspire students using access to the twin 2 metre Faulkes Telescopes (shown in Figure 2) to address the outlined issues by improving student engagement and retention of students into higher years. This project is bounded by a single curriculum (NSW), covered a limited content strand (astronomy) within a small number of educational jurisdictions (three). Within such bounds we were better able to focus on getting a much more detailed picture of the issues to be addressed in order to enable effective approaches within realistic science classrooms. With these issues in mind, we were able to iteratively design and evaluate in-class solutions to overcome hurdles and blocking factors identified.

Figure 2: Faulkes Telescopes (FTS Left, FTN Right. Image Source: lcogt.net image library.)

Externally to this PhD project, curriculum materials were developed by the author of this PhD and David McKinnon. The materials were developed to take a person with no knowledge about astronomy or science and provide them with a plausible scaffolded pathway to gaining a deep understanding and appreciation of stellar astronomy. These materials were the primary vehicle that made the actual on-ground implementation of the project possible. In the earlier sections of these materials (Projects 1 & 2) students discover what telescopes are all about, what types of objects there are out in the universe and get their first taste of working with astronomical data by making their own colour image, preferably of their own choice taken for them by the telescopes. A class of students undertaking this process, as well as some of their created images are shown in Figure 3

Figure 3: Students and colour images. (Danaia et al. 2012)

The aim of the earlier material was to engage and excite the students generally in astronomy and science but also provide them with motivation to interact with the more abstract material in Project 3. In this project, scaffolding is provided to students to learn the concepts and mechanics behind broadband astronomical photometry through an inquiry-based exploration of the lifecycle of stars in the context of star clusters. It is the intention behind this project to provide an authentic experience of astronomical science to all students while also providing the capacity for keen students to undertake their own open inquiry in stellar astronomy.

The thesis structure

The objectives of this research are:

Objective 1: What is the context and background within which this project is set?

Objective 2: What are the important blocking factors and perceptions affecting this project?

Objective 3: Can we develop, implement and evaluate an approach to meet the challenges and issues raised?

The core of the thesis is organised into three separate themes, representing approaches to answer each of the three objectives. Each theme has multiple papers collected within. The first theme represents the background information necessary to situate this research in context. In the first Paper, *"Students Perceptions of High School Science: What has changed over the last decade?"* we explore whether there has been any significant changes in the general science classroom since the Goodrum (et al. 2001) study, along the lines of Danaia et al. (2013), using the same questionnaire.

In the second Paper, *"A Review of High School Astronomy Student Research Projects over the last 20 years"* we examine the variety of similar intervention projects that use real data from real telescopes in the classroom with the focus on students undertaking some form of astronomical research. As well as a general history, we seek to define what does and does not classify as an Astronomy Research

Project for students as well as define the dimensions upon which these projects differ. We also outline the various issues uncovered through informal conversations with project personnel which can have an effect on the success, or otherwise, of these style of projects. The third Paper, *"Space to Grow: LCOGT.net and Improving Science Engagement in Schools"* outlines in detail the intervention project within which this thesis is situated. It outlines its initial purpose, funding sources, institutional partners and approach as well as some earlier preliminary results.

The second theme presents the results of our investigations into the blocking and contextual factors that prevent adequate implementation in the classroom at our smaller, NSW-based, scale. Teachers were interviewed in depth about a variety of these issues which are formed into the first two papers. The first paper *"Blocking Factors Inhibiting Inquiry-Based Science Teaching and Potential Solutions"*, explores the variety of factors teachers perceive as preventing them from undertaking inquiry-based science in the classroom. It also outlines the two main methodologies used to extract the qualitative relationships between the factors and concepts in the data.

The second paper in this theme, *"Difference in Perception of High School Science between students and teachers"* takes a quantitative approach from a large sample (2512) of students and a relatively large sample (86) of their respective teachers and compares their perceptions of the science classrooms using the same instrument as that used in the Goodrum et al. (2001) study as well as the first paper in the first theme.

The third theme presents the design, evaluation and results of our attempted intervention in response to the issues identified in the second theme. In the first paper *"Educational Design for Large-Scale High School Astronomy Projects Using Real Telescopes"* we outline our core design approach to solving the problem of high school in-class inquiry astronomy. We define the core issues to be addressed, the core design principles taken and the theoretical underpinning of the whole model as they relate to the actual implemented design.

In the second paper "*Impact on students of an inquiry-based astronomical high school education intervention"* evaluates the impact of the educational design in the real-life classroom using pre-post quantitative evaluations of both their content knowledge, using a customised astronomical diagnostic test and their opinions and perceptions of their science classroom experience using the secondary school science questionnaire.

This theme is rounded off by two examples of student research that has culminated in scientific publications, the first *"RR Lyraes in the Globular Cluster NGC6101"* involves the work of two Year 11 students who updated the periods for a variety of RR Lyraes and gained an independent estimate of the distance to NGC6101, while the second *"Photometric and Proper Motion Study of Neglected Open Cluster NGC2215"* was undertaken largely by one Australian Year 10-12 student over the course of a year with collaboration with two students and their teacher in Canada. The thesis is then summarised with an exegesis chapter summarising the main findings, results and conclusions from this research.

Res Sci Educ
DOI 10.1007/s11165-012-9318-x

Students' Perceptions of High School Science: What has Changed Over the Last Decade?

Lena Danaia · Michael Fitzgerald · David McKinnon

Abstract This paper presents comparative questionnaire data from three different samples of Australian high school students in an attempt to see if anything has changed in relation to how they perceive the science they experience in the compulsory years of secondary school (grades 7–10). Questionnaire data were obtained from 1,585 high school students in 2011 and 2,016 students in 2005 and findings are compared with those reported in a national report (Goodrum et al. 2001). Results show significant increases in the frequency with which students report that their science teacher takes notice of their ideas and in the use of computers and the Internet. There have also been changes regarding the rapid provision of feedback, the use of understandable language by teachers and the contextualisation of the new work in terms of work already covered. Little appears to have changed, however, in relation to the teacher-directed pedagogies employed to teach science where there appears to be a higher incidence of copying notes and fewer opportunities for students to investigate topics in which they are interested. The findings suggest that while there have been some positive changes, there are still many students who indicate that the science they experience in secondary school is irrelevant to their everyday life and to their future. It seems that the curiosity and wonder one would hope is associated with studying science is missing for a large proportion of students. It is clear that further actions need to be undertaken to transform this continuing situation.

Keywords School science · Secondary/high school · Student perceptions

---

L. Danaia (✉) · D. McKinnon
Faculty of Education, Charles Sturt University, Bathurst, NSW 2795, Australia
e-mail: ldanaia@csu.edu.au

M. Fitzgerald
Macquarie University Research Centre in Astronomy, Astrophysics & Astrophotonics,
Macquarie University, North Ryde, NSW 2109, Australia

M. Fitzgerald
Department of Physics & Astronomy, Macquarie University, North Ryde, NSW 2109, Australia

Over the last two decades, in a number of developed countries, there has been a growing concern about both the waning interest many high school students display towards science at school and the declining number of students pursuing science in the post-compulsory years of secondary education (e.g. American Association for the Advancement of Science (AAAS) 1990; Committee for the Review of Teaching and Teacher Education (CRTTE) 2003; Drury and Allen 2002; Goodrum et al. 2012; International Bureau for Education 2001; Lyons and Quinn 2010; Millar and Osborne 1998). The science content offered by schools is often perceived by students to be irrelevant to their needs and appears not to tempt many to continue with it beyond the compulsory years (Osborne and Collins 2000; Simpson and Oliver 1990; Tytler 2007). Often, science education has focused on developing the elite students to become scientists and has neglected to meet the needs of the majority of students (Fensham 1985; Millar and Osborne 1998). This neglect has resulted in many students being alienated by, and turning away from, science at school.

In response, attempts have been made to transform science education to meet the needs of both the society and students. The general purpose of these attempts has been to make it more relevant for all and more interesting for those who endeavour to pursue a career in science (e.g. AAAS 1990; Duschl et al. 2007; Fensham 1985; Goodrum et al. 2001; Millar and Osborne 1998). Schools and teachers are thus faced with the responsibility of delivering science subjects that will produce these two outcomes (Lawrance and Palmer 2003). A major implication for the delivery system is that rather than simply *teach* students to learn and accept the scientific information as presented, science education should empower them to question and challenge it, to investigate matters in which they are interested, and to be informed about current scientific issues (e.g. Goodrum et al. 2001; Osborne and Collins 2000). In the process, it could be argued that they will learn to take responsibility for their learning so that in the future they are better able to make informed decisions about science issues.

Despite calls for reform, changes to the ways in which science education is implemented have not necessarily occurred (e.g. AAAS 1990; Australian Academy of Technological Sciences and Engineering (AATSE) 2002; Gibbs and Fox 1999; Harris et al. 2005; Lyons 2006; Millar and Osborne 1998). That is to say, both the way science is taught at school, and the content covered, often continue to reflect traditional approaches. For example, there is still too much emphasis placed on the teaching of content and too little time devoted to scientific inquiry or to an understanding of the applications of science; all issues raised more than 20 years ago (Australian Science Teachers' Association 1985). Furthermore, the transmissive approaches that tend to dominate science instruction are often employed as a consequence of teachers having to cover an overcrowded science curriculum within a specified timeframe to ensure that students are prepared for the norm-referenced test, which is generally given at the end of each topic (Goodrum et al. 2001; Millar and Osborne 1998; Tytler et al. 2008).

Many argue that the negative perceptions which students develop towards school science together with their increasing disenchantment as they progress through school leads to the development of entrenched negative attitudes (Barmby et al. 2008; Braund and Driver 2005; Murphy and Beggs 2003; Krogh and Thomsen 2005) and disposes them not to undertake science in their final years of school (Dekkers and de Laeter 2001; Hackling et al. 2001; Lyons 2006). Other factors that may deter the uptake of science include the perceived difficulty associated with science subjects in the senior years and the stereotypical image that many students possess of scientists (Cleaves 2005).

In Australia, in response to these issues, the Commonwealth Department of Education, Training and Youth Affairs (DETYA) commissioned a research to investigate the status and quality of teaching and learning of science in primary and secondary schools across Australia (Goodrum et al. 2001). Data were collected from teachers, students, administrators, scientists and community members to ascertain the status and quality of teaching and learning of science in Australian schools. The data revealed a disappointing picture of teaching and learning science in Australia.

The authors established two pictures of science teaching and learning: the *actual* and the *ideal*. The *actual* picture portrayed what was generally happening in the teaching and learning of science in Australian schools and that it lacked relevance and failed to captivate the majority of students. Furthermore, the curriculum was described as overloaded with content and the pedagogy focused on students memorising facts. In contrast, the *ideal* picture of science teaching and learning defined best practice where scientific literacy is a high priority for society, where the science curriculum is relevant and meaningful to the needs and interests of students. Furthermore, in this *ideal* picture, the learning experiences in science are based on inquiry and supported by quality equipment and resources.

Specifically, more than half of the secondary school students surveyed in the study felt that the science they learnt at school had no bearing on their future, was not practical and/or did not relate to their everyday life experiences. The majority revealed that copying notes and working from textbooks was a regular occurrence in science and was something they disliked. Many reported that they found the science they experienced in class to be boring and that they did not understand the scientific concepts covered. Teachers reported that they lacked the professional development and resources needed to support their teaching, and their students' learning, in science classes.

The report also highlighted the need for attention to be devoted to closing the gap between the *actual* and the *ideal* science curriculum (Goodrum et al. 2001). There were nine recommendations that provided relevant stakeholders with strategies to improve the status and quality of science education in schools so that it reflects more the *ideal* picture. It was suggested that further reviews of the quality and status of science learning and teaching be undertaken to assess the impact of the actions arising from the report.

Since the release of the 2001 national report, there have been subsequent major reviews and reports released that reiterate many of the aforementioned concerns and describe Australian school science education as being in a state of crisis (Lawrence and Palmer 2003; Lyons and Quinn 2010; Tytler 2007; Tytler et al. 2008). One of the major concerns is the continuing downward trend in the proportion of secondary students electing to take traditional science subjects in the post-compulsory years of school (Ainley et al. 2008; Lyons and Quinn 2010). This has been linked to science in the compulsory years of school failing to engage the broad range of students (Goodrum et al. 2012).

During this time, there have also been a number of initiatives, at various levels, focussed on improving science education. The Australian School Science Education National Action Plan for 2008–2012 provides a comprehensive map of some of the initiatives that have been undertaken since 2001 to improve the quality of science education (Goodrum and Rennie 2007). Since the release of that report, there has been subsequent initiatives one of which is *science by doing* (Australian Academy of Science 2010).This is a large-scale national initiative to improve secondary science education. In 2010, it was trialled in 28 schools across Australia and the professional learning approach employed was evaluated. Despite the apparent positives of this project, federal government funding was cut in 2011 before the programme was fully developed.

Given the recommendations that have been made in Australia coupled with the initiatives that have been implemented, the purpose of this paper is to investigate students' perceptions of the science they experience in secondary school and to examine if the picture has changed since 2001. Comparative questionnaire data are presented for three different samples of high school students from 2011, 2005 and 2001. The 2011 sample is drawn from an ARC Linkage project (Danaia et al. 2012) and comprises students in years 9 and 10. The 2005 sample is from a DEST study (McKinnon 2005) involving students in grades 7–9 while the 2001 sample is drawn from the DETYA national study (Goodrum et al. 2001) and comprises students in grades 7–11. Results are contrasted between the samples to gain insights into students' perceptions of the science they experience at school and to examine what has changed, if anything, over this 10-year period.

Method

As noted above, the participants in this research are drawn from three different studies. The 19 schools in the 2011 sample were drawn from one Australian state, New South Wales. The participants were 1,585 students in grades 9 (N=241) and 10 (N=1,344). The 30 schools involved in the 2005 sample were drawn from four jurisdictions located on the eastern side of Australia (the Australian Capital Territory, New South Wales, Queensland and Victoria). The participants were 2,016 students in grades 7–9 of which 1,277 were drawn from the first year of secondary school/high school (grade 7), 520 from the second year (grade 8) and 219 from the third year of secondary school (grade 9). The 2001 sample is drawn from the DETYA national study (Goodrum et al. 2001) that was conducted in seven of the eight Australian states and territories. The 2001 sample comprised 2,802 students in grades 7–11 of which 407 were grade 7, 763 grade 8, 738 grade 9, 641 grade 10, and 253 grade 11.

A stratified random sample was employed for the 2001 sample where the intended and actual numbers of schools sampled are reported in the Goodrum et al. report (2001, p. 77). Opportunity sampling (Johnson and Christensen 2004) was employed to recruit participants in the 2005 and 2011 samples. It was necessary to employ this type of nonrandomised sampling for practical reasons; that is, the research had a limited time in which it was to be completed and the research was conducted within educational settings where class groups are already formed making it unrealistic for participants to be randomly selected. The researchers recognise that this sampling method could create significant bias in the results obtained. A second source of potential bias exists in the fact that the 2011 sample comprises students in grades 9–10, while the 2005 sample was constrained to grades 7–9 and the 2001 sample surveyed students in grades 7–11. A third source of bias may be due to the fact that the 2001 sample comprised students from seven of the eight Australian educational jurisdictions while the 2005 sample dealt with only four and the 2011 sample was drawn from only one. We acknowledge that the differences in sample sizes and characteristics are sources of sampling bias and could therefore have implications that impact on interpretation of the data.

In this research, we compare the results of the 2005 sample drawn from four jurisdictions with the results of the 2001 national study. We also compare the 2011 sample drawn from one jurisdiction (NSW) with both of the earlier samples. Table 1 shows the differences in the sizes of the three samples where the breakdown of students from the public and private educational sectors is presented. It is evident that the proportions of students from the public and private sectors are very similar for the 2005 and 2001 samples. In the 2011 sample, however, the proportion of students drawn from the private sector is much higher than the public sector. This is attributable to the focus of where the research project is directed.

In order to address the difference in proportion of public and private sector samples for the 2011 study compared with the other two, it was deemed necessary to check if there was

Table 1 Breakdown of students by sector

	2011		2005		2001	
Sector	*N*	%	*N*	%	*N*	%
Public	372	23.5	1,041	51.6	1,425	50.9
Private	1,213	76.5	975	48.4	1,377	49.1
Total	1,585	100.0	2,016	100.0	2,802	100.0

any difference in the patterns of response between these two sectors. Consequently, we drew six random samples of 100 students from each of the public and private sectors and compared the response patterns for the 2011 sample. The analyses revealed that there was little difference in the patterns of responses for the public and private sectors in 34 of the 37 rating scale items. The exceptions were using a textbook, computer use and finding information on the Internet where there seemed to be a higher incidence of textbook use in the private sector and computer and Internet use in the public sector. Given that there were few differences in the response patterns by students in these two sectors, we have chosen to combine all responses into one dataset without weighting them according to the sector of origin and report the results accordingly. The sample size of the 2011 and 2005 samples, it could be argued, are sufficiently large to make reasonable comparisons for those jurisdictions with the 2001 national study results in an attempt to track any changes that have occurred in students' perceptions of the science they experience in the compulsory years of secondary school. Nonetheless, the results should be interpreted with the caveat that there is the potential for sampling bias and that comparisons should be interpreted with caution.

The Secondary School Science Questionnaire (SSSQ; Goodrum et al. 2001) comprising 42 rating scale items was used to collect information from students regarding their perceptions of, and experiences in, the compulsory years of secondary science classes (grades 7–10 in NSW). Slight modifications were made to the SSSQ in the 2005 and 2011 versions. Thus, across the three samples, 37 of the 42 rating scale items were the same. Consequently, the results in this paper will present results for the 37 common rating scale items across all three research projects with the results presented in the same manner as Goodrum et al. (2001) so that comparisons can be made with the 2005 and 2011 samples.

Results

A non-parametric chi-square test is used to determine whether the patterns of responses obtained from the 2011 and 2005 samples differ significantly from those reported in the 2001 national study. A chi-square test is the most appropriate method to use to detect changes in the patterns of responses because we are looking at the differences (if any) between three different samples. More importantly, for the 2001 sample, we only had access to the percentages reported for students' responses to each of the rating scale items in the national study (Goodrum et al. 2001). The significant chi-square statistic (suitably protected) indicates the independence of the pattern of responses from the three different studies (Gaur and Gaur 2007). To reduce the likelihood of a type I error given that 37 items are being compared, and to minimise the risk of a type II error occurring, we have employed a modified Bonferroni correction (SISA 2012) where the generally accepted *p* value of 0.05 is substituted by a more rigorous *p* value of 0.0012. Significant differences in the response

Table 2 Learning activities—dealing with content in science in the secondary school

Item		Year	% Response					Sig. *p*	
			Never	Once a term or less	Almost once a month	About once a week	Nearly every lesson		
In my science class								B	C
I copy notes the teacher gives me	A	2011	2.4	1.6	4.0	15.1	76.9	0.3217	0.0292
	B	2005	1.7	2.1	5.7	22.7	67.8		0.6896
	C	2001	3.0	3.0	7.0	26.0	61.0		
I have opportunities to explain my ideas	A	2011	10.4	8.1	16.3	28.3	36.9	0.28666	0.9795
	B	2005	6.2	6.1	13.9	30.6	43.2		0.2829
	C	2001	11.0	9.0	15.0	30.0	35.0		
I read a science textbook	A	2011	19.3	12.8	18.7	24.5	24.8	0.0111	0.5626
	B	2005	10.8	8.2	16.7	31.2	33.1		0.1332
	C	2001	20.0	10.0	15.0	24.0	31.0		
We have class discussions	A	2011	6.2	5.4	10.6	23.9	53.8	0.7497	0.0863
	B	2005	4.7	6.0	12.7	27.8	48.9		0.4500
	C	2001	7.0	8.0	14.0	31.0	40.0		
We do our work in groups	A	2011	5.4	7.5	21.9	40.4	24.9	0.6289	0.1844
	B	2005	3.1	7.2	19.1	42.4	28.1		0.3796
	C	2001	5.0	7.0	16.0	36.0	36.0		
In science, we									
Investigate to see if our ideas are right	A	2011	12.1	11.3	22.0	33.8	20.7	0.1544	0.0000**
	B	2005	15.1	17.8	24.1	28.3	14.7		0.0117
	C	2001	25.0	22.0	25.0	19.0	9.0		
My science teacher									
Lets us choose our own topics to investigate.	A	2011	54.3	22.7	12.5	6.8	3.8	0.3128	0.3759
	B	2005	62.0	18.5	12.9	4.7	1.9		0.7599
	C	2001	59.0	24.0	11.0	4.0	2.0		

$^{*}p<0.0012$, $^{**}p<0.0002$

patterns of the 2011, 2005 and 2001 samples are presented in the tables below where a single asterisk indicates a *p* value less than 0.0012 and a double asterisk signifies a *p* value less than 0.0002. While such a correction can be regarded as a conservative approach, it will be seen in the results below that few differences exist whether or not such a correction to the *p* value is made. Thus, the probability of detecting a real difference between two sets of results is enhanced by employing the modified Bonferroni correction.

SSSQ Rating Scale Results

The response patterns are expressed as percentages in each rating scale option for the 37 items in the SSSQ. In each of the tables below, the items are presented in clusters that correspond with the way in which the 2001 findings were presented (see Goodrum et al. 2001, pp.118–123).

Learning Activities—Content in Science in the Secondary School

Table 2 results show that there is a significant difference in the patterns of responses for only one of the seven items related to learning activities that deal with content in secondary school science. Students in the 2011 sample appear to have significantly more opportunities to investigate to see if their ideas are correct compared with the 2001 sample, but there still appears to be little opportunity for students to choose their own topics to investigate. The majority of students from all three samples report that copying notes is a frequent activity and which happens *nearly every lesson* with higher percentage of the 2011 sample (76.9 %) selecting this response compared with 2005 and 2001. These differences, however, are not significant.

Learning Activities—Practical Work in Science in the Secondary School

Table 3 results show that there is only one of the items concerned with practical work for which there is a significant difference in the patterns of responses. Specifically, a significantly higher proportion of students in the 2005 sample indicated that they watched their teacher do an experiment on a regular basis in science lessons compared with the 2001 sample. For the 2011 sample, there is a slight but non-significant decrease in the percentage of students indicating that they do experiments by following instructions *nearly every lesson*. There still appears to be little opportunity for students to plan and do their own experiments with over half of the students from each of the samples indicating that this happens *once a term or less*.

What Students Need to be Able to do in Science in the Secondary School

Table 4 shows that for the four items related to what students think they need to be able to do in science, there are no significant differences in the patterns of responses. The majority of students in both samples indicate that they need to be able to think and ask questions and remember many facts frequently in science classes. The results show that more than half of

Table 3 Learning activities—practical work in science in the secondary school

Item		Year	% Response					Sig. p	
			Never	Once a term or less	Almost once a month	About once a week	Nearly every lesson		
In my science class								B	C
I watch the teacher do an experiment	A	2011	8	13.3	31.3	31.7	15.7	0.0086	0.6908
	B	2005	4.5	8.3	25.2	32.6	29.4		0.0000**
	C	2001	10.0	17.0	32.0	27.0	14.0		
We do experiments by following instructions	A	2011	4.7	6.9	21.8	35.7	31.0	0.0636	0.8625
	B	2005	1.9	5.2	17.8	32.8	42.4		0.3716
	C	2001	3.0	7.0	20.0	37.0	33.0		
We plan and do our own experiments	A	2011	31.2	23.7	20.4	16.3	8.3	0.8962	0.8509
	B	2005	32.3	20.1	20.1	17.2	10.2		0.4116
	C	2001	33.0	25.0	22.0	13.0	7.0		

*$p<0.0012$, **$p<0.0002$

Table 4 What students need to be able to do in science in the secondary school

			% Response						
Item		Year	Almost never	Sometimes	Often	Very often	Almost always	Sig. *p*	
In science we need to be able to								B	C
Think and ask questions	A	2011	5.0	11.8	25.1	24.7	33.4	0.4463	0.9605
	B	2005	2.8	9.9	21.3	27.4	38.5		0.6625
	C	2001	5.0	13.0	22.0	26.0	34.0		
Remember lots of facts	A	2011	5.0	12.9	24.7	28.4	29.0	0.4969	0.9979
	B	2005	2.8	10.4	22.7	33.5	30.7		0.7419
	C	2001	5.0	12.0	24.0	29.0	30.0		
Understand and explain science ideas	A	2011	5.0	12.5	24.1	29.2	29.2	0.9077	0.7791
	B	2005	3.4	12.6	26.2	30.0	27.8		0.7045
	C	2001	6.0	15.0	25.0	30.0	24.0		
Recognise science in the world around us	A	2011	6.4	14.1	24.8	25.1	29.6	0.9435	0.2895
	B	2005	5.6	16.1	24.2	27.0	27.0		0.4971
	C	2001	9.0	17.0	27.0	26.0	21.0		

the students in both studies *very often* or *almost always* think that they need to be able to understand and explain science ideas in their classes.

Teacher Feedback and Guidance in Science in the Secondary School

Table 5 shows that there is a significant difference in the patterns of responses for four of the nine items related to teacher feedback and guidance in secondary school science. A significantly higher proportion of students in the 2011 and 2005 samples report that their teacher marks their work and gives it back quickly, frequently uses language that is easy to understand, takes notice of their ideas and shows how new work relates to what they have already done in their science classes. For the remaining items, there is very little difference in the patterns of students' responses.

Computer Use in Science in the Secondary School

Table 6 shows that there is a highly significant difference in the patterns of student responses for the two items related to computer use in secondary school science. Fewer students in the 2011 and 2005 samples report that they *never* get to use computers to do science or look for information on the Internet. One would expect an increase in the use of technology, given that schools have many more computers and access to the Internet compared with 2001.

Enjoyment and Curiosity in Science in the Secondary School

Table 7 results show that there is a highly significant difference in the patterns of student responses for one of the items related to enjoyment and curiosity in secondary school science. A large proportion of students from the three samples are seldom excited about the science they experience at school where there is a significant difference in the patterns of responses for the 2011 and 2001 samples.

Table 5 Teacher feedback and guidance in science in the secondary school

			% Response						
Item		Year	Never	Once a term or less	Almost once a month	About once a week	Nearly every lesson	Sig. *p*	
My science teacher:								B	C
tells me how to improve my work.	A	2011	11.4	16.2	21.3	28.9	22.1	0.9960	0.5936
	B	2005	11.0	15.3	20.7	30.6	22.4		0.4661
	C	2001	16.0	15.0	24.0	27.0	18.0		
gives us quizzes that we mark to see how we are going.	A	2011	18.0	26.7	36.5	14.9	3.9	0.2680	0.3832
	B	2005	14.5	20.4	38.9	19.5	6.7		0.2376
	C	2001	23.0	22.0	32.0	16.0	7.0		
talks to me about how I am getting on in science.	A	2011	20.6	23.8	26.2	20.5	8.9	0.4060	0.0031
	B	2005	25.3	28.9	22.5	16.5	6.8		0.3745
	C	2001	33.0	29.0	21.0	12.0	5.0		
			Almost never	Sometimes	Often	Very often	Almost always	Sig. *p*	
My science teacher								B	C
Marks our work and gives it back quickly	A	2011	10.8	15.5	27.3	32.7	13.7	0.9951	0.0000**
	B	2005	12.1	15.4	27.1	32.6	12.8		0.0000**
	C	2001	19.0	26.0	20.0	17.0	18.0		
Makes it clear what we have to do to get good marks	A	2011	6.0	8.8	16.5	29.9	38.8	0.7646	0.0039
	B	2005	6.6	11.0	19.9	28.6	33.9		0.1180
	C	2001	10.0	18.0	22.0	24.0	26.0		
Uses language that is easy to understand	A	2011	5.9	5.9	11.8	21.8	54.6	0.9211	0.0000**
	B	2005	6.0	7.1	9.5	20.6	56.9		0.0000**
	C	2001	9.0	14.0	21.0	24.0	32.0		
Takes notice of students' ideas	A	2011	8.1	8.2	13.0	26.7	44.0	0.9996	0.0000**
	B	2005	8.4	8.3	12.7	27.5	43.2		0.0000**

Table 5 (continued)

Item		Year	% Response Never	Once a term or less	Almost once a month	About once a week	Nearly every lesson	Sig. *p*	
	C	2001	14.0	19.0	22.0	23.0	22.0		
Shows us how new work relates to what we have already done	A	2011	9.6	7.9	16.4	32.6	33.4	0.2697	0.0000**
	B	2005	9.5	11.8	20.7	33.2	24.8		0.0001**
	C	2001	15.0	25.0	24.0	21.0	15.0		
During science class									
We have enough time to think about what we are doing	A	2011	7.4	22.3	29.7	24.9	15.7	0.7472	0.0190
	B	2005	7.2	26.4	31.6	22.3	12.4		0.2201
	C	2001	13.0	31.0	29.0	17.0	10.0		

$^*p<0.0012$, $^{**}p<0.0002$

Table 6 Computer use in science in the secondary school

			% Response						
Item		Year	Never	Once a term or less	Almost once a month	About once a week	Nearly every lesson	Sig. *p*	
In science, we								B	C
Use computers to do our science work	A	2011	7.4	14.5	30.4	32.4	15.3	0.0000**	0.0000**
	B	2005	29.9	24.4	22.4	15.1	8.1		0.0000**
	C	2001	67.0	20.0	7.0	4.0	2.0		
Look for information on the Internet at school	A	2011	8.7	13.0	30.1	34.4	13.7	0.0000**	0.0000**
	B	2005	23.5	23.3	26	19.4	7.9		0.0000**
	C	2001	54.0	27.0	12.0	5.0	4.0		

$^*p<0.0012$, $^{**}p<0.0002$

Perceived Difficulty and Challenge of Science in the Secondary School

Table 8 shows that for the four items related to the perceived difficulty and challenge of science in the secondary school there are no significant differences in the patterns of responses. Approximately three quarters of the students in the three samples indicate that they rarely find science at school to be either too easy or too hard. In the 2011 sample, 58.8 % of students found science challenging *often*, *very often* or *almost always* compared with 55.3 and 55 % in the 2005 and 2001 samples, respectively.

Perceived Relevance of Science in the Secondary School

Table 9 results show that for the five items related to the perceived relevance of secondary school science, there are no significant differences in the patterns of responses. More than

Table 7 Enjoyment and curiosity in science in the secondary school

			% Response						
Item		Year	Almost never	Sometimes	Often	Very often	Almost always	Sig. *p*	
During science class								B	C
I get excited about what we do	A	2011	21.8	36.1	19.5	13.0	9.7	0.5025	0.0000**
	B	2005	25.6	40.2	17.2	10.3	6.7		0.0326
	C	2001	39.0	37.0	14.0	6.0	4.0		
I am curious about the science we do	A	2011	14.8	25.3	23.2	19.2	17.5	0.0480	0.0021
	B	2005	19.2	33.5	22.3	14.8	10.2		0.8597
	C	2001	23.0	32.0	22.0	15.0	8.0		
I am bored	A	2011	16.2	39.4	13.6	12.3	18.4	0.9991	0.9152
	B	2005	16.1	40.4	13.7	12.4	17.4		0.8199
	C	2001	17.0	37.0	13.0	11.0	22.0		

$^*p<0.0012$, $^{**}p<0.0002$

Table 8 Perceived difficulty and challenge of science in the secondary school

			% Response						
Item		Year	Almost never	Sometimes	Often	Very often	Almost always	Sig. *p*	
During science class								B	C
I don't understand the science we do	A	2011	25.5	45.3	14.4	7.3	7.5	0.8027	0.8039
	B	2005	27.5	48.0	13.3	5.9	5.3		0.7902
	C	2001	31.0	43.0	12.0	7.0	7.0		
I find science too easy	A	2011	35.2	37.7	16.1	6.6	4.5	0.9445	0.8727
	B	2005	35.2	41.0	14.1	5.7	4.0		0.8926
	C	2001	39.0	37.0	13.0	6.0	5.0		
I find science challenging	A	2011	6.9	34.3	25.8	19.8	13.2	0.7075	0.4432
	B	2005	9.7	35	27.9	16.8	10.6		0.9612
	C	2001	12.0	33.0	28.0	16.0	11.0		
I think science is too hard	A	2011	33.0	35.0	14.8	6.9	10.3	0.5661	0.6342
	B	2005	37.4	37.0	11.6	6.9	7.1		0.9452
	C	2001	39.0	35.0	11.0	6.0	9.0		

half of the students from each of the three samples indicate that the science they learn at school is rarely useful in everyday life nor relevant to their future. It seems that for the majority of students in the three samples, secondary school science seldom deals with things

Table 9 Perceived relevance of science in the secondary school

			% Response						
Item		Year	Almost never	Sometimes	Often	Very often	Almost always	Sig. *p*	
The science we learn at school								B	C
Is relevant to my future	A	2011	23.9	33.2	19.9	12.4	10.6	0.5308	0.6969
	B	2005	19.6	39.1	22.4	10.9	8.0		0.9448
	C	2001	19.0	36.0	23.0	13.0	9.0		
Is useful in everyday life	A	2011	22.6	38.2	20.2	10.6	8.4	0.5039	0.5609
	B	2005	16.7	41.2	23.2	12.2	6.7		0.9933
	C	2001	18.0	40.0	24.0	12.0	6.0		
Deals with things I am concerned about	A	2011	26.5	36.6	20.1	10.1	6.8	0.3763	0.6113
	B	2005	33.7	35.4	19.4	7.2	4.3		0.9006
	C	2001	31.0	36.0	19.0	10.0	4.0		
Helps me make decisions about my health	A	2011	25.1	36.3	19.1	11.8	7.8	0.1166	0.1078
	B	2005	36	33.4	16.7	9.8	4.2		0.9958
	C	2001	35	35.0	17.0	9.0	4.0		
Helps me understand environmental issues	A	2011	10.7	25.3	27.6	22.7	13.7	0.8373	0.5114
	B	2005	11.4	28.7	28.8	19.2	11.8		0.9685
	C	2001	12	31.0	28.0	19.0	10.0		

that they are concerned about or rarely helps them make decisions about their health. More than half of the students from the three samples report that science at school frequently helps them understand environmental issues.

Conclusions

This paper presents comparative data from three studies in 2011, 2005 and 2001. Even though there are some limitations in comparing the three different samples, the findings suggest that there have been some positive changes in students' perceptions of school science in NSW for the 2011 sample and in the responses of students in four jurisdictions in the 2005 sample. It would seem, however, that many of the problems identified in the 2001 national study continue to exist.

Overall, there were highly significant differences detected in the patterns of student responses for nine of the 37 rating scale items some of which indicate that positive changes may be occurring. Of these, the most notable difference was in relation to using computers and the internet where there was a highly significant increase in the patterns of student responses for the 2011 and 2005 samples compared with the 2001 sample. Furthermore, highly significant and positive changes in the patterns of student responses regarding the rapid provision of feedback, the use of understandable language by teachers and the contextualisation of the new work in terms of work already covered are apparent in the 2011 and 2005 samples compared with the 2001 sample. These could be considered as improvements to the delivery of science education. Also of note is the significant and positive change in the frequency with which students report that their science teacher takes notice of their ideas.

Some disappointing findings from the 2011 and 2005 samples were that there appears to be a higher incidence of copying notes and few opportunities for students to investigate topics in which they were interested, though there was an increase in the incidence of students reporting that they get the chance to investigate to see if their ideas are right. Students in the 2011 and 2005 samples, however, still rarely find school science relevant to their future or to everyday life. Many of these findings are consistent with those reported in the recently released national report on the status and quality of science in the senior years of secondary school (Goodrum et al. 2012). Science in the senior years of secondary school (grades 11 and 12) also appears to be taught in a traditional way involving students copying notes nearly every lesson and completing *recipe-based* practical work.

Given the ongoing recommendations that have been made coupled with the initiatives that have been established, the results from these comparisons suggest that while there have been some positive changes in students' perceptions during this 10-year period, many of the negative perceptions identified in the 2001 report still seem to remain in NSW in 2011. There is a need for future research both to identify what impacts upon, or influences, students' perceptions of science, and to investigate if science education initiatives impact their perceptions of school science. Given the baseline data presented here, the SSSQ is one measure that could be used to monitor changes in students' perceptions of the science they experience at school. With the impending implementation of the National Curriculum in Australia that is, in part, focused on inquiry science together with the continued implementation of initiatives at all levels, it is crucial that we continue to investigate what could be considered to be major influences on students' perceptions of school science.

Acknowledgments We acknowledge the three projects from which the student data are drawn: Space to Grow Australian Research Council Linkage Grant (grant number: LP0989264); The Eye Observatory Remote Telescope Project: Practical Astronomy for Years 7, 8 and 9—funded by the Department of Education, Science and Training; and, The Status and Quality of Teaching and Learning Science in Australian Schools- funded by the Department of Education, Training and Youth Affairs. We also thank each of the jurisdictions, the schools, the teachers and the students involved in this research.

References

Ainley, J., Kos, J., & Nicholas, M. (2008). *Participation in science, mathematics and technology in Australian Education: research monograph no 63*. Melbourne: Australian Council for Education Research.

Australian Academy of Science (2010). Science by doing: engaging students with science. http://www.science.org.au/sciencebydoing/index.html. Accessed May 2012

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans: project 2061*. New York: Oxford University Press.

Australian Science Teachers Association (ASTA). (1985). *Science in Australian schools: today's problems and tomorrow's challenges*. Canberra: Australian Science Teachers Association.

Australian Academy of Technological Sciences and Engineering. (2002). *The teaching of science and technology in Australian primary schools: a cause for concern*. Victoria: Australian Academy of Technological Sciences and Engineering.

Barmby, P., Kind, P. M., & Jones, K. (2008). Examining changing attitudes in secondary school science. *International Journal of Science Education, 30*(8), 1075–1093.

Braund, M., & Driver, M. (2005). Pupils' perceptions of practical science in primary and secondary school: implications for improving progression and continuity of learning. *Educational Research, 47*(1), 77–91.

Cleaves, A. (2005). The formation of science choices in secondary school. *International Journal of Science Education, 27*(4), 471–486.

Committee for the Review of Teaching and Teacher Education (CRTTE). (2003). *Australia's teachers: Australia's future advancing innovation, science, technology and mathematics agenda for action*. Canberra: Department of Education, Science and Training.

Danaia, L., McKinnon, D. H., Parker, Q. A., Fitzgerald, M. F., Stenning, P. (2012). Space to grow: LCOGT.net and improving science engagement in schools. Astronomy Education Review 11(1): 010106.

Dekkers, J., & De Laeter, J. (2001). Enrolment trends in school science education in Australia. *International Journal of Science Education, 23*(5), 487–500.

Drury, C., & Allen, A. (2002). Task force on the physical sciences: report and recommendations. Department of Education and Science, Ireland. http://www.sciencetaskforce.ie/. Accessed September 2005

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: learning and teaching science in grades K-8. A research report for the Committee on Science Learning, Kindergarten through Eighth Grade*. Washington, DC: The National Academies Press.

Fensham, P. J. (1985). Science for all: a reflective essay. *Journal of Curriculum Studies, 17*(4), 415–435.

Gaur, A. S., & Gaur, S. S. (2007). *Statistical methods for practice and research: a guide to data analysis using SPSS* (2nd ed.). Thousand Oaks: SAGE.

Gibbs, W. W., & Fox, D. (1999). The false crisis in science education. Scientific American, 87–92.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools*. Canberra: Department of Education, Training and Youth Affairs.

Goodrum, D., & Rennie, L. (2007). *Australian school science education national action plan 2008–2012*. Canberra: Department of Education Science and Training.

Goodrum, D., Druhan, A., & Abbs, J. (2012). *The status and quality of year 11 and 12 science in Australian schools*. Canberra: Australian Academy of Science.

Hackling, M. W., Goodrum, D., & Rennie, L. J. (2001). The state of science in Australian secondary schools. *Australian Science Teachers Journal, 47*(4), 6–17.

Harris, K. L., Jensz, F., & Baldwin, G. (2005). *Who's teaching science? Meeting the demand for qualified science teachers in Australian secondary schools*. Melbourne: Centre for the Study of Higher Education.

International Bureau for Education. (2001). *Science education for contemporary society: problems, issues and dilemmas*. Geneva: International Bureau for Education, UNESCO.

Johnson, B., & Christensen, L. (2004). *Educational research: quantitative, qualitative, and mixed approaches* (2nd ed.). Boston: Allyn and Bacon.

Krogh, L., & Thomsen, P. (2005). Studying students' attitudes towards science from a cultural perspective but with a quantitative methodology: border crossing into the physics classroom. *International Journal of Science Education, 27*(3), 281–302.

Lawrance, G. A., & Palmer, D. H. (2003). *Clever teachers, clever sciences: preparing teachers for the challenge of teaching science, mathematics and technology in 21st century Australia*. Canberra: Department of Education, Science and Training.

Lyons, T. (2006). Different countries, same science classes: students' experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–613.

Lyons, T., & Quinn, F. (2010). *Choosing science: understanding the declines in senior high school science enrolments*. Research report to the Australian Science Teachers Association (ASTA). University of New England, Australia: National Centre of Science, ICT and Mathematics Education for Rural and Regional Australia (SiMERR Australia).

McKinnon, D. H. (2005). *The eye observatory remote telescope project: practical astronomy for years 7, 8 and 9. A research and development report prepared for the Department of Education, Science and Training (DEST)*. Canberra: DEST.

Millar, R., & Osborne, J. (1998). *Beyond 2000: science education for the future (The report of a seminar series funded by the Nuffield Foundation)*. London: King's College London, School of Education.

Murphy, C., & Beggs, J. (2003). Children's perceptions of school science. *School Science Review, 84*(308), 109–116.

Osborne, J., & Collins, S. (2000). *Pupils' and parents' views of the school science curriculum*. London: King's College London.

Simpson, R. D., & Oliver, J. S. (1990). A summary of major influences on attitude toward achievement in science among adolescent students. *Science Education, 74*(1), 1–18.

SISA (Simple Interactive Statistical Analysis) (2012). Bonferroni. http://www.quantitativeskills.com/sisa/calculations/bonhlp.htm. Accessed 25 May 2012.

Tytler, R. (2007). *Re-imagining science education: engaging students in science for Australia's future*. Camberwell: Australian Council for Educational Research.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Engagement in STEM across the primary–secondary school transition: opening up pathways*. Canberra: Australian Department of Education, Employment and Workplace Relations.

Publications of the Astronomical Society of Australia (PASA), Vol. 31, e037, 23 pages (2014).
© Astronomical Society of Australia 2014; published by Cambridge University Press.
doi:10.1017/pasa.2014.30

A Review of High School Level Astronomy Student Research Projects Over the Last Two Decades

M. T. Fitzgerald[1,6], R. Hollow[2], L. M. Rebull[3], L. Danaia[4] and D. H. McKinnon[5]

[1]Department of Physics and Astronomy, Macquarie University, NSW, 2109, Australia
[2]CSIRO Astronomy and Space Science, PO Box 76, Epping, NSW 1710, Australia
[3]Spitzer Science Center/Caltech, M/S 314-6, 1200 East California Boulevard, Pasadena, CA 91125, USA
[4]School of Teacher Education, Charles Sturt University, Bathurst, NSW 2795, Australia
[5]School of Education, Edith Cowan University, Joondalup, WA 6050, Australia
[6]Email: mfitzasp@gmail.com

(Received March 4, 2014; Accepted July 15, 2014)

Abstract

Since the early 1990s with the arrival of a variety of new technologies, the capacity for authentic astronomical research at the high school level has skyrocketed. This potential, however, has not realised the bright-eyed hopes and dreams of the early pioneers who expected to revolutionise science education through the use of telescopes and other astronomical instrumentation in the classroom. In this paper, a general history and analysis of these attempts is presented. We define what we classify as an Astronomy Research in the Classroom (ARiC) project and note the major dimensions on which these projects differ before describing the 22 major student research projects active since the early 1990s. This is followed by a discussion of the major issues identified that affected the success of these projects and provide suggestions for similar attempts in the future.

Keywords: astronomy education – astronomy public outreach – history and philosophy of astronomy

1 INTRODUCTION

Student research, pitched at an appropriate level, can be an effective approach to address the disenchantment about science that results from traditional 'chalk'n'talk' styles of teaching (Hollow 2000). While students can be excited by the breathtaking images in astronomy alone, through research a student can gain a sense of pride and ownership in their work, as well as gain useful secondary meta-skills such as organisational techniques and problem-solving approaches that become invaluable in later studies and work. In addition, some students demonstrate greater capabilities when they are exposed to study at depth than one would have previously expected from their in-class behaviour. Gifted students as well as underachievers and the easily bored can be motivated by tackling some of the 'big questions' that a typical everyday science class lacks (Hollow 2005).

It is also the case that traditional styles of schooling tend to compartmentalise learning into very discrete entities, such as English in English class or computing in computer science class. In the modern world, regardless of whether the career is scientific or not, skills are generally built from many varied components drawn from a variety of traditional subject domains (Gilbert 2005). This reality is modelled much better by a research approach to learning in science than the traditional transmissive mode evident in high school science.

The capacity for true high school-based astronomical research has exploded over the last twenty years and this has a lot to do with rapid technological advancement. In the early nineties, affordable charge-coupled device (CCD) cameras became available which delivered near-instantaneous images from telescopes rather than the previous long and tedious processing of photographic film (Baruch 1992). While unimaginably slow by present day standards, early modems and bulletin board systems and then the Internet provided a method of 'instantaneous' and cheap long-distance delivery of these images (at least compared to sending the images through the post on disk), as well as the potential for remote control of the observatory itself.

As it was noted while it was occurring (Baruch 2000, Sadler et al. 2000, Hollow, McKinnon, & White 1998), it is the recent development of fast internet infrastructure that has allowed high school research projects involving astronomy to scale up in recent years. Other Information Technology (IT) developments, such as inexpensive hardware especially in terms of speed and capacity to share large amounts of data, and software to undertake a full analysis, have also contributed. It is also these factors that have allowed remote observing on major research grade observatories to become technically feasible.

Developments in IT even the playing field as less well-resourced schools can freely access such equipment and tools. Prior to this, access may have been the province of the wealthier schools (Gould, Dussault, & Sadler 2007). Even schools who (due either to budgets, Occupational Health & Saftery (OH&S) requirements or the nature of the school's neighborhood) deny students access at night can remotely observe, e.g., from Japan or Australia during a school day in the US. The development of freely available, or relatively inexpensive software, potentially capable of scientific grade measurements, such as Astrometrica (http://www.astrometrica.at/), Makali'i (Horaguchi, Furusho, & Agata 2006), ImageJ (Hessman & Modrow 2008), Aperture Photometry Tool (Laher et al. 2012), and SalsaJ (Doran et al. 2012) go some of the way towards solving earlier issues of inaccessibility to adequate astronomical analysis software (Beare 2006).

The earliest endeavours were initially made with more modest smaller $\approx 12''$ scale telescope systems. As the nineties and early 2000s progressed, larger telescopes and wider, more public, distribution networks grew, e.g., Telescopes in Education (Clark 1998), the Global Telescope Network (http://gtn.sonoma.edu/), the $24''$ at Yerkes Observatory (Hoette 1998) and the MicroObservatory telescopes (Gould et al. 2007). Recently, larger research grade telescope systems have been constructed which provide telescope time to education projects, e.g., Las Cumbres Observatory Global Telescope (LCOGT; 2×2m Faulkes; Hidas et al. 2008, Gomez & Gomez 2011; http://lcogt.net) in Hawai'i, USA and Australia, the National Schools Observatory/ Liverpool Telescope (NSO/LT; 1x2m; Steele 2004; http://telescope.livjm.ac.uk/) in La Palma, Canary Islands and MOnitoring NEtwork of Telescopes (MONET) (2x1.2m, http://monet.unigoettingen.de) in Texas, US and South Africa. There are also more modest aperture, but still quite sophisticated setups such as the Astronomical Research Institute (http://www.astro-research.org/) in Illinois, US and Tzec Maun Observatory (http://blog.tzecmaun.org/) who host various telescopes in the US and Australia. Notably for optical projects, the ability to connect to a telescope on the other (dark) side of the world opens more possibilities where once it may have required night time observing sessions. As a very useful side-effect, it requires a much decreased learning curve on the part of the teacher to access a remote automated telescope through the internet than to drive a semi-automatic telescope in person (Beare 2004).

The use of radio astronomy equipment, data and observing techniques at the high school level has been far less widespread than in optical astronomy. In part, this is due to the greater conceptual difficulty of viewing and interpreting radio data compared with optical data but it is also due to equipment issues. Some schools such as Taunton School in the UK (Hill 1995) achieved remarkable results in building and using a variety of radio telescopes, including making interferometric observations of the emission from the collision of Comet Shoemaker-Levy 9 with Jupiter. Some schools have used equipment projects such as Radio Jove to establish a radio astronomy provision within their school. Two schools in Australia relocated old dish antennae from the CSIRO Culgoora Radio Heliograph for use within their schools but at least one of these is no longer in use. More recently, several other successful schemes have been implemented in the US and Australia.

In this paper, we aim to provide a summary and analysis of the types of projects that try to, at some reasonable scale, get high school students and/or teachers to undertake, or contribute to, some type of astronomy research. We summarise the criteria used to select projects for this review, define the major dimensions on which the projects differ, provide a description of each project and end with a discussion of the general issues that impact on the success of these projects.

2 DEFINITION OF AN 'ARiC' PROJECT.

It is very difficult to categorise these projects into one homogeneous easily inter-comparable group because, while there are many similarities, there are also many differences. The core similarity is that high school students (Yr 9–12) have, at some point, participated in original astronomy using real data from a real instrument, or as close to this as could be realistically practical.

This is too broad and simple a definition to be generally useful, so we seek to define further criteria for what is, or is not, an Astronomy Research in the Classroom (ARiC) project. Providing and using criteria will always leave out some projects that others may have chosen to leave in. It is, however, beyond the scope of this paper to be too permissive and include every possible astronomy-focussed project. There are other repositories available online that collect lists of programs attempting to bring astronomy data into the classroom (http://nitarp.ipac.caltech.edu/page/other_epo_programs).

The following are our nine criteria that a project needs to meet to be defined as an ARiC project. Within reason, these criteria are flexible, especially over the dimension of time; for example, due to technology constraints, earlier projects were much more difficult to run than more recent projects.

(1) Within the project, there is some capacity for original research.

The first criterion is basically a simple definition of an ARiC project. The contribution must be intended to be new, however small, and not be a re-run of previously undertaken research. We are not looking at simulations of real methodologies, such as the CLEA materials (http://www3.gettysburg.edu/ marschal/clea/CLEAhome.html) where the methodological steps that scientists take from observations to results are very well simulated, or canned exercises using real astronomical data contained within existing programs. It can be argued that these activities do have their place in education, and are often vital stepping stones to doing real astronomical research, but they are not the same as actually doing the research. At best, an ARiC project contains within itself mechanisms that can direct the student's novel results towards publication, even in a journal aimed at student publications.

(2) Data should be from a research-grade instrument and detectors, preferably taken by the students themselves.

The second criterion allows multiple astronomical research techniques, perspectives and methodologies to be valid within reason. For instance, optically observing a variable star/s with an amplitude of a large fraction of a magnitude can be undertaken on nearly any clear night, whereas to get a decent colour-magnitude diagram of an open or globular cluster could require precision photometry with outstanding seeing in near-perfect observing conditions. In this case, the direct use of an optical telescope by the student is an option for the first instance above, whereas pulling the data from a research-quality archive is a better option for the second instance. This is a scientific precondition that drives certain pedagogical decisions rather than the other way around. It is important that the end result of a student's research is a scientifically valid contribution, however small, and not, in actuality, a waste of time due to methodological errors. To that end, if the scientific endeavour requires the data-mining of previous observations rather than taking brand new observations, this is also considered to be valid. This criterion also incorporates practical considerations, e.g., if the resources or manpower required to get the project running are prohibitive then requirement for completely new observations is relaxed. This criterion is thus intended to be flexible within reason.

(3) ARiC projects should focus on the interpretation of data, not just the acquisition.

ARiC projects should mimic a real-world research project as much as possible, and encompass at least a few of the steps from the generation of an original idea, through research proposal, literature search, data acquisition, data reduction, and data interpretation, followed by new questions to pursue as a follow-up. Preferably, students should use Flexible Image Transport System (FITS) files, or other standard research data containers and formats, directly. This distinguishes ARiC programs from programs such as the crowd-sourced citizen science programs such as Galaxy Zoo (http://www.galaxyzoo.org/) or Moon Mappers (http://cosmoquest.org/mappers/moon/) as outlined in Mendez et al. (2010), where many people participate in looking at real data, but most of the participants typically require a comparatively smaller understanding of the data acquisition, reduction, or interpretation of the ensemble of crowd-sourced results.

Whilst most citizen science projects are not specifically aimed at formal education but rather at informal education, programs such as the Zooniverse are now actively attuned to possibilities and potential of use of programs within the classroom. Such projects are developing useful education tools and educator communities. These are likely to offer some exciting possibilities for ARiC projects in the near future.

(4) The project must rely fundamentally on the methodologies and typical approaches of the science of astronomy.

It is true that there can be much interdisciplinary crossover between astronomy, by which we mean the study of celestial objects, and that of planetary science, whether of Earth or other planets (e.g. http://marsed.asu.edu/mesdt-home, http://minirf.jhuapl.edu/), or that of Space Science, the study of nearby interplanetary space (e.g. http://cse.ssl.berkeley.edu/artemis/epo.html), or with chemistry or biology. For this paper, we choose to focus specifically on astronomical topics. While craters on the Moon and the atmosphere on Mars are interesting extra-planetary topics and are of course not truly distinct from the rest of astronomy (e.g., via extrasolar planets), they often use different language, methodology and approaches to what we typically call 'astronomy'. In the context of this paper, however, since we study asteroids with the general techniques of astrometry and photometry, we make a small exception and include here projects involving asteroids. The study of the nature of the Moon and other planets in our Solar System, however, is beyond the scope of this paper. Unavoidably, this is a criterion with somewhat ill-defined boundaries, boundaries that can also move with time as scientific approaches to the study of natural phenomena themselves change.

(5) The focus of the project must be on astronomy rather than general science.

There are many organisations and projects around the world that offer generic 'science research projects' where students or educators are generally paired up with a mentor for a one-off science project in any of a wide variety of subjects. The projects we consider here are solely those that are specifically astronomically focussed, and not those that necessarily lead to a one-off science project (see also criterion 7 below).

(6) Interaction with Students and Teachers must be active, not passive.

ARiC projects must involve active, rather than passive, interaction of project personnel with teachers and students. Curriculum repositories such as the SDSS Skyserver materials (http://skyserver.sdss.org/public/en/), the Hands-On

Astrophysics/Variable Star Astronomy materials developed by Donna Young, Janet Mattei and John Percy (Mattei, Percy, & Young 1997, http://www.aavso.org/education/vsa) or the Chandra activities (http://chandra.harvard.edu/edu/) while valuable, therefore do not qualify. Simple technology provision kits, while enabling science discovery in the classroom, do not necessarily actively promote interaction of scientists with teachers or students.

(7) Involvement of multiple teachers and/or multiple student groups.

We do not focus on single teacher led-projects at specific schools for specific populations of students, even though there have been some fine examples of great projects occurring, such as work at the Taunton Hill Radio Observatory (Hill 1995), Blue Mountains Grammar School (Hollow 2000), The Latin School of Chicago (Gehret, Winters, & Coberly 2005). Nor do we consider one-off field trips, since they do not mimic the scientific process. This criterion is to ensure that the ARiC project can work in more than one classroom, involving more than one teacher, enabling at least the possibility that the project is scalable and sustainable.

(8) Projects are aimed at students or teachers at the high school (School Years 9-12) level.

We consider only the high school level components of the projects discussed. Some of the listed projects have, additionally, more substantial undergraduate, elementary or middle school components. To get students interested in science and astronomy, it is well recognised that recruitment needs to begin by the middle school level (Tytler et al. 2008, Barmby, Kind, & Jones 2008, McKinnon & Geissinger 2002). However, projects that are aimed at this level are of a different nature and are outside the scope of this review.

(9) Established continuing track record

In this review, we have omitted some potential projects due to the fact that they are still in development but have mentioned student research as one of their goals as this review is written. We mention these projects here for completeness: Comenius Asteroid Project (http://grudziadz.planetarium.pl/comenius/), Global Jet Watch (http://www.globaljetwatch.net/) or the SOFIA Airborne Observatory (http://sofia.usra.edu/). It is simply our requirement that something substantial must have occurred within the project for us to be able to discuss it.

There are other projects that have begun but have yet to generate enough data. One example is MONET, using a pair of 1.2 m telescopes, one in Texas and one in South Africa (Bischoff et al. 2006), that have had some early success and published some articles (Backhaus et al. 2012, Beuermann et al. 2011 & Beuermann et al. 2009) but is yet to get rolling in a stable manner. Another example is the Spice-Physics-ICRAR Remote Internet Telescope (SPIRIT) (http://www.spice.wa.edu.au/) pair of observatories at the University of Western Australia. It was officially opened in 2010 for the use of high school students, both remotely and robotically.

3 DIMENSIONS OF PROJECTS

Even within the limitations we have imposed, there are nearly as many types of ARiC projects as there are actual projects. They can display different approaches, have widely varying budgets, and hence cannot generally be compared directly. The dimensions outlined here are not rating scales, but rather descriptions of difference. Few of these projects have detailed descriptions in the widely available literature, and so we have defined dimensions in an effort to describe some basic differences and similarities amongst the projects. There are quite a large number of conference proceedings outlining project directions as well as media releases that advertise particular project successes. However, there are many fewer publications of scientific outputs available in the literature (as may be reasonably suspected), and only very rarely are there methodologically strong evaluations of efficacy in terms of student knowledge or motivation outcomes in science. This is also to be expected as a recent analysis of IAU papers (Bretones & Neto 2011) comes to similar, more rigorous conclusions that research into astronomy education, in general, requires deeper treatments. The lack of good quantitative data in high school astronomy education has been known for a while (Hollow 2000). We now go into detail about the various dimensions we have used to characterise broadly each of the projects. Where each project sits in relation to these dimensions are listed at the top of the description of each of the projects.

3.1 Teachers / Students / Both

One of the major dimensions we use below is whether the project focus is on teachers or students as a group or on both groups. Some projects seek to get research undertaken in the classroom via empowering the teacher with inquiry-based scientific skills in the hope that they will in turn get their students to undertake research. In this respect, these projects are also attempting to empower the teacher to better present science to their current and future students in a more engaging manner in addition to implementing authentic research in the classroom.

Other projects act to try to extract particularly interested students from their classrooms as candidates to undertake research. The teacher is used as a recruitment tool to find highly engaged students. Some projects involve the personnel taking control and direction of the classroom activities (either by going into the classroom or bringing the students to the project's staff) leaving the teacher to act in a supervisory or administrative role.

Teacher professional learning about authentic inquiry-based science education is something that takes a large amount of time, effort and resources (e.g., Supovitz, Mayer, & Kahle 2000, Gerbaldi 2005, Loucks-Horsley et al. 2003) but can have flow-on benefits for the teachers' future students (e.g., Silverstein et al. 2009), and a multiplicative impact on science education. Student-focussed projects cut straight to the student, eliminating the costs and resources in both money and time, for large amounts of teacher training.

3.2 Structured / Guided / Coupled Inquiry

The tradition of four categories of inquiry were first defined by Schwab (1960) and Herron (1971). Confirmatory Inquiry is where the results of a scientific undertaking are largely known in advance and the scientific endeavour is simply to re-confirm accepted knowledge. By definition, and via criterion number one, this style of inquiry is excluded from this review. Structured Inquiry is where, the larger question and the methodology of an endeavour are quite rigidly set by the teacher/mentor, and the students are led through the methodology to gain a new answer at the end. Guided Inquiry is where, the question is set by the teacher/mentor, but the methodology and process are to a reasonable extent left to the students to design and undertake. Open Inquiry is where students can decide upon their own research question and methodology within the resources available, while the teacher/mentor acts as a guide or facilitator rather than a traditional instructor.

It is quite unlikely, and pedagogically not feasible, for any student or novice researcher, without prior conceptual and methodological understanding of the scientific field, to launch simply straight into Open Inquiry. More reasonably, the idea of 'Coupled Inquiry' (Dunkhase 2003) is a feasible approach, where students are initially led through either Structured or Guided or some combination to a level where they are capable of undertaking true Open Inquiry. As Open Inquiry has to be preceded by scaffolding at some time and at some level, we leave this out of our discussion. More importantly, scaffolding is required because students cannot do research if they do not understand the content area and methodology of the research field itself (Etkina, Matilsky, & Lawrence 2003).

3.3 Archival / Pre-Observed / Newly Observed

This dimension captures whether the project uses data which has been previously analysed and exists in archival datasets, data which has been pre-collected but not analysed or whether the data is collected during the project itself.

3.4 Selective / Non-Selective / Partially-Selective

Some projects are open to all who are interested and some are highly academically selective. Others are not necessarily selective, but through their recruitment procedure, end up being selective.

3.5 Easily Scalable / Non-Scalable / Scalable with Difficulty

This dimension is a question of ability to expand given sufficient funding. For instance, an easily scalable project would be one where you would involve twice or more of the population for twice the cost or less. The limiting aspects can relate to the use of a specific instrument or telescope. Unless the telescope is specifically devoted for student use or educational projects, there is an inevitable restriction on time availability if the education projects require their own observations. If the data are primarily archival, the limiting factor may be the number of project personnel recruited to work with the teachers and students.

3.6 At School / External / Mixture

This describes whether the teachers and students undertake the project predominantly in their schools or from home (At School), or at another external institution (External), or it is a mixture (i.e. a workshop at an external institution, then some work back at school/home).

4 SUMMARY DESCRIPTIONS OF PROJECTS

In the description of the projects, we have left out the general motivations for the project as they tend to be quite similar. In sum, there is much focus on motivating students in science in high school to inspire them to become scientists or engineers or simply scientifically literate voters in the future through engaging with authentic research experiences. Few science teachers have deep experience in scientific research. This can be a problem because it is difficult to teach what one has never experienced; an analogy would be that one would never hire a sporting-team coach for a high-profile team who had never played that particular game.

There are many statements comparing the gap between "best practice" and "actual practice" in science teaching (e.g., Goodrum, Hackling, & Rennie 2001; Goodrum, Druhan, & Abbs 2012; European Commission 2007; Osborne & Dillon 2008) as well as a gap between the pupils', parents' and teachers' perception of the curriculum (Osborne & Collins 2000). Often there is also reference to the necessity of having enough Science, Technology, Engineering and Mathematics (STEM) trained people or of a particular shortfall within their respective countries (e.g., Select Committee on Science and Technology 2002; European Commission 2004; Tytler 2007; Tytler et al. 2008). Other goals include advancing teacher and student understanding of the nature of science and technology (Duschl, Schweingruber, & Shouse 2007), teacher professional learning (Osborne & Dillon 2008) and use of information technologies as well as making links between science and other parts of the school curriculum. Rather than focus on individual motivations, we focus on what the projects do or did. We have also steered clear of commenting on the project's applicability to its related curriculum, because this can be highly variable across, as well as within, nations.

It may be noted that the majority of these projects are English-speaking and primarily from the USA with a small number of projects from the UK and Australia. Significant effort was made to find projects in non-English speaking countries, most notably Japan and Continental Europe, however projects fitting the criteria outlined in this paper were not found in our search

Each of the projects is presented in alphabetical order. We briefly summarise their major statistics in terms of Project Era, Budget, Scope, and Participants as well as where they fall in terms of the dimensions defined above in tables 1–22. The project is then described briefly, with information sourced from a mixture of published papers, conference proceedings and through informal interviews conducted face-to-face, by telephone, via Skype or through email.

4.1 Arecibo Remote Command Center (ARCC)

The Arecibo Remote Command Center (ARCC), based at UT Brownsville, uses the largest single radio dish in the world, the 305 m Arecibo Radio Telescope in Puerto Rico, as well as the 64 metre dish at Parkes, NSW Australia (http://www.parkes.atnf.csiro.au/) and the Green Bank Telescope (GBT; https://science.nrao.edu/facilities/gbt/). The instruments are used to get high school and undergraduate students to make observations and undertake analyses in searching the galaxy for pulsars. There is also an ARCC at the University of Wisconsin, Milwaukee (http://www.gravity.phys.uwm.edu/arcc/). High School students can access a summer school program "21st Century Astronomy Ambassadors", which involves a three- week residential program and further ongoing involvement. Students use archival data from GBT, Arecibo, Parkes and LWA. There is also capacity to conduct new observations with GBT and Arecibo as well. Students have discovered 25 pulsars; in 2011 they discovered approximately 40% of all pulsars discovered that year.

Table 1. Arecibo Remote Command Center Summary.

Founded	2005
End Date	Continuing
Budget/Yr	10 000 USD
Funding source	NSF & NASA
Cost to participants	Free
N (Teachers)	NA
N (Students)	15-20/year
N (Schools)	5-10/year
Location	SW USA
Website	http://arcc.phys.utb.edu
Population	Students
Inquiry depth	Varies
Data rawness	Varies
Selectivity	Selective
Scalable	No, due to limited telescope time
On/Off-campus	External

4.2 Bradford Robotic Telescope (BRT)

Originally commissioned in 1993 in the Yorkshire Pennines (Baruch 2000), the Bradford Robotic Telescope (BRT) is now a 0.365 m completely autonomous robotic telescope sited in Mount Teide, Tenerife in the Canary Islands. Initially, the telescope was begun as an engineering/astronomy project, but over time transitioned into a primarily educational/outreach organisation, as teacher interest was unexpectedly high and sustained and education related funding started to flow towards the project. BRT allows schools and the general public to submit observing 'jobs' to the telescope over the internet through a portal website. The images are then queued, observed robotically, and then returned to the user. The telescope itself has three main cameras, a 'constellation' camera (40 degree field of view (FOV)), a 'cluster' camera (4 degree FOV) and a 'galaxy' camera (20 arcminute FOV). Requested images are usually obtained and returned within a night or two, depending on weather conditions and celestial location of the object.

Table 2. Bradford Robotic Telescope Summary.

Founded	1993
End date	Continuing
Budget/Yr	280 000 UKP
Funding source	Self-funded + 1 University position
Cost to participants	70 UKP/year/school
N (Teachers)	4000 Total, 450 per year
N (Students)	90,000 Total, 13,000 per year
N (Schools)	1500 Total, 200 per year
Location	UK, Europe
Website	http://telescope.org
Population	Both
Inquiry depth	Structured
Data rawness	Newly observed
Selectivity	Non-selective
Scalable	Easily scalable
On/Off-campus	At school

Schools are charged for usage as the administrating university wants the project to pay its own way. While amateur astronomers, some of whom looked for supernovae and NEOs, have had free use for many years, they are also now charged. Historically, the telescope was run mainly through a variety of grants and subsidised by in-kind support from the university. Nowadays, BRT only receives grants for educational research and outreach work. There are six staff members, five of whom are covered by the income from the project, while the PI's income comes from university. Overall, there are 100,000s of school users (and 30,000 amateur users).

The BRT is focussed at Grades 3 to 6 (Key Stage 2) up to Grades 10 and 11 (Key Stage 4) and provides education and teaching materials for all years. The main focus of the project is on education and learning rather than on authentic research itself. There are possibilities for open-ended use of

Table 3. Charles Sturt University Remote Telescope Summary.

Founded	1999
End date	Continuing
Budget/Yr	2500AUD
Funding Source	Self-funded
Cost to participants	Donations
N (Teachers)	70/Year, 800 Total
N (Students)	1500/Year, 25,000 Total
N (Schools)	50/Year, 400 Total
Location	Australia, Europe, Canada, USA
Website	http://www.csu.edu.au/telescope/
Population	Both
Inquiry depth	Structured
Data rawness	Newly observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	At school

Table 4. Faulkes Telescope Project Summary.

Founded	2003
End date	Continuing
Budget/Yr	Internal university funding
Funding source	Initially grant-funded, now internal university.
Cost to participants	Free
N (Teachers)	Exact numbers unknown
N (Students)	Exact numbers unknown
N (Schools)	200-250 Schools per year
Location	UK, Europe
Website	http://www.faulkes-telescope.com
Population	Teachers
Inquiry depth	Structured/Guided
Data rawness	Newly observed
Selectivity	Not selective
Scalable	Scalable
On/Off-campus	At school

the BRT through its various programs, although currently the inability of the scheduler to acquire calibration frames easily or series of related images limits its use to general colour imaging. While it is possible for the students to undertake research through the BRT, the general focus is on getting all students familiar with the night sky and pushing the more interested students to larger research-based projects such as others listed in this paper.

Largely, teachers have approached BRT to get involved themselves through finding the project through the web or via word of mouth. BRT also actively looks for teachers by choosing an area, looking for supportive grants in the area and then linking up with the secondary schools and the primary schools that feed the secondary schools. A large recent thrust of the BRT project is to provide professional development for teachers in the area of astronomy subject knowledge because it is perceived that one source of what discourages students in science is the teacher's relatively poor perception of science. The program provides professional development (PD) for a teacher in his or her classroom. This has resulted in a far larger usage of the telescope than other more traditional models in terms of number of students involved, projects undertaken, and activity on the website. In one year, the project generally provides in-classroom PD for 200 to 300 teachers.

4.3 Charles Sturt University Remote Telescope Project

The Charles Sturt University Remote Telescope Project (CSURTP) was initially set up, in 1999, for use specifically by upper primary school (Years 5 & 6) students (McKinnon & Mainwaring 2000) as a 12″ telescope that could be used to gather images in real time via the internet. This has since been expanded to include high school level (Years 7–10) (McKinnon 2005, Danaia 2006) and beyond. Some senior students in Australia and Canada have used the system to acquire data on variable stars as part of their science assessment requirements to undertake an individual research projects.

The primary use of the CSURTP is driven through the 'A Journey through Space and Time' curriculum materials. These materials lead teachers and their students through preparing and planning for using the telescope remotely as well as interpreting their observations after the observing session. Many different sets of materials are provided that allow students to explore various aspects of astronomy from simple astrophotography up to monitoring variable stars and creating colour-magnitude diagrams of stellar clusters. The depth to which the teacher goes is decided by the teacher in their particular context.

The 'Eye Observatory' Project, using this facility and materials developed for the CSURTP, provided an educational evaluation of over 2000 students and 101 teachers from 30 schools as they went through an investigative structured inquiry procedure (Danaia 2006). Highly significant gains in terms of the students' understanding of astronomical phenomena and a marked reduction in alternative conceptions via using a subset of questions from the Astronomy Diagnostic Test (Hufnagel et al. 2000) were achieved. Students' perceptions of science in school and in the larger world showed significant gains, although these varied dramatically between differing schools, teachers and student groups.

4.4 Faulkes Telescope Project

The Faulkes Telescope Project (FTP) is hosted at the University of Glamorgan. It was initially based in Cardiff, Wales from 2003 to 2010, using Faulkes Telescope North (FTN) from early 2004 and Faulkes Telescope South (FTS) from early 2006. The FTP focuses on providing access to telescope time to UK schools and educational groups for general use, as well as materials facilitating student research (Lewis et al. 2010, Roche & Szymanek 2005) through collaboration with FTP astronomers.

FTP was initially set up as an educational team by the Dill Faulkes Educational Trust (http://www.faulkes.com/dfet/)

who had constructed the Faulkes Telescopes via a substantial GBP10 million donation in the late 1990s/early 2000s. In 2003, just before FTN came online, the team started building an education program using funds provided by Dr Dill Faulkes and also a 600,000 GBP grant from the UK government. In particular, this program focussed on teacher training to get teachers capable of using the telescopes. It was, from late 2005 to 2010, an educational and research arm of LCOGT, but is now an internally funded university program.

Initially, many of the schools that joined were from the private sector in the UK rather than the publicly funded sector. The reason for this seemed to be because teachers from these schools are usually more highly qualified and have greater control over the curriculum offerings at their schools. Over time however, publicly funded schools slowly came on board. There are 200–250 schools using the telescope regularly out of about 4500 high schools in the UK. The project is currently working to branch out into Europe; they have some European schools on board in Portugal, France, and Germany, amongst other countries. With the new European focus, there are more projects coming on board as well as well as involvement with ESA.

The project is trying to build projects where astronomy researchers require data and teachers and students can be involved in the acquisition of those data using the Faulkes Telescopes. While there were some issues with quality control of the data, the early feedback indicated that schools liked the fact that they were helping real astronomers. The projects had to be something that students could actually get their heads around, rather than an obscure topic where they may not know what they are doing, and preferably produce something aesthetically pleasing. Topics that seemed to work well were topics such as open clusters as well as galaxies, but the asteroid and comet studies were what really had an impact and which have also seen significant involvement by the amateur community. Approximately half of the schools involved undertake just "pretty picture imaging" once a year during their astronomy topic. Not all schools are doing astronomy as part of the formal curriculum; some are using FTP materials in their after-school or lunch-time programs. The other half regularly engage with projects that have been made available online.

A recently tested approach has been to suggest targets for the students to observe for scientists during their ordinary observing sessions. The most popular though, in terms of getting schools on board, was advertising "themed observing days/weeks/months", where an entire period of time (usually a day) is spent looking at a particular object, such as an asteroid or a group of galaxies. Schools had to sign up to be allocated time, usually 30 minutes, on that day and these were generally two to three times oversubscribed. In return, scientists got eight hours of concentrated data.

A group of UK schools helped name an asteroid, 2004WB10 'Snowdonia' that they observed with FTN as well as 2005HJ4 'Haleakala'. Working with Richard Miles, other schools determined the rotation rate of the rapidly rotating asteroid 2008HJ (Lewis & Roche 2009). In addition, there are many asteroid observations published through the Minor Planet Centre (http://www.minorplanetcenter.net/). Students are also involved in collecting data for an X-ray Binary monitoring project (Lewis et al. 2008), although they do not analyse the data directly due to the restrictive software requirements.

4.5 Goldstone Apple Valley Radio Telescope (GAVRT)

The GAVRT Program was initially run through JPL and the Lewis Center for Educational Research. The core of the GAVRT is a 34-meter radio telescope previously used as a node in NASA's Deep Space Network, which is now provided for teachers and students to use. As of early 2012, GAVRT had served 490 Teachers in 290 Schools, mainly in the US, but also 14 other countries including Chile, Germany, Italy, Japan, South Korea and the UK. Current statistics can be seen here (http://gsc.lewiscenter.org/gavrt/schools.php). Permanent staff in the project include a part-time manager and a full-time and part-time operator.

The main professional learning approach for teachers is via a 5-day workshop providing skills in radio astronomy basics, radio telescope control and curriculum support. Project scientists take time out of their schedules to visit students in their classroom or connect via video conferencing as well as answering questions by email. The current astronomical focus of GAVRT is on Jupiter, Quasars and the Search for Extraterrestrial Intelligence (SETI). The students have their observing routine relatively well laid out for them in the curriculum materials in terms of what scans to run, frequencies, sources and rates, although in the SETI program there is more freedom in terms of target selection and analysis. Access to data is through an online access tool, but during the sessions, students undertake calculations to convert the data into something they can understand.

Table 5. Goldstone Apple Valley Radio Telescope Summary.

Founded	1997
End date	Continuing
Budget/Yr	Unknown
Funding source	Congressional appropriations
Cost to participants	Free
N (Teachers)	490 Total
N (Students)	32,000 Total
N (Schools)	290 Total
Location	USA and 13 other countries
Website	http://www.lewiscenter.org/gavrt
Population	Teachers
Inquiry depth	Structured
Data rawness	Newly observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	Mixture

Table 6. Hands On Universe Summary.

Founded	early 1990s
End date	early 2000s
Budget/Yr	400 000 USD
Funding source	Initially NSF
Cost to participants	Free
N (Teachers)	800 Total
N (Students)	Unknown
N (Schools)	Unknown
Location	Global but predominantly USA
Website	http://www.globalhou.net
Population	Both
Inquiry depth	Structured
Data rawness	Varies
Selectivity	Not selective
Scalable	Scalable
On/Off-campus	At school

4.6 Hands On Universe

Hands-on Universe (HOU) (http://www.handsonuniverse.org/) started in the early 1990s as a project to get students, primarily in grades 9–12 (Rockman et al. 1994) actively 'hands-on' with real noisy astronomical data, rather than traditional lecture-style teaching. The current version of the project is run through Global Hands-on Universe (GHOU, http://www.globalhou.net/) at UC Berkeley in the USA and Nuclio in Portugal, and is primarily a teacher training project rather than an ARiC style project.

The earlier form (pre-2000) of the HOU project was supported by much more substantial funding than the current form. A lot of this early funding went into development on various fronts such as software, telescope infrastructure, curriculum development, and teacher training. During this earlier era, HoU attempted to create a network of observatories from various university, private, and public institutions who could provide a percentage of their observing time to the HoU project. This network initially started out using the 30″ automated telescope at Leuschner Observatory at U.C. Berkeley (Asbell-Clarke et al. 1996) and expanded to a variety of telescopes around the world (Boer et al. 2001).

The materials originally created for Hands-On Universe are now part of the Global Systems Science curriculum (http://www.globalsystemsscience.org/). Teacher training in the earlier version of HOU was provided during summer workshops using a model where teachers who had previously undertaken the workshop trained the next cohort of teachers and acted as 'Teacher Resource Agents'. By mid-1998, it was estimated there were over 500 US teachers and hundreds of international teachers who had undertaken the training under a TRA (Pennypacker 1998). Projects included measuring variable stars, sizes of objects in the Solar System and telescope construction (Pennypacker & Asbell-Clarke 1996), as well as more open-ended curricula via acquiring images from the automated telescopes. Custom HOU software that performed a variety of image display and analysis tools was constructed for this purpose, but has since been dropped as more recent technologies and better software has arisen in the community.

A web based asteroid search project using archive images from the 4m CTIO Blanco telescope was designed in the mid 1990s. Using an image subtraction method, many main belt asteroids were found, but the most interesting success was that students had found a Trans-Neptunian object (1998 FS144) which was reported to the Minor Planet Centre (MPC) (Pack 2000). Two students from Oil City High School involved with the project also helped measure the lightcurve of a supernovae and were co-authors on a scientific paper (Richmond et al. 1996).

4.7 Hawaii' Student Teacher Astronomy Research Program (HISTAR)

The Hawai'i Student/Teacher Astronomy Research Program (http://www.ifa.hawaii.edu/UHNAI/HISTAR.html) started in 2007. Approximately seventeen 12 to 16 year old students per year are selected from local Hawaiian schools, as well as teachers, to attend the week long 9 am to 9 pm workshop at the Institute for Astronomy at the University of Hawai'i. During the workshop accompanied by traditional lectures, students undertake a research project with an astronomical mentor lasting the full week. They do a 10-minute presentation of their results at the end of the program. They also have observation sessions with the DeKalb 16″ Telescope in Indiana (http://www.starkey.ws/new observatory.html) and the 2-meter Faulkes Telescope in Hawai'i (lcogt.net), and attend a variety of field trips to planetariums and university departments.

The program authors' intention is to equip students and teachers with the background knowledge to undertake astronomy research that they will continue on return to their schools with the help of a mentor. Projects include such topics as variable star photometry, comets, extra-solar planets,

Table 7. HISTAR Summary.

Founded	2007
End date	Continuing
Budget/Yr	15 000 USD
Funding source	Grants, Donations, Agency Funds
Cost to participants	150 USD
N (Teachers)	Unknown
N (Students)	12–16/year
N (Schools)	NA
Location	Hawaii', Continental US
Website	http://www.ifa.hawaii.edu/ UHNAI/HISTAR.html
Population	Both
Inquiry depth	Guided
Data rawness	Newly observed
Selectivity	Selective
Scalable	Scalable
On/Off-campus	External

and rotational velocities and masses of galaxies (Garland, Kadooka, & Nassir 2008). About 30% of each year's intake are returning HI STAR students who have completed a research project and have come back to learn more. These students have entered their research in science fairs and won a variety of awards (Kadooka, private communication). This project is sponsored by NASA's National Astrobiology Institute (NAI), Institute of Astronomy (IfA) and the Center for Computational Heliophysics in Hawai'i (C2H2) as well as contributions from a NASA IDEAS grant and LCOGT.

4.8 International Asteroid Search Campaign (IASC)

Commencing in October 2006, the focus of the Hardin-Simmons University-based International Asteroid Search Campaign (IASC) is to guide students through the process of astrometrically analysing supplied asteroid and NEO observation data sets to, at the final stage, publish their discoveries and measurements to the Minor Planet Center (Miller et al. 2008). The data were initially collected solely for this purpose using two (0.81 m and 0.61 m) telescopes at the Astronomical Research Institute in Illinois (http://www.astroresearch.org/). Now data collection has progressed to include the Pan-STARRS telescope, the 2m Faulkes Telescope in Hawai'i, a 1.3m instrument at Kitt Peak and the 60–90 cm Schmidt Telescope from National Astronomical Observatories of China, as well as a variety of other telescopes and ones coming online.

There is no cost to participate. The program ran with help from volunteers and without funding until 2012 when grant funding started. Funding included a grant from the European Commission through the Paris Observatory and supplemental funding from Texas. IASC is a volunteer organisation; the data reduction team consists of four people around the world who donate their time. They validate the MPC reports sent in by students after which they send the validations to the MPC. Teachers are predominantly self-trained using supplied materials, practice data sets and the Astrometrica software package (http://www.astrometrica.at/). Online help is provided at any time, although there have been the occasional face-to-face training session as well. The project plans to offer more face-to-face sessions. The training for the main belt observations must be done and class implementation must occur before teachers are invited back to undertake further training using the raw data used in the NEO campaigns. The actual structure of any in-class implementation is left heavily up to the teacher to design.

Table 8. International Asteroid Search Campaign Summary.

Founded	2006
End date	Continuing
Budget/Yr	None until 2012
Funding source	Small grants
Cost to participants	Free
N (Teachers)	500/year
N (Students)	5000/year
N (Schools)	500/year
Location	Global
Website	http://iasc.hsutx.edu
Population	Teachers
Inquiry depth	Structured
Data rawness	Pre-observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	At school

Prior to delivery to the teacher, the data are pre-screened for astrometric quality. IASC is performed on pre-set 30-day main belt and 60-day NEO asteroid campaigns each year, with team members post-validating any discovery made by the students. Approximately 500 schools in 60 countries are now participating. There are ten five-week segments and anywhere from 30 to 80 schools participating in any one segment. Participation is largely dependent on the telescope resources available during the period. The ultimate goal and capacity is to grow to around 1000 schools. To achieve this, IASC is looking for grant funding to automate a lot of the processing and MPC reports. If professional staff can be hired, then the project could be expanded to 5,000-10,000 schools.

As of 2008, with the publication of their outline paper cited above, 36 new Main Belt asteroids, 197 NEOs and one comet were discovered (Miller et al. 2008). As of this writing, the number is around 350 asteroids, of which 15 are now numbered and being named by their students. The outputs include more than 100 Minor Planet Center Circulars published, two Earth-threatening NEOS and a Trojan asteroid of Jupiter (Miller, private communication).

4.9 MicroObservatory / Other Earths, Other Worlds

MicroObservatory saw first light in 1995 (Sadler et al. 2000) (http://mo-www.harvard.edu/MicroObservatory/). It is a series of five 6-inch automated waterproof telescopes built by the Harvard-Smithsonian Center for Astrophysics (CfA) at 2 locations: the CfA itself and Whipple Observatory in Arizona. It provides images freely with a specific focus on education. Participation in the project is free of charge to all schools and is primarily funded by the National Science Foundation (NSF).

The earlier MicroObservatory project has since evolved into 'Laboratory for the Study of Exoplanets' via a pilot project called 'Exploring Frontiers of Science with Online Telescopes' (Gould, Sunbury, & Krumhansl 2012). The focus of both projects has been to engage students in detecting and describing exoplanets using the MicroObservatory telescopes. The focus is on providing online tools to explore exoplanets, albeit exoplanets that have previously been identified by astronomers. The students take the data themselves.

The telescopes are operated robotically. However, if different schools request the same object with the same exposure time and filter, the telescopes will only take one, rather than multiple, sets of data. Around 20 known exoplanets are large

Table 9. MicroObservatory Summary.

Founded	1988, first light 1995
End date	Continuing
Budget/Yr	Unknown
Funding source	NSF
Cost to participants	Free
N (Teachers)	Unknown
N (Students)	Unknown
N (Schools)	Unknown
Location	Global
Website	http://mo-www.cfa.harvard.edu/ MicroObservatory/
Population	Both
Inquiry depth	Structured
Data rawness	Newly observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	At school

Table 10. NITARP Summary.

Founded	2005
End date	Continuing
Budget/Yr	300 000 USD
Funding source	NASA
Cost to participants	Free
N (Teachers)	18/Year, 87 Total
N (Students)	¿200 Total
N (Schools)	18/Year, 85 Total
Location	USA
Website	http://nitarp.ipac.caltech.edu
Population	Teachers
Inquiry depth	Guided/Coupled
Data rawness	Archival and pre-observed
Selectivity	Selective
Scalable	Scalable
On/Off-campus	Mixture

enough (and their host stars bright enough) to have transits detected by the MicroObservatory telescopes. By 2006 (Gould et al. 2007), more than half a million 650 × 500 pixel, 12 bit images covering one square had been taken primarily for students, but also for public outreach endeavours (Sadler et al. 2001). The telescopes can be used in three modes: ‘Full Control’ where the user can drive the telescope remotely in real time, ‘Guest Observer Mode’, where users request images from the telescopes in a more traditional robotic fashion, and ‘Research Mode’, where Target of Opportunity (TOO) triggers can take over the telescope to observe time-dependent transient phenomena.

Personnel at the MicroObservatory have created their own simple image processing program to deal with the FITS files from the telescopes, with the most complexity lying in the creation of colour images from the raw FITS files and making simple animations. Curriculum materials are also provided that lead the students through the basic concepts of telescopes and what they can see so that they can undertake simple structured inquiry with the telescopes.

4.10 NASA/IPAC Teacher Archive Research Program (NITARP) / Spitzer Space Telescope Research Program

The Spitzer Space Telescope Research Program ran from 2005 to 2009. It transitioned into the NASA/IPAC Teacher Archive Research Program (NITARP), running from 2010 until the present (http://nitarp.ipac.caltech.edu). The original program, run by the Spitzer Science Center (SSC) located at the California Institute of Technology in Pasadena, CA, USA, which is part of the Infrared Processing and Analysis Center (IPAC). The discretionary funding currently comes from NASA, and until 2014 some EPO funds tied to the archives housed at IPAC. In 2014, the funding was reduced from \$300K to \$200K meaning a reduction in teachers per year from 18 to 9.

NITARP partners small groups of educators with a mentor professional astronomer for an original year-long research project. It involves three trips for participants (and two trips for two of each of their students), all of which are paid for by the program. Participants kick off their year by attending an American Astronomical Society (AAS) winter meeting, then come with $\lesssim$2 students per educator to visit Caltech for a week in the summer, and then return to an AAS meeting (with $\lesssim$2 students per educator) to present their results. Much of the work is done remotely during the rest of the year. Each team consists of a mentor astronomer, a mentor teacher (who has been through the program before), and typically 2-4 new teachers.

An annual program cycle runs for a calendar year with applications available annually in May and due in September. Teachers are encouraged to bring students on the second two trips. The number of teams that NITARP can support in any given year depends primarily on having an available mentor scientist and enough money to support the trips.

NITARP and its predecessor have historically been aimed at high school classroom teachers, but now solicits applications from teachers in 8th grade through to community college, and from both formal and informal educators (e.g., museum staff). Applicants must have had some experience in astronomy, preferably having worked with astronomy data but not necessarily having conducted any research. In the earlier Spitzer Space Telescope version of the project, teachers must have been graduates of the NOAO Research Based Science Education (RBSE) program.

NITARP teams all must use astronomical data housed at IPAC. Thus, the NITARP teams use the same data in the form used by professional astronomers. All of these data are necessarily pre-observed, but they are reduced to varying degrees. In the early (Spitzer) years of the program, participants in the program were granted relatively small amounts of telescope time on the Spitzer Space Telescope to conduct their research.

Some limited evaluation was conducted as part of the Spitzer program before NITARP started. At that point, 32 teachers had been through the program and had brought a total of 79 students to either Caltech or the AAS, and over 1200 students had used Spitzer data in their classrooms. The teachers and their students made nearly 200 presentations reaching an estimated 14,000 people. A little over 100 students reported that the program had influenced them to pursue careers in science, and 42 had entered Spitzer-related science-fair projects, including contributions that made it to the Intel Science Fair level. A detailed evaluation is being conducted on the NITARP 2013 participants with results expected in 2014, with results expected in 2014. A brief survey was also conducted on the entire set of NITARP+Spitzer alumni in Spring 2014, with 50% survey response rate. As reported in Rebull et al. (2014), the NITARP participants estimate that 13,000 students have benefitted from skills or resources the educator learned about via NITARP, 21,000 students are taught by NITARP educators per year, and 4300 other educators have been reached with NITARP information.

There have been 43 science and 49 education AAS posters presented by NITARP-affiliated educators and scientists. There have been 5 refereed journal articles in major professional astronomy research journals that directly involve NITARP teachers and scientists (Howell et al. 2006, Guieu et al. 2010, Howell et al. 2008, Rebull et al. 2011, Rebull et al. 2013). There have been 2 more astronomy journal articles involving NITARP scientists, describing the software developed in conjunction with NITARP and its Spitzer predecessor (Laher et al. 2012). Finally, there is one more refereed article written by a NITARP alumni teacher for The Physics Teacher (Pereira, Millan, & Martin 2013).

4.11 Pisgah Astronomical Research Institute

The site upon which the Pisgah Astronomical Research Institute (PARI) stands is about 50 years old. The site was originally used for line-of-sight communication and telemetry with satellites as well as for human spaceflight. As the Apollo program wound down, the site was transferred to the U.S. Department of Defense (DoD) in the early 80s and turned it into a military installation until 1995 when it was shut down. In 1999 the facility was purchased from the DoD and is now used as a science and technology center supporting public, private, commercial and government endeavours.

PARI's mission is primarily educational; although initially aimed at university level, it was discovered that there were many opportunities at different year levels. PARI also provides school group tours and group visits that occur daily. The instruments on the site used for educational programs include a variety of optical telescopes (10-inch to 14-inch) for both imaging and spectroscopy and 'Smiley', the 4.6m radio telescope (PARI, 2011). There are two main PARI high school programs; the Space Science Lab Program (SSLP), which is funded through a Burroughs Wellcome Fund Grant, and the Duke Talent Identification Program (Duke TIP), which is run from Duke University.

Table 11. Pisgah Astronomical Research Institute Summary.

Founded	1999
End date	Continuing
Budget/Yr	5 000 USD
Funding source	Private Donations
Cost to participants	$100
N (Teachers)	300 Total, 15/Year
N (Students)	400 Total, 45/Year
N (Schools)	500 Total, 30/Year
Location	North Carolina, Southern USA
Website	http://www.pari.edu/
Population	Students
Inquiry depth	Structured/Guided
Data rawness	Newly observed
Selectivity	Semi-Selective
Scalable	Not easily scalable
On/Off-campus	External

The Duke TIP program is competitive entry, takes in 30 students/year and generally has a waiting list. In the SSLP, while also intended to be competitive, the students are more directly recruited by PARI staff giving talks in schools at the invitation of teachers. The drawing area for SSLP is in Western North Carolina, in general a low socioeconomic area, whereas Duke TIP is nationwide, although draws more frequently from the Southern states of the US.

In the DUKE TIP program, the students have to make posters on research they perform at the site, which are printed and presented on the PARI website. More directed research is possible; however, the nature of the research is restricted by the 2 week limit. Students are helped in brainstorming ideas to come up with possible projects plausible within the constraints of time and instrumentation. Projects vary from spectroscopic binary stars, to the rotation of Saturn's rings, to radio jets in galaxies, amongst many others, all having some substantial component using a real telescope.

The SSLP uses Radio Jove as an introduction to radio astronomy and the technical side of instrumentation. They then use the Smiley telescope upon which they can book observing time. Usually it is used primarily to make continuum observations of the Sun, which are comparable to the Jovian system. There are 500 users in total registered on Smiley; the majority of whom are teachers who use it once per year, while approximately 10-20 per year use it for a directed research project per year.

4.12 Pulsar Search Collaboratory (PSC)

Beginning in 2008, the Pulsar Search Collaboratory (PSC) was a 3 year NSF-funded project jointly run by the National Radio Astronomy Observatory (NRAO) and West Virginia University (Rosen et al. 2010) which is currently continuing on a volunteer-run basis. While undergoing maintenance,

Table 12. Pulsar Search Collaboratory Summary.

Founded	2008
End date	Continuing
Budget/Yr	900 000 USD (currently volunteer run)
Funding source	Initially NSF, now volunteer
Cost to participants	Free
N (Teachers)	106 Total
N (Students)	2431 Total
N (Schools)	103 Total
Location	West Virginia and surrounds
Website	http://pulsarsearchcollaboratory.org
Population	Both
Inquiry depth	Guided
Data rawness	Pre-observed
Selectivity	Not selective
Scalable	Scalable
On/Off-campus	Mixture

1500 hours of observing data are recorded via drift scanning at the GBT. Of these, 300 hours were reserved for the use of high school students who were initially from West Virginia Schools, but over time, this expanded to surrounding states. The total funding for the three-year project was around $900,000, which predominantly funded participants' food and housing, and salaries for those involved.

The PSC runs with an approach where teacher and student leaders are trained in radio and pulsar astronomy techniques at a three-week workshop held annually. They go back to their schools and recruit other interested teachers and students. Admission is not selective, but tends to attract students at the top of their classes.

The students attend the last six days of the workshop while the teachers are there for the full three weeks. A 40 foot telescope is used to become familiar with telescope usage and concepts before they are moved onto a pulsar project using the GBT. The teachers and students go back to their schools to work on the project over the course of a year, whether in class or in an astronomy club, with the participating students acting as team leaders. At the end of the year, PSC organises a seminar at West Virginia University for students and teachers to present their results as well as also providing videoconferencing to any follow-up observing sessions based on student analysis.

Evaluation reports suggest that interest is significantly increased in STEM careers after participation in PSC, with 39% reporting increased interest and 55% reporting similar interest after participation. They also see a significant increase in self-confidence and self-efficacy in science, particularly amongst girls (Rosen et al. 2010). A large amount of the gain in engagement comes from students going to Green Bank or West Virginia University to meet up with other schools or other teams. There have been a number of discoveries by students of new pulsars and one potential rotating radio transient (https://sites.google.com/a/pulsarsearchcollaboratory.com/pulsar-search-collaboratory/Home/new-psc-pulsars). One of the students, the discoverer of a potential rotating radio transient, Lucas Bolyard, got to meet the President and First Lady at a White House star party. A scientific paper outlining the discovery and timing of five pulsars identified in the project with many student co-authors has been published (Rosen et al. 2013).

4.13 PULsar Student Exploration online at Parkes (PULSE@Parkes)

PULSE@Parkes (Hollow et al. 2008) was established at CSIRO's Australia Telescope National Facility (ATNF), now CSIRO Astronomy and Space Science (CASS), in late 2007 as a means of engaging high school students in science through radio astronomy with the use of a major national facility. Intrinsic to the program is the opportunity for students to meet and engage with professional astronomers and PhD students. Staffing comprises a Coordinator and Education Lead, Project Scientist and post-doctoral fellow. Other former CSIRO post-doctoral fellows have been active team members, and both PhD students and undergraduate students have taken part in observing sessions or contributed to the development of materials.

Papers have been presented at science teacher and astronomy conferences in Australia and internationally (Hollow et al. 2008). To date, one science paper describing the observing process and data has been published (Hobbs et al. 2009) whilst another paper based on a specific pulsar is currently being written.

Schools apply for observing sessions that are determined by the schedule for the Parkes radio telescope which is allocated twice per year in six-month blocks. The maximum recommended class size is 24. Prior to the observing session, the project coordinator visits the school to give a one-lesson background talk preparing students for the observations.

On the day, the school group links directly via a Skype link to the astronomer in the tower at Parkes itself. The project catalog has 42 pulsars, selected to provide sufficient coverage

Table 13. PULSE@Parkes Summary.

Founded	2007
End Date	Continuing
Budget/Yr	Internally funded
Funding source	CSIRO Astronomy and space science
Cost to participants	Free
N (Teachers)	1-2/School group
N (Students)	950 Total
N (Schools)	78 Total
Location	Australia
Website	http://pulseatparkes.atnf.csiro.au/
Population	Students
Inquiry depth	Structured/Guided
Data rawness	Newly observed
Selectivity	Not selective
Scalable	Not Scalable, limited by telescope time
On/Off-campus	External

at any time of day and year, and that exhibit a variety of pulsar properties. Students split into small groups of 2-4 students; each group has to identify 2-3 pulsars that are up, control the telescope and gather data for the pulsars, and then analyse their data to determine pulsar distance. Observations usually last for two hours and are aided by at least three staff and/or PhD students.

The project is ongoing and continues to evolve. One of the aims of the project was to inform development of future radio astronomy projects for schools that would utilise the massive data sets expected from new generation radio telescopes, specifically the Australian Square Kilometre Array (ASKAP), operated by CSIRO and the international Square Kilometre Array (SKA).

4.14 Remote Access Astronomy Project (RAAP)

A 14-inch remote access telescope equipped with an impressive array of filters and polarisers, named the Remote Observation Telescope (ROT), was constructed from scratch by undergraduate students from 1988/9 to about 1992 on top of the physics building at UC Santa Barbara. It was used for about 15 years, initially by undergraduates, but later included high schools accessing and requesting CCD image data as well as communicating with each other and the university via a bulletin board system named AstroRAAP. It was decommissioned around the turn of the millenium due to a roof renovation.

An early grant for computers and a phone line was acquired and one of the project team initially used it in her high school classroom. A high school course for astronomy that was approved for a college-entrance/college-preparatory class was also designed and used for RAAP. Students learned digital image processing in the first semester and in the second semester doing an actual observing project where they would directly go and sit in the lab at UCSB to use the telescope.

Table 14. Remote Access Astronomy Project Summary.

Founded	1988, First light 1992
End date	2003
Budget/Yr	Unknown
Funding source	UCSB grant, NSF EPO
Cost to participants	Free
N (Teachers)	Unknown
N (Students)	Unknown
N (Schools)	Unknown
Location	Global, mainly USA.
Website	None
Population	Both
Inquiry depth	Structured/Guided
Data rawness	Newly observed
Selectivity	Not selective
Scalable	NA
On/off-campus	Mixture

Based around this approach, workshops were given around the country focussed on digital image processing as well as how to use the RAAP telescope itself. Image processing workshops were conducted at professional meetings and conferences around the country. Initially there was no commercially viable software, so the project ended up writing their own. The software used was called ‘IMAGINE-32’, a professional quality image processing program (Lubin 1992), which could also be used to control a telescope, CCD camera and its filter wheel.

To make the telescope manageable, RAAP accepted lists of object name or RA & Dec, filters required, and the exposure time. Some amount of human interaction was needed as the dead pointing of the system was not perfect, so a volunteer would come in during the evenings to help out with the process. The telescope was never completely automated, but approximately 50 images a night were taken depending on the exposure time. There was no huge volume of external users, as there were few teachers who had the capacity to dial in and teach the course during the early modem period. Hence, most of the use was by local high schools.

4.15 Research Based Science Education (RBSE)/Teacher Leaders in Research Based Science Education (TLRBSE) / Astronomy Research Based Science Education (ARBSE) (NOAO)

In 1997, a four-year teacher enhancement National Science Foundation grant set up the initial Research Based Science Education (RBSE) project. Its focus was on providing research astronomy experiences to teachers to enable them to bring these into their classrooms to address the issue that teachers may be teaching misconceptions about what science is all about. This continued past the original grant stage and became Teacher Leaders in Research Based Science Education (TLRBSE) until 2005, which added an aspect of teacher leadership development to the training. Then for four years after this period, it became an internal program at the National Optical Astronomy Observatory (NOAO). With budget stress, it was decided that it was not maintainable and the project’s last year in this form was 2008. Many of the teachers involved from RBSE were suggested as teachers for the Spitzer Space Telescope Research Program (also described in this paper under NITARP). A form of RBSE for undergraduates is still run by Travis Rector at the University of Alaska.

The original budget was $200,000 to $300,000 a year for 20 teachers. The major costs were to run a distance-learning course, to bring the teachers to Kitt Peak for two weeks, and to take the teachers to a National Science Teachers Association (NSTA) meeting, to provide materials for the teachers as well as to pay some consultants. When the grants came to an end and the project became a core project, the budget contracted to about $100,000 a year. Some members of NOAO staff donated their time as well. The funding rate

Table 15. Research Based Science Education Summary.

Founded	1997
End date	2008
Budget/Yr	100 000–300 000 USD
Funding source	NSF (1st 8 yrs) & NOAO
Cost to participants	Free
N (Teachers)	200 Total
N (Students)	NA
N (Schools)	NA
Location	USA
Website	http://www.noao.edu/education/arbse/
Population	Teachers
Inquiry depth	Guided/Coupled
Data rawness	Newly observed
Selectivity	Selective
Scalable	Scalable
On/Off-campus	Mixture

per teacher was the primary rationale for the NSF in cancelling these styles of grants. In the initial RBSE, around 16 teachers undertook a 180-hour summer workshop involving image processing training, observing with the five major Kitt Peak telescopes with mentoring provided by professional astronomers and educators interspersing the more traditional lecture-type activities. (Rector et al. 2000).

A total of 57 middle and high school teachers undertook the workshop in the first four-year grant with each successive year involving an entirely fresh group of teachers. There was a 15-week distance-learning course that demanded about 10–15 hours a week from teachers. A two week on-campus course was then held in Tucson to help develop their skills, astronomy knowledge and leadership. About a week of this time was spent on Kitt Peak collecting data for their observational projects. Students and teachers could then take their datasets home to the classroom as well as the datasets obtained in previous years. In order to focus the teachers' attention on the professional side of teaching, they would present their work at the annual NSTA meeting approximately two months after the Kitt Peak course.

ImageJ was the software primarily used to examine the images. However a lot of preliminary work (such as image calibration and embedding a WCS) was undertaken by an astronomer. In this sense, teachers never really used completely raw data. Sometimes custom-software was used for particular projects while other projects used Excel spreadsheets to work with the data.

There were a number of distinct projects. Initially, there were three: a novae search, AGN spectroscopy and a sunspot position project. Further projects developed over time: making recovery observations of asteroids, spectroscopy of variable stars, and a search for high redshift galaxies. The asteroid data were published in the MPC. The Novae search project is currently wrapping up and is in the process of standardising the photometry ready for publication. It has found more novae than any other prior research group. The novae search was double-blind and there were thousands of students involved over the years.

The RBSE also created a journal (http://www.noao.edu/education/arbse/arpd/journal) that ran for the twelve years and contained much of the research undertaken by students. Initially, this was printed but then moved online. As well as the journal, there more than 30 science fair projects. One RBSE participant, Rick Donahue, won the $20,000 New York Wired Technology Award for his Project SunSHINE (Lockwood, private communication).

4.16 Research Experience for Teachers (RET) - NRAO

Research Experience for Teachers, initiated in 1999, is an NRAO eight-week summer research programme located in Socorro NM, Charlottesville VA and Green Bank WV, where high school teachers are matched with astronomy mentors to participate in a research activity over the course of eight weeks. These teachers are provided with a stipend during the period. The teachers are required to develop, document and implement a unit of work based on their experience, assess and evaluate the efficacy of the unit and then disseminate this work through both their teaching peers via the internet and through an AAS poster, to the astronomical community.

4.17 Rutgers Astrophysics Institute

The Rutgers Astrophysics Institute (RAI) focuses on the X-ray range of the electromagnetic spectrum rather than the typical optical or radio. It is a free-of-charge year-long research program for high achieving high school students, teachers, and pre-service teachers (Etkina, Lawrence & Charney 1999, Etkina et al. 2003) using data obtainable through the High Energy Astrophysics Science Archive Research Centre (HEASARC) (http://heasarc.gsfc.nasa.gov/) which is the data repository for all NASA high-energy missions.

Table 16. Research Experience for Teachers Summary.

Founded	1999
End date	Continuing
Budget/Yr	Unknown
Funding source	NSF
Cost to participants	Free, Paid stipend
N (Teachers)	Unknown
N (Students)	NA
N (Schools)	NA
Location	USA
Website	http://www.gb.nrao.edu/epo/ret.shtml
Population	Teachers
Inquiry depth	Guided
Data rawness	Varies
Selectivity	Selective
Scalable	Not scalable
On/Off-campus	External

Table 17. Rutgers Astrophysics Institute Summary.

Founded	1998
End date	2013
Budget/Yr	30 000 USD
Funding source	Educational foundation of America and then NASA
Cost to participants	Free
N (Teachers)	6–8/Year, 25 Total
N (Students)	25/Year, 375 Total
N (Schools)	6–8/Year
Location	New Jersey area
Website	http://xray.rutgers.edu/asi/asi_general.html
Population	Both
Inquiry depth	Coupled
Data rawness	Archival
Selectivity	Selective
Scalable	Scalable
On/Off-campus	External

Funding of around $50,000 per year was originally received from the Educational Foundation of America. After the funding ended, the project tried to get funding from the NSF three times and was rejected for different reasons. Currently the program is running on $30,000/year funding from NASA. Originally, a small stipend was provided to teachers, but now only snacks are provided. The grant primarily pays for the instructors. Funding ran out in 2013 after 15 years. In the later stages of the project, New Jersey physics teachers have actually run the institute, rather than academic staff.

There were typically six to eight participating schools per year each with two to four students and one teacher. The process started with a four-week, six hours/day, summer school in June where they learn the necessary physics and astronomy background and methodology through an authentic research education methodology built around the ISLE model (Etkina & Van Heuvelen 2007). After this, an X-ray source of interest, and of previously unknown nature, was picked to be the object of study for the year. The students and teachers met at Rutgers every two months with a culminating year-end conference as well as discussions on an online board. In total, approximately 25–30 teachers in general have been trained via the program and overall 25 students per year (375 in total) have been through the project.

The nature of the sources that the students analyse changes over time as Chandra and other X-ray observatories collect more data, but the fundamentals of the program, learning about physics and astronomy and data within a constructivist inquiry-based framework, remains the same. The typical types of objects observed were quasars, bursters, X-ray binary sources and super-novae remnants. The students gained significant skills in experimental design and modelling in an authentic research situation, improved their raw physics capacity in terms of an advanced physics test and changed their approach to learning about science (Etkina et al. 2003).

4.18 Skynet/Project Observe

Skynet began in 2004 with funding to build a cluster of six 0.4m telescopes at CTiO for gamma ray burst follow-up. As a lot of time is spent waiting for an actual burst, the non-observing time was to be used for educational purposes, initially in North Carolina. The focus of the educational part of this project is primarily at the undergraduate level, although high school use has also been made. In total, there have been approximately 40,000 users.

There was a five- year high school project run with these telescopes through the on-campus Morehead Planetarium. Approximately 75 high school teachers have been trained to use the Skynet Interface and who have used it with thousands of North Carolina school students using the ‘Project Observe’ curriculum materials. These have a heavy image processing focus. Approximately 5000 students used the high school program and about half of the teachers are still active users of the Skynet telescopes. Although no formal evaluation has taken place, students do arrive at the University of North Carolina (UNC) stating that they have used Skynet in high school. Currently, Skynet is in the process of building a middle-school curriculum.

A high school and undergraduate lab course has been developed at UNC. Custom web-based software was created to overcome installation problems on locked down student computers where the number crunching is done on the server rather than on the students’ local computers. Astronomy tools were developed to manipulate FITS files as well as a batch aperture-photometry tool based on IRAF. There are also some simple astrometric tools as well as movie-making functions. Observations can be queued online using a web-page which will usually be executed overnight and telescopes can be monitored as they undertake observations. There is also a 20m radio telescope being built into the Skynet system. This telescope has the same backend as professional telescopes but is designed to be used for education as well.

Table 18. SkyNet Summary.

Founded	2004
End Date	Continuing
Budget/Yr	50 000 USD
Funding source	NSF
Cost to participants	Free
N (Teachers)	75 Total
N (Students)	5000 Total
N (Schools)	75 Total
Location	USA focussed
Website	http://skynet.unc.edu/
Population	Both
Inquiry depth	Structured
Data rawness	Newly observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	Mixture

Table 19. Space to Grow Summary.

Founded	2009
End date	2013
Budget/Yr	800,000 AUD
Funding source	Australian research council
Cost to participants	Free
N (Teachers)	80 Total
N (Students)	4000 Total
N (Schools)	37 Total
Location	Australia (NSW)
Website	http://physics.mq.edu.au/astronomy/space2grow/
Population	Teachers
Inquiry depth	Varies
Data rawness	Newly and pre-observed
Selectivity	Non-selective
Scalable	Scalable
On/Off-campus	At school

4.19 Space to Grow

The Space to Grow project (Danaia et al. 2013) was a 3 year funded Australian Research Council grant run through Macquarie University and Charles Sturt University with support from LCOGT and three educational jurisdictions in New South Wales, Australia. The focus of the project was to get high school teachers to utilise the two 2 metre Faulkes telescopes in their classrooms to undertake authentic science. Most of the funding was used to provide capacity for teacher release for training as well as an administrator and postdoctoral position. Over the course of the project, nearly one hundred teachers and thousands of students were involved.

Various levels of professional learning were provided in the project with the main model being multiple (3 to 5) workshop days where the teachers undertook the same processes as the students would in class but with deeper reflection on the materials and how to implement them. The actual in-class implementation involved students undertaking various scaffolding activities such as learning about what telescopes are (Project 1) and how optical astronomical images work (Project 2) based on an investigation approach. The main content-area focus was on the lifecycle of stars (Project 3) through performing interpretation of colour magnitude diagrams that the students created in the classroom from their analysis of open clusters. The materials are described in more detail in (Fitzgerald, McKinnon, & Danaia 2014a)

In Projects 1 and 2, students and their teachers were able to submit observation requests for any object that interests them. Most requests were for ‘pretty picture’ images, but there was a capacity for students to undertake their own authentic research on stellar cluster astronomy building upon the skills they had learned in Project 3. A number of student groups have had their research published (Fitzgerald et al. 2012, Frew et al. 2011) or have publications currently in review with further research currently at various levels of completion. Research on the impact of the project on students’ learning and perceptions of science were assessed using a pre/post design, results of which can be seen in (Fitzgerald, McKinnon, & Danaia 2014c).

4.20 Summer Science Program (SSP)

The Summer Science Program (SSP) (http://www.summerscience.org/home/index.php) is one of the longest running hands-on astronomy focussed programs in the world. It was set up by Paul Routly and George Abell in 1959 (Furutani 2001) and currently runs through support from the membership of their alumni association, and is funded by a related endowment.

The cost to each student is a $3950 program fee although there is a provision for needs-based financial aid. The typical budget overall is $500,000 per year, of which the largest cost is for room and board for 86 people for about six weeks. The funding sources are about 45% from students, about 45% from individual donations (mostly alumni and their parents), and about 10% from grants and investment returns. Initially, the students were all from California who came to the Thatcher School in Ojai, California. Now, participants come from all over the world to two campuses, one in Santa Barbara, California, and one in Socorro, New Mexico. There is one permanent staff member running the project.

Entry to the SSP is highly academically selective. Since 2003, there have been 73 students per summer out of approximately 600–700 applicants. Students attend the program for six weeks over the summer holidays. While there are traditional lectures in the program as well as general field trips, the main focus is on a Near-Earth asteroid observing project with a heavy focus on actually computing the orbital determination from scratch. Most of the time students take most of their data from high-end (14″) amateur telescopes, although sometimes students have used larger telescopes, both remotely and in person. They are currently now using CCDs, PCs and the Python programming language. In the early years, this was undertaken using photography, mechanical calculators and

Table 20. Summer Science Program Summary.

Founded	1959
End date	Continuing
Budget/Yr	500 000 USD
Funding source	Fees (45%), Alumni (45%), Grants
Cost to participants	3 950 USD
N (Teachers)	NA
N (Students)	70/year, 1916 Total
N (Schools)	NA
Location	Global, mainly USA
Website	http://www.summerscience.org
Population	Students
Inquiry depth	Coupled
Data rawness	Newly observed
Selectivity	Selective
Scalable	Scalable
On/Off-campus	External

Table 21. Telescopes in Education Summary.

Founded	1992
End Date	2005 (Currently reemerging)
Budget/Yr	120 000 USD
Funding source	Unknown
Cost to participants	Free
N (Teachers)	2-4 Teachers/School
N (Students)	Unknown, 100,000 Users/Year
N (Schools)	400+ Total
Location	Global
Website	None currently
Population	Both
Inquiry depth	Not specific
Data rawness	Newly observed
Selectivity	Not selective
Scalable	Scalable
On/Off-campus	At school

their human minds. The results of this project are then submitted to the Minor Planet Center (MPC) at CfA.

4.21 Telescopes in Education

The Telescopes in Education (TIE) project began in 1992 by providing remote control access to a refurbished 24-inch telescope, on loan from Caltech, at Mt Wilson, CA. A control system was built and was controlled via a modified version of Software Bisque's The Sky planetarium software and a control system allowing telescopic control via a modem. Later, a 14″ telescope at Mt Wilson and an 18″ near Golden, Colorado were brought online (Clark 1998).

Most people involved in the project were volunteers. A telescope operator was employed full-time as well as a part-time administrator. As more volunteers accumulated, the three telescopes were operating every dark minute possible; at its peak, about 100,000 students a year were utilising them. TIE, after a respite, is now focussing on getting Australian students into science and technology through universities and government bodies using real telescopes by using graduate students in the high school classroom.

Initially from 1993, schools could book time and use the 24-inch. As well as being able to control the telescope, the schools would also call in on a speakerphone to speak to the operator at the telescope in case something went wrong, or to ask for advice on such things as exposure times as well as rotating the dome. As technology improved and the internet started taking off, the system was modified to become internet controllable.

While teacher recruitment was gained through presenting at the national education conferences, much of the recruitment was primarily word of mouth. There were no firm requirements set for what was to be done in class with the telescope, although guidance was given when requested. Three teacher workshops per year with 15 teachers per class were held at Mt Wilson for those who wanted to know more about how the telescope actually operated. In terms of curriculum material provided, there were 12 projects, each with only two pages of instructions. Teachers would usually have a mentor who could help. Many students undertook the photometry projects, a few did astrometry, while only three or four schools did spectroscopic work.

Many students won first place in science fairs they entered. One student won a science fair for Los Angeles (CA, USA) county by determining the rotation rate of Vesta. Another student won the Intel Science Award by getting pictures of NEOs simultaneously from two observatories on a very long baseline and computed their distances while comparing these to the Jet Propulsion Laboratory's radar ranging data acquired at the same time.

4.22 Towards Other Planetary Systems (TOPS)

Towards Other Planetary Systems (TOPS) was a five-year Teacher Enhancement project that ran from 1999 to 2004. It originated from an earlier pilot project which ran from 1993–1995 (Meech et al. 2000). It primarily provided professional learning to teachers although students were also funded to participate in the program to gain insights into a career in astronomy or science. The unifying theme was the search for 'habitable' worlds, planetary origins and primitive bodies' (Kadooka et al. 2002).

In a three-week intensive workshop, there were active components where the teachers and students used small 8-inch and 10-inch telescopes to undertake nightly observations. These most commonly involved variable star and double star measurements using photomultiplers and CCDs based around the 'Hands-on Astrophysics' curriculum (Mattei et al. 1997). In addition, simple spectroscopes were used. The results of the investigations were provided to the AAVSO. Other activities included measuring the heights of mountains on the Moon using the smaller telescopes. Some students were involved in an observing run on the NASA Infrared Telescope Facility (http://irtfweb.ifa.hawaii.edu/).

Table 22. Towards Other Planetary Systems Summary.

Founded	1993 (Pilot), 1999 (Main)
End Date	1995 (Pilot), 2004 (Main)
Budget/Yr	Unknown
Funding source	NSF & Private donors
Cost to participants	Free
N (Teachers)	20–30/Year
N (Students)	20/Year
N (Schools)	5–10/year
Location	USA and Micronesia
Website	http://www.ifa.hawaii.edu/tops/
Population	Both (Mainly teachers)
Inquiry depth	Guided
Data rawness	Newly observed
Selectivity	Selective
Scalable	Scalable
On/Off-campus	External

Other students were involved in the 2002 TOPS program and presented their work at the July 2002 AAS meeting which included the discovery of a new variable star and a remote observing project utilising the 31″ Lowell Observatory telescope (Kadooka 2002). This project eventually evolved indirectly into the Hawai'i Student Teacher Astronomy Research Program (HISTAR) project, described above.

5 ISSUES IDENTIFIED IN PROJECTS

During the research for this article, many informal discussions were conducted with various project personnel from most of the investigated projects as well as executing a more standard literature review. In this section, we present a discussion of project issues that commonly arose during the discussions, as well as those apparent in the published literature.

5.1 Funding

It is quite apparent from all of the projects described that sources of funding are a key aspect of long-term project success. Most of the funding for many of the projects came from short-term grants lasting two to four years that had to be renewed, usually with difficulty, as each grant period came to an end. Many projects end up running on shoestring budgets or with volunteer time after the initial grant period expired. Of very recent note, most of the current projects are in turmoil, or have been terminated, due to programmatic uncertainties associated with NASA EPO funding issues.

While a scientific project can be undertaken in a discrete manner and a question addressed in a particular time-period, educational projects need to be funded in the long-term to maximise their impact on students and teachers. The development time for any education project to get to a stable state typically takes a few years before gains are seen in the classroom (e.g. Johnson, Kahle, & Fargo 2007, Banilower, Heck, & Weiss 2007, Supovitz et al. 2000) after a typical initial negative 'implementation dip' (Hall & Hord 2010). That time is spent in developing the materials and ironing out any bugs, as well as reaching a substantial fraction of the intended education community. Once this has been achieved, it requires continual resource input to keep the project alive.

It is still not clear what the best 'business model' is to provide continual and ongoing support and resources to teachers and projects to ensure their continuation beyond finite funding cycles. Those projects that seem to survive are those that tend to be ones that are relatively low budget and run by volunteers, that are funded as a longer-term project through an existing government body, have become self-funded through charging for their services or through philanthropy.

5.2 Importance of Evaluation

In terms of educational research and evaluation, overall there is little known about these projects. There are some minor shining lights, but most projects do not present evaluations, and those that do suffer from significant methodological flaws. For instance, some evaluations focussed simple on very short post-hoc qualitative comments from teachers while others reported no estimates of confident intervals for results from quantitative surveys or used anecdotal successful 'case studies' as an indicator of general success. This situation is not unexpected, as Bretones and Neto (2011) state, educational research in astronomy education needs deeper treatments. The usual reason provided for the lack of evaluation is that it was not part of a grant and was not funded as part of the project.

However, not all forms of evaluation need be as costly as it is commonly claimed. Simple pre/post-test surveys, such as the Astronomy Diagnostic Test (Hufnagel et al. 2000) for content knowledge and the Secondary School Science Questionnaire (Goodrum et al. 2001) for attitudinal change, can be used in quasi-experimental designs (Gribbons & Herman 1997) to gain understanding of whether the particular educational design achieved their intended results in the short-term. We recommend that evaluation be undertaken in collaboration with an experienced educational evaluator if at all possible and definitely significantly in advance of the commencement of the project itself. A good general introduction to the issues and techniques project evaluation, "The 2010 User-Friendly Handbook for Project Evaluation" (Frechtling et al. 2010) is available from the National Science Foundation. A recommended guide with a much more direct astronomical focus is "Discipline-Based Science Education Research: A Scientist's Guide." by Slater et al. (2011)

Indeed, evaluation becomes part of the feedback loop that provides evidence for further grant funding applications. If a project cannot present solid evidence of efficacy, then the likelihood of further grant funding is reduced dramatically. Hence, evaluation is a necessary component that should be built into the structure of any given project.

Beyond simply acquiring more grant funding, adequate evaluation allows researchers and investigators to learn from the successes and failures of other projects. Without this knowledge, this field is basically relying on anecdotes from researchers to illuminate any future design process. This is fraught with danger as it is well known that such anecodotal or 'expert' evidence suffers from a "pro-innovation bias" (Rogers 2010), where people involved with projects, due to the nature of human socio-psychology, will evaluate and rate their own projects much more highly than they probably truly are. This leads to complacency on the path to improvement of these projects.

Evaluation itself, of course, is dependent upon the goals of a project. Producing a scientific paper out of a project looks very good for the project, especially in the eyes of research astronomers. It is likely, however, that it is only the peak population in any project who can produce such outcomes. Small numbers of such papers are produced by these projects and are likely to be weighted far too heavily as a measure of success with respect to the educational goals of a project.

If the paper is taken in the light of the common goals of these projects, viz., giving young people an experience of the scientific method and, more generally, a better understanding of science so that they can appraise the nature of science as a human endeavour to help them make valid choices in the future, then these papers alone are not an adequate measure of ‘success’.

An estimation of the level of impact on an individual student can be measured at quite reasonable cost in the short-term. However, longitudinal studies (at higher cost of money and time resources) of the educational impact of such projects on students, such as tracking their actual career path, long-term interest in science or general academic performance, are noticeably absent from the evaluation literature.

What is required is adequate educational research into the true impact of such projects on participating students. Even if the teachers are the primary audience for any given program, the overarching goal of the evaluation should be in seeking answers to the question: “How does this project broadly affect the students?”. Some recent work in fields other than astronomy has suggested that having teachers’ experience authentic research has a positive effect on their students who were not involved in the research. For example, Silverstein et al. (2009) find that, within their New York state project, students of teachers who have experienced authentic scientific research pass their state science exams at a rate that is 10% higher than the students of teachers who have not. The effect on students cannot be discovered by mere exit polls about whether teachers enjoyed a project or found that it improved their teaching. Especially as it is fairly clear that teachers themselves suffer from the same pro-innovation bias that project investigators do (Fitzgerald, Danaia, & McKinnon 2014d).

5.3 Scalability

In a perfect world, we would like any astronomical educational initiative to reach as many people as possible, but there are significant barriers for any project in attempting to do this. Usually, funding sets project limits. Many projects by necessity are bounded in size by geography and by time. In the geographical vicinity of a project, it is relatively easy to provide on-campus experiences to teachers and students. Once the project expands beyond the local jurisdiction, the necessity for accommodation of participants, or the travel of facilitators/investigators, is at huge cost. Some projects are also limited by access to telescope time or finite access to archives of data.

Another less apparent requirement for scalability of these projects is staffing. The skill set necessary to provide adequate staffing for these projects is fairly rare. Faculty personnel with the right mixture of astronomical and educational experience can be difficult to find. If the faculty do not exist, then significant training is necessary to develop the experience in interested people. A unique mixture of content knowledge, pedagogical knowledge, charisma, interpersonal skills and organisational skills must be distributed amongst the project personnel. Even when this is available, the amount of communication overhead in dealing with all of the students’ and teachers’ questions can be quite large.

5.4 Adequate Focus and Design

The experiences of personnel in the projects reviewed make it clear that true open inquiry from scratch simply does not work. This is also clear from the projects reviewed, and also from the literature (Alfieri et al. 2011); providing a telescope to teachers and students with no structure seems not to generate preferable outcomes in an educational context. Sufficient thought into how students interact with the data, what they can learn from the meaning of the data and how they will learn to understand the data is necessary.

Some thought about how students are actually learning to become scientists within the project is also necessary, as students can manipulate the data and even work out the mechanics of certain aspects but may not be gaining a fundamental understanding of how science works in the process. Sufficient scaffolding of this aspect is necessary to get the students authentically involved in the scientific process.

5.5 Technology

A major barrier that prevented teachers from implementing projects was computing requirements. These have varied strongly with what the project was trying to do, but they have also changed dramatically with the passage of time. The earlier projects (1990s) had a near impossible task trying to get teachers to use computers, even in the rare cases where computers actually existed in their classrooms, let alone getting teachers to interact significantly with the data.

The technology available in schools can be many years behind that available to research scientists and/or even the home. This presents problems to the provision of cutting-edge hardware and software for research purposes. Even for the more recent projects, lack of bandwidth and user friendliness of the required software were significant impediments to their implementation, both of which are coupled with the need for scientific validity of data and data analysis. Even at this point in time, school email fails often and requires participants to use centralised servers like gmail.com. In addition, schools frequently impose limitations on what and how software can be installed on computers that have to be accessed by students. Technology is also a moving target as the software required to undertake astronomical research forms only a small niche market and the software development can move much more slowly than the pace at which technology itself changes.

5.6 Authenticity vs Reality

A naive research scientist, when approaching this style of project, will generally want the project to be as authentic as possible from the ground up. This, however, is not possible in normal educational settings. Teachers have limited time within their school year and within the scope of what they are expected to teach. In addition, few teachers or students have experience in computer programming. Generally, some projects have shown that if teachers and students acquire the observations and undertake the reductions of their raw data, once they got to interpretation and analysis of the data they had both run out of steam and time. At some point, a decision needs to be made about how authentic the research can be compared to the actual plausibility of the project being successfully undertaken by teachers and students within the educational context. The more authentic the science is to be then more support from project personnel and from research astronomers is necessary, the stronger the skill set that needs to be developed, and, a much greater amount of time needs to be devoted to undertake the project.

5.7 Teachers as Scientists

Another problem arises from the fact that teachers are generally not research scientists and have had no authentic experience of the scientific method. Teachers are generally trained to implement ‘activity-based’ science where discrete class-long activities can be undertaken successfully with a previously known correct answer. They also have little understanding of the complexities of the actual scientific endeavour beyond that which appears in textbooks and, concurrently, can equally be fairly unaware of their lack of knowledge. Hence, teachers can generally undertake a more ‘trivial’ rather than an ‘intended’ authentic scientific investigation approach.

A relatively common comment in the informal discussions was that many of the teachers only undertook the measurement aspects which were relatively more cook-book like and ‘safe’ while deliberately avoiding interpretation or analysis in their approach. This ‘trivial’ approach is not unexpected though, as there are extreme demands and limitations on what teachers can undertake within their classroom both in terms of the time and the curriculum-related constraints.

6 CONCLUSION

In this paper, we have explored 22 major large-scale projects that have attempted to bring authentic astronomy research into the classroom since the enabling dawn of the internet era and the birth of affordable CCD cameras two decades ago. While there have been many successes and obviously many rewarding valuable experiences for the teachers, students, and project personnel involved, the field still has a number of important issues and problems to address before major successes can be seen in the field.

The major apparent problems are the very distinct lack of evaluation apparent in the field and, where such evaluation exists, it is hard to access, not publicly available and/or it is methodologically problematic. A closely related issue is the funding of such projects. The best business model for these projects is not at all clear, but without adequate proof of efficacy, any attempt to extract the long-term funding necessary for the support of these educational projects to allow measurable success to become apparent is problematic.

With sufficient concentration on solutions of these two major issues, and addressing the no less important, but secondary, issues of scalability, good design, technology barriers and the realities of the limitations of classrooms, teachers and time, in the future, we may see sustained large-scale classroom research projects emerging with verifiable measurements of their true efficacy and impact on students and teacher practice.

ACKNOWLEDGEMENTS

Appreciation goes out to those project personnel who were interviewed or provided important information in the creation of this paper. John Baruch, Richard Beare, Richard Bowden, Bryan Butler, Gilbert Clarke, Rosa Doran, Ryan Dorcey, Eugenia Etkina, Catherine Garland, Katy Garmany, Edward Gomez, Roy Gould, Frederic Hessmann, Suzanne Jacoby, Rick Jenet, Mary-Ann Kadooka, Fraser Lewis, Jeff Lockwood, Philip Lubin, Patrick Miller, Carl Pennypacker, Stephen Pompea, Jordan Raddick, Travis Rector, Dan Reichart, Paul Roche, Rachel Rosen, Phillip Sadler, Jatila van der Veen, Christi Whitworth and Donna Young.

References

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R., 2011, Journal of Educational Psychology, 103(1), 1
Asbell-Clarke, J., Pack, H., Pennypacker, C., & Toler, D., 1996, ASPC, 89, 158
Backhaus, U., et al., 2012, A&A, 538, A84
Banilower, E., Heck, D., & Weiss, I., 2007, Journal of Research in Science Teaching, 44(3), 375
Barmby, P., Kind, P. M., & Jones, K., 2008, Journal of Science Education, 30(8), 1075
Baruch, J., 1992, Vistas in Astronomy, 35, 399
Baruch, J. E. F., 2000, PASA, 17, 119
Beare, R. 2004, School Science Review, 85:313, 115
Beare, R., 2006, AER, 5, 1
Bessell, M. S., 2000, PASA, 17, 179
Beuermann, K., Diese, J., Paik, S., Ploch, A., Zachmann, J., Schwope, A. D., & Hessman, F. V., 2009, A&A, 507, 385
Beuermann, K., et al., 2011, A&A, 526, A53
Bischoff, K., Tuparev, G., Hessman, F. V., & Nikolova, I., 2006, Proc of SPIE, 6270
Boer, M., Thiebaut, C., Pack, H., Pennypacker, C., Isaac, M., Melchior, A., Faye, S., & Ebisuzaki, T., 2001, ASPC, 238, 103
Bretones, P. S., & Neto, J. M. 2011, AER, 10
Clarke, G., 1998, Astronomical Education with the Internet, Frontiers of Science series no. 27, ed. M. Okyudo, et al. (Tokyo: Universal Academic Press), 37
Danaia, L., 2006, Students’ experiences, perceptions and performance in junior secondary school science: An intervention study involving astronomy and a remote telescope, PhD Thesis, Charles Sturt University
Danaia, L., McKinnon, D., Parker, Q., Fitzgerald, M., & Stenning, P., 2013, AER 11, 1

Doran, R., et al., 2012, http://arxiv.org/abs/1202.2764

Dunkhase, J. A., 2003, Science Educator, 12(1), 10

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W., 2007, Taking science to school: Learning and teaching science in grades K-8. A research report for the Committee on Science Learning, Kindergarten through Eighth Grade (Washington D.C.: The National Academies Press)

Etkina, E., Lawrence, M., & Charney, J., 1999, Physics Education 34(5), 300

Etkina, E., Matilsky, T., & Lawrence, M., 2003 Journal of Research in Science Teaching, 40(10), 958

Etkina, E., & van Heuvelen, A., 2007, Investigative Science Learning Environment–A Science Process Approach to Learning Physics, in Research Based Reform of University Physics, ed. E. F. Redish, & P. Cooney

European Commission 2004, Europe needs More Scientists: Report by the High Level Group on Increasing Human Resources for Science and Technology, Brussels. European Commission

European Commission 2007, Science Education Now: A Renewed Pedagogy for the Future of Europe, Brussels, Belgium: European Commission, Directorate General for Research

Fitzgerald, M., Criss, J., Lukaszewicz, T., Frew, D. J., Catelan, M., Woodward, S., Danaia, L., & McKinnon, D., 2012, PASA, 29, 72

Fitzgerald, M., Danaia, L., & McKinnon, D., 2014d, “Differences in perception of high school science: Students and Teachers views.”, Journal of Research in Science Teaching, Submitted

Fitzgerald, M., McKinnon, D., & Danaia, L., 2014a, “Educational Design for Large-Scale High School Astronomy Projects using Real Telescopes.”, Science Education and Technology, Submitted

Fitzgerald, M., McKinnon, D., & Danaia, L., 2014c, “A large scale inquiry based astronomy intervention project: Impact on high school students’ performance and perceptions in science”, Research in Science Education, Submitted

Frechtling, J., Mark, M. M., Rog, D. J., Thomas, V., Frierson, H., Hood, S., & Hughes, G., 2010, The 2010 User-Friendly Handbook for Project Evaluation. National Science Foundation, 2010. Available from: https://apps-spisu.sws.iastate.edu/resources/view/id/50

Frew, D., et al., 2011, PASA, 28, 83

Furutani, T., 2001, S&T, 101(3), 76

Garland, C., Kadooka, M. A., & Nassir, M., 2008, HI STAR 2007 : An Astronomy Research Program for Middle and High School Students, AAS 2008 poster

Gehret, L., Winters, W., & Coberly, S., 2005, AER, 3(2), 170

Gerbaldi, M., 2005 in Teaching and Learning Astronomy: Effective Strategies for Educators Worldwide, ed. J. Pasachoff, & J. Percy (Cambridge: Cambridge University Press), 146

Gilbert, J., 2005, Catching the Knowledge Wave? The Knowledge Society and the Future of Education (Wellington: NZCER)

Gomez, E., & Gomez, H., 2011, IAU Proceedings, 260

Goodrum, D., Druhan, A., & Abbs, J., 2012, The Status and Quality of Year 11 and Year 12 Science in Australian Schools (Canberra: Australian Academy of Science)

Goodrum, D., Hackling, M., & Rennie, L., 2001, The Status and Quality of Teaching and Learning Science in Australian Schools, Department of Education, Traing and Youth Affairs (Canberra: Government Printer)

Gould, R., Dussault, M., & Sadler, P., 2007, AER, 5, 127

Gould, R., Sunbury, S., & Krumhansl, R., 2012, AmJPh, 80, 445

Gribbons, B., & Herman, J., 1997, Washington DC, ERIC Clearinghouse on Assessment and Evaluation

Guieu, S., et al., 2010, AJ, 720(1), 46

Hall, G. E. & Hord, S. M., 2010, Implementing Change: Patterns, Principles, and Potholes (London: Pearson)

Herron, M. D., 1971, The School Review, 79(2), 171

Hessman, F. V. & Modrow, E., 2008, An Introduction to Astronomical Image Processing with ImageJ, http://www.astro.physik.uni-goettingen.de/h̃essman/ImageJ/Book/

Hidas, M. G., Hawkins, E., Walker, Z., Brown, T. M. & Rosing, W. E., 2008, Astron. Nchr., 329(3), 269

Hill, T., 1995, Phys. Educ., 30, 135

Hobbs, G., et al., 2009, PASA, 26, 468

Hoette, V. L., 1998, Astronomical Education with the Internet, Frontiers of Science series no. 27, ed. M. Okyudo (Tokyo: Universal Academic Press), 79

Hollow, R. P., 2000, PASA, 17, 162

Hollow, R. P., 2005, Teaching and Learning Astronomy: Effective Strategies for Educators Worldwide, ed. J. Pasachoff & J. Percy (Cambridge: Cambridge University Press), 27

Hollow, R. P., McKinnon, D. H., & White, G. L., 1998, Astronomical Education with the Internet, Frontiers of Science series no. 27, ed. M. Okyudo et al. (Tokyo: Universal Academic Press), 21

Hollow, R., et al., 2008, ASPC, 400, 190

Horaguchi, T., Furusho, R., & Agata, H., 2006, ASPC, 351, 544

Howell, S. B., Hoard, D. W., Brinkworth, C., Kafka, S., Walentosky, M. J., Walter, F. M., & Rector, T. A., 2008 ApJ, 685, 418

Howell, S. B., et al., 2006, ApJL, 646, 65

Hufnagel, B., Slater, T., Deming, G., Adams, J., Adrian, R. L., Brick, C., & Zeilik, M., 2000, PASA, 17(2), 152

Johnson, C., Kahle, J., & Fargo, J., 2007, Journal of Research in Science Teaching, 44(6), 775

Kadooka, M. A., Meech, K. J., & Bedient, J., 2002, jAAVSO, 31, 39

Laher, R., Gorijan, V., Rebull, L. M., Masci, F. J., Fowler, J. W., Helou, G., Kulkarni, S. R. & Law, N. M., 2012, PASP, 124(917), 737

Lewis, F., & Roche, P., 2009, http://arxiv.org/abs/0902.4809

Lewis, F., Russell, D. M., Fender, R. P., Roche, P., & Simon Clark, J., 2008, Monitoring LMXBs with the Faulkes Telescopes, VII MicroquasarWorkshop: Microquasars and beyond, Foca, Izmir, Turkey, Sep 1-5, 2008

Lewis, F., Street, R., Roche, P., Stroud, V., & Russell, D. M., 2010, Advances in Astronomy, Article ID 873059

Loucks-Horsley, S., Love, N., Stiles, K., Mundry, S., & Hewson, P., 2003, Designing Professional Development for Teachers of Science and Mathematics (London: Sage Publications)

Lubin, P., 1992, I.A.P.P.P. Communications, 49, 17

Mattei, J. A., Percy, J. E., & Young, D., 1997, Hands-On Astrophysics (Cambridge: AAVSO)

McKinnon, D., 2005, The Eye Observatory Remote Telescope Project: Practical Astronomy for Years 7, 8, and 9, Research and Development report prepared for Department of Education Science and Training (DEST)

McKinnon, D., & Geissinger, H., 2002, Educational Technology & Society, 5(1), 124

McKinnon, D., & Mainwaring, A., 2000, PASA, 18, 125

Meech, K. J., Slater, T. F., Mattei, J. A., & Kadooka, M. A., 2000, ASPC, 213, 679

Mendez, B., Day, B., Gay, P. L., Jacoby, S. H., Raddick, J., Walker, C., & Pompea, S. M., 2010, ASPC, 431, 324

Miller, J. P., Davis, J. W., Holmes, R. E., Devore, H., Raab, H., Pennypacker, C. R., White, G. L., & Gould, A., 2008, AER, 7, 1

Osborne, J., & Collins, S., 2000, Pupils' and Parents' Views of the School Science Curriculum (London: King's College/Wellcome Trust)

Osborne, J., & Dillon, J., 2008, Science Education in Europe: Critical Reflections (London: Nuffield Foundation)

Pack, H., 2000, ASPC, 220, 303

Pennypacker, C., 1998, Hands-On Universe and Plans for Large-Scale Internet-Mediated Teacher Training, Astronomical Education with the Internet, Frontiers of Science series no. 27, ed. M. Okyudo (Tokyo: Universal Academic Press)

Pennypacker, C., & Asbell-Clarke, J., 1996, ASPC, 89, 61

Pereira, V., Millan, J., & Martin, E., 2013, The Physics Teacher, 51, 211

Rebull, L. M., Gorjian, V., Brinkworth, C., Squires, G. K., & Burtnyk, K., 2014, 2014, AAS #223, #249.01

Rebull, L. M., et al., 2011, AJ, 142, 25

Rebull, L. M., et al., 2013, AJ, 145, 15

Rector, T., Jacoby, S. H., Lockwood, J. F., & McCarthy, D. W., 2000, ASPC, 220, 386

Richmond, M. W., et al., 1996, AJ, 111, 327

Roche, P., & Szymanek, N., 2005, The Faulkes Telescope Project, The ESO/ESA/IAU Conference: Communicating Astronomy with the Public 2005

Rockman et al., 1994, The Hands-On Universe Program Year Two Evaluation Report (Rockman: San Francisco)

Rogers, E., 2010, Diffusion of Innovations (New York: Free Press)

Rosen, R., et al., 2010, AER, 9

Rosen, R., et al., 2013, AJ, 768, 85

Sadler, P. M., Gould, R. R., Brecher, K., & Hoffman, B., 2000, Innovations in Science and Mathematics Education, eds. M. J. Jacobson, & R. B. Kozma (Mahwah, NJ: Erlbaum), 259

Sadler, P., et al., 2001, Journal of Science Education and Technology, 10(1), 39

Schwab, J., 1960, The School Review, 68(2), 176

Select Committee on Science and Technology 2002, Science Education from 14 to 19, House of Commons: UK Parliament

Silverstein, S. C., Dubner, J., Miller, J., Glied, S., & Loike, J. D., 2009, Sci, 326(5951), 440

Slater, S. J., Slater, T. F., & Bailey, J. M., 2011, Discipline-Based Science Education Research (San Francisco: WH Freeman)

Steele, I. A., 2004, Astron. Nchr., 325(6), 519

Supovitz, J. A., Mayer, D. P., & Kahle, J. B., 2000, Educational Policy, 14(3), 331

Tytler, R., 2007, Re-imagining Science Education: Engaging Students in Science for Australia's Future (Camberwell, Victoria: Australian Council for Educational Research)

Tytler, R., Osborne, J., Williams, G., Tytler, K. & Cripps Clark, J., 2008, Engagement in STEM Across the Primary-Secondary School Transition: Opening up Pathways, Australian Department of Education, Employment and Workplace Relations: Canberra

A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

2012, AER, 11, 010106-1, 10.3847/AER2012007

Space to Grow: LCOGT.net and Improving Science Engagement in Schools

Lena Danaia
Charles Sturt University, Australia
David McKinnon
Charles Sturt University, Australia
Quentin Parker
Macquarie University and Australian Astronomical Observatory, Australia
Michael Fitzgerald
Macquarie University, Australia
Paul Stenning
Catholic Education Diocese of Parramatta, Australia
Received: 03/5/12, Accepted: 04/18/12, Published: 05/14/12

Abstract

Space to Grow is an Australian Research Council Grant that engages high school students in real science and supports their teachers in implementing inquiry-based approaches using astronomy as the focus. Currently, Grade 9–12 students and their science teachers from three educational jurisdictions in one Australian state are acquiring, and making scientific use of, observational data from the 2-m Faulkes Telescopes owned by Las Cumbres Observatory Global Telescope Network. Data are being collected to investigate the impact of the project on students and teachers. Some investigations have led students to work with astronomers to publish their results in the astronomical literature.

1. INTRODUCTION

In many western countries, secondary school science education continues to suffer from a number of problems. These include a lack of student interest in science (Barmby, Kind, and Jones 2008, Osborne and Collins 2000; Sjøberg and Schreiner 2010) and a declining proportion of the student cohort pursuing science in the postcompulsory years of schooling, particularly in the physical and Earth sciences (Ainley, Kos, and Nicholas 2008, Osborne and Dillon 2008). In addition, there is variability in teacher competence where a number of teachers are teaching outside their area of expertise and have limited, if any, effective professional learning opportunities (Darling-Hammond *et al*. 2009, Harris, Jensz, and Baldwin 2005). More often than not, the transmissive, traditional way in which the science content is covered stands in contrast to the collaborative, inquiry-based practices of real scientists (OECD 2006, Osborne and Dillon 2008). Moreover, this content is disconnected from real science. There have been many calls from Governments and relevant stakeholders to transform school science to make it more engaging for students (AAAS 1989, Bybee and Fuchs 2006, Millar and Osborne 1998). Recommendations have focused on making the curriculum more student centered by employing inquiry-based pedagogies and supporting teachers in implementing these approaches through ongoing professional development (Bybee and DeBoer 1994, European Commission 2007, National Research Council 1996, Osborne and Dillon 2008). It would seem, however, that even though there have been calls for reform over the past two decades, there is little evidence to suggest that any real wide-scale, sustainable change has happened.

The situation in Australia is no different. Science education in Australia has been described as being in "a state of crisis" (Tytler 2007, p. 1). The seminal reports on the Status and Quality of Teaching and Learning of Science in Australian Schools (Goodrum, Druhan, and Abbs 2011, Goodrum, Hackling, and Rennie 2001) concluded that science teaching in Australia's elementary and secondary schools was far from ideal. In secondary school science, a major concern identified related to the prescriptive way in which science is taught involving information transfer and memorization of facts from textbooks, notes, or the chalkboard. Transmissive, teacher-dominated approaches toward teaching and learning appear to be commonplace in many science classrooms (Stocklmayer, Rennie, and Gilbert 2010). Employing open-ended tasks, building teacher confidence and supporting them through professional development have been identified as key elements in reimagining school science (Tytler 2007 and Tytler *et al.* 2008).

What has been lacking in the literature previously associated with telescope use in the classroom is information on what is required to make "scientific use" of these instruments using inquiry approaches for the benefit of students and teachers (Slater, Slater, and Olsen 2009). Often, what happens when teachers and students use or request data from optical telescopes to acquire images is that they obtain the image(s) or "pretty pictures" of the object(s) and little, if anything, is done in their science lessons with the scientific information contained within the image(s) (Rosing 2010). One of the main aims of the Space to Grow project is to explore and identify ways in which students and teachers could make scientific use of the images obtained from research-grade telescopes and to investigate the impact of the approaches adopted on both students and teachers.

The purpose of this paper is to describe briefly the Space to Grow project, the curriculum materials used in the project, professional learning program instigated, and the educational research undertaken that underpins the project. The methodology to investigate the impact of the project on students' perceptions of school science, their knowledge outcomes, and teachers' professional learning will be described. The results section presents some preliminary findings from the project, while the final section outlines its future goals and directions.

2. OVERVIEW OF THE SPACE TO GROW PROJECT

The Space to Grow project is a 3 year funded Australian Research Council Linkage Grant administered by astronomers at Macquarie University and supported by curriculum experts and educational researchers at Charles Sturt University. It also is backed by four partner organizations that each contribute to the project in a variety of ways. Specifically, Las Cumbres Observatory Global Telescope Network (LCOGT.net) provides students and their science teachers with observing time on the two robotically controlled 2.0 m Faulkes telescopes so that they can acquire scientific data, which they use to undertake real scientific investigations in their school science lessons. Three educational partner organizations are responsible for the 37 participating schools within one Australian state: New South Wales. These educational partners also are concerned with the declining numbers of students pursuing science in the postcompulsory years of school. They are interested in developing professional learning approaches for science teachers that focus on supporting them to implement inquiry-based approaches and to move away from the transmissive approaches typically employed to deliver school science. The partners provide access to students in Grades 9–12 and their science/physics teachers, and fund their professional learning sessions.

The largest of the educational jurisdictions contains 22 metropolitan high schools. The other two jurisdictions are classified as regional with ten and five participating high schools located in the western region of the state. The largest and smallest jurisdictions contain a mixture of co-educational and single-sex schools, while the middle-sized one contains entirely co-educational schools. The 37 schools will eventually provide access of up to approximately 9000 students in the four grades and approximately 200 science teachers. We say "up to" because participation in the project is at the discretion of the Principal of each school, the Head Teacher of Science, and the individual science teachers. Thus far, 19 schools have provided teachers who have elected to participate. Many of the remaining schools are planning to implement in 2012.

The project is focused on the science curriculum of Grade 9–12 and more specifically the physics and astronomy content. Toward the end of Grade 10, in Australian schools, students elect to take their subjects for the final two years of high school. The originators of the project hoped to influence students' science subject choice for Grades 11 and 12, in particular Physics, which has significant astronomy components in both grades.

One of the key features of this project is to develop and implement a professional learning program for teachers that builds their confidence and competence in implementing investigative science. The approach requires them to acquire and use real scientific data and to process it with various computer applications and associated technologies. Teachers are provided with a set of curriculum materials that have been designed to support them in implementing inquiry-based science. The project also comprises an educational research program that will investigate the impact of the approaches on both students and teachers. These project components are described more explicitly in the relevant sections below.

2.1. Components of the Space to Grow Research Project

Key to the Space to Grow project is the curriculum materials and the professional learning program for teachers. A carefully staged approach to both has been adopted by the research team.

2.1.1. Teaching and Learning Materials

The teaching and learning materials have been designed by two of the authors [Michael Fitzgerald (MF) and David McKinnon (DM)] to support teachers in implementing inquiry-based science that makes scientific use of the observational data obtained from the telescopes, and which also meet the various learning outcomes of the State's science and physics curricula. To date, three projects have been developed using an educational design described below and which have been informed by extensive feedback provided by participating teachers.

The educational design that underpins these materials employs backward-faded scaffolding (Slater, Slater, and Lyons 2010), draws on the 5Es learning cycle (Bybee 1997) as a framework within and across projects, and provides opportunities for students to engage in the four types of inquiry-based learning: confirmatory, structured, guided, and open-ended. Thus, teacher direction and support for students are provided initially at depth, but as students develop the necessary analytical and scientific skills and become more autonomous, the teacher's support is faded backwards and their role changes to that of facilitator.

It is important to note that the development of the materials described below is an ongoing iterative process involving two of the project team (DM and MF) writing the materials and trialing them with small groups of teachers. The teachers provide in-depth feedback and insights both before and after they run these materials with their classes. The feedback and suggestions are incorporated into the next iteration before more widely distributing the project materials.

To date, the materials developed comprise three projects that contain a number of learning experiences and include teaching and learning resources such as PowerPoint presentations and student worksheet guides. In addition, a set of movies, involving famous public astronomers such as Professors Fred Watson and David Malin, have been created that are used in conjunction with the materials to introduce and engage students and teachers in the topics under investigation. The materials contain various exit points to cater for the different ability levels and interests of students and teachers within a school setting. That is to say, the projects are designed in such a way that they could span four lessons for a simple introduction to astronomy, 10–12 lessons for a conceptual and mathematical introduction to stellar properties and evolution, or they could involve an entire school semester's worth of work. There is also information for teachers on how they could implement the materials within their class where they are provided with opportunities for students to work both independently and collaboratively.

The first project entitled *Discovering Telescopes and Deep Sky Objects: Introduction to the Faulkes Telescopes and LCOGT.net* provides students and teachers with an overview of the Space to Grow Project and how telescopes work. Students and teachers have the opportunity to obtain some images from the Faulkes telescopes and, in the process, they begin to understand how robotic telescopes work and become familiar with a number of different classes of deep sky objects. They will then use these images in the second project: *Understanding the universe through color: Astronomical imaging with LCOGT.net.* Before they do, students and teachers gain an understanding of how astronomers create color images of celestial objects using a set of black and white images taken through different colored filters. They acquire the skills of creating color images from a library supplied with the project using two software packages, MAKALI'I and GIMP. Students and teachers are thus prepared for the arrival of "their" images. This is designed to be a motivating activity as they understand that they actually *own* the images. Figure 1 displays three images that were created by students undertaking these projects.

The third project, *Uncovering the Nature and Lives of Stars: Star Cluster Photometry with LCOGT.net*, spans a series of classes that involve students and teachers analysing a set of images of an open cluster of stars. They first understand the correlation between color and the shape of a cluster's color-magnitude diagram before they

Figure 1. Example of images that students selected to image in Project 1 and created color versions of in Project 2. (From left: M20, M3, part of the Veil Nebula).

generate their own color-magnitude diagram of one of two well known clusters: a minimally reddened cluster NGC2420 and, a heavily reddened cluster, NGC654 (confirmatory inquiry). They calculate the distance and age of the chosen cluster, and, in the process, they need to understand various concepts such as the inverse square law and stellar parallax (structured inquiry). If NGC654 is the cluster of choice, students also will have to conceptually learn about, and understand how to correct for, reddening and extinction (guided inquiry). More advanced components of this project involve the use of isochrones to determine more accurately the age and distance, and an aperture photometry method to calculate the size, of the cluster. Figure 2 shows a color image of the cluster NGC654 (left) and displays an example of a color magnitude diagram (center) that was created by a group of students who measured a representative sample of 60 stars. These data illustrate the fundamental components of this project. The color-magnitude diagram included at far right compares the student data with the latest published data for this cluster. Students' estimates for distance, reddening, and age are within the estimated error of the published values.

The backward-faded scaffolding coupled with the 5Es learning cycles embedded within the design of the materials equips students and teachers with the necessary knowledge and skills to pursue real open-ended inquiry. They can then proceed to acquire images of unstudied or poorly studied clusters, and if they are interested, have the opportunity to work with professional astronomers on existing projects or to initiate their own research proposal and submit requests to obtain data from the faulkes telescopes. To date, four groups of students have chosen to proceed to this level of open-ended inquiry.

Within the projects, two supplementary documents guide students and teachers through how to request images from the telescopes. In collaboration with astronomers, a list of potential targets is provided from which classes and/or students choose objects to investigate. In working through these documents, they develop the necessary skills and knowledge needed to submit an image proposal request. This involves them doing research on the objects, determining whether their object(s) will be visible during the night and from which hemisphere, and lastly identifying the essential information needed in order to request scientific images (i.e., types of filters to be used, exposure times, number of images needed, and time intervals between images). They then complete an image proposal request that presents both their argument for why their object(s) should be photographed and the

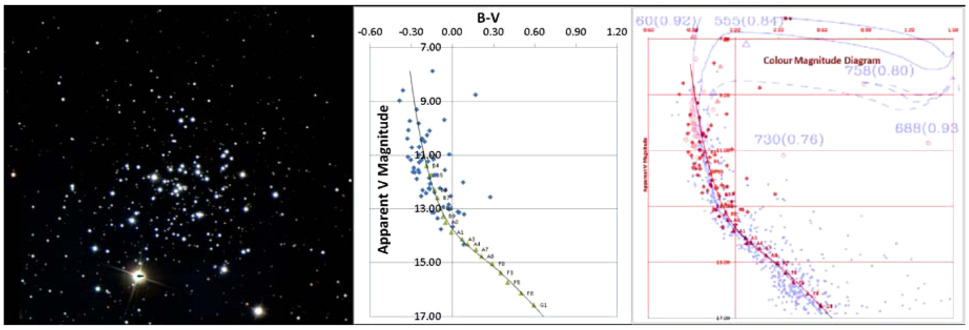


Figure 2. (Left) Image of NGC654 constructed from project data, (middle) Dereddened data and ZAMS visual fit from a sample of 60 Stars from the cluster measured by students, and (right) Student data overlaid (RED) on data from latest NGC654 photometric CMD study from Pandey *et al.* (2005).

essential information. This image proposal is emailed to Space to Grow personnel who check the information and enter it into the LCOGT.net web interface. Observations are then automatically scheduled and robotically taken. Some preprocessing takes place automatically at the observatory (e.g., flat field, dark, and bias frame correction) before being sent to Space to Grow personnel. The images are then preprocessed and made available to students and teachers to allow them to commence their data analyses. Typically, from the time that the observations are taken, the preprocessing takes only 1 day. Weather at the observatory, however, is the major determinant of turnaround time.

2.1.2. Professional Learning for Teachers

Teacher professional learning is central to the Space to Grow project. A unique aspect of our research into professional learning is that a number of approaches are being concurrently trialed. These are totally dependent on the needs and requirements of both the teachers and the educational partners involved. In all cases, however, they are being examined in terms of their scalability and effectiveness to inform future models of teacher professional learning.

The first approach to teacher professional learning is covered within the materials used in the project and which were outlined briefly above. The materials are constructed in such a way that everything a teacher *needs to know* in order to implement the activities using the inquiry-based approaches is contained within the documentation and supported by resources. For example, the materials provide teachers with a "running commentary" on how to implement the inquiry-based activities, e.g., suggestions for grouping and using cooperative learning strategies are explicitly unpacked. The background information needed in order to teach the scientific content is provided together with curriculum links and instructions on how to use the software needed for various activities. Short movies on how to manipulate and understand the software and spreadsheets as well as interpret the output are provided to help the teachers and students in the context of what they are doing at the time. The activities are structured in such a way that they lead the teachers through the four levels of inquiry-based learning identified above.

A second approach to teacher professional learning involves groups of teachers from the same jurisdiction meeting with the Space to Grow team in a small number of intensive face-to-face day-long sessions. To date, we have employed three- to five-day-long sessions, but it is important to note that this number is flexible and is based on the needs of the teachers involved. This intensive, face-to-face approach allows them to "trial" the materials and to become confident and competent at using the technologies involved. In the process, they become familiar with the scientific content and how to use inquiry-based approaches to cover the content. The sessions are designed to model how teachers should implement the activities within their science classes. One of the key features of this model is that it requires teachers to assume two roles: that of teacher and that of student. That is to say, teachers are not only learning how to "implement" or "teach" the materials in their classrooms, they also are acquiring the scientific content knowledge and engaging with the materials from the perspective of a student. Teachers are released from their regular classes to undertake this form of professional learning. Figure 3 displays two photographs. The first was taken during one of the intensive teacher professional learning sessions and the second is at a school location where students are working through project two that involves them creating color images. The students are deeply engaged in what they are doing.

Figure 3. (Left) A group of teachers collaboratively working together during one of the intensive professional learning days, (right) groups/pairs of students working through Project 2.

During the initial sessions, teachers are immersed in the materials and technologies and exposed to the inquiry-based teaching strategies required to implement each of the activities. In between face-to-face sessions, "homework" is set for the teachers that requires them to complete activities from the materials. This involves them working collaboratively and remotely, using communications technology, and employing cooperative learning strategies such as Jigsaw, Jigsaw II, and role cards (Aronson *et al.* 1978, Prince George's County Public Schools 2012, Slavin 1986). These initial sessions and the homework feed into the next face-to-face session where teachers work in pairs to teach the first three projects to students whom they do not know. This experience gives teachers the opportunity to "trial" the materials in a "supportive" way before trying them out in their own school with their own science classes. A final face-to-face session is conducted after all teachers have implemented the materials within their school science classes. It is designed to allow them to reflect on the process and provide feedback that will inform future implementation. These teachers then become facilitators for the other teachers within their science departments who intend to implement the projects. A variant of this latter approach involves teachers in remote schools interacting with project personnel and each other using various communications technologies and video conferencing.

2.1.3. Educational Research

The educational research component is designed to investigate the impact of the project on students and teachers. In particular, students' perceptions of science, their knowledge outcomes, and their intentions to pursue science beyond the postcompulsory years of school are examined both before and after their involvement in the project. In addition, teachers' perceptions of the science they teach at school and the pedagogies they employ are explored both before and during their involvement with the Space to Grow project. Where possible, pre/postdata are collected from students and teachers who are located within participating schools but who have not been exposed to the materials used in Space to Grow in their science lessons. These classes cover the required astronomy content in the "normal" way, i.e., the way it has been taught in the previous years.

A subset of the research, involving teacher participants, is part of a PhD study that is concerned with teacher professional learning and the impact of the project and approaches adopted on teachers' pedagogical practice. This study involves collecting additional data from teachers and is complemented by in-depth interviews to elicit the impact of the approaches in relation to their science teaching self-efficacy and practice. Results from this subset of the research will be reported in subsequent papers.

A multiple-baseline, multiple-probe, concurrent nested mixed-method approach employing a nonequivalent dependent variables design is employed to investigate the impact of the materials and pedagogical approaches on students and teachers. The data collection procedures for this research involve the collection of questionnaire, interview, observational, and work sample data. The data are collected on multiple occasions from different cohorts, groups and classes of students, and their teachers of Science and Physics.

A modified version of the Secondary School Science Questionnaire (SSSQ) (Goodrum *et al.* 2001), is employed to gather information on students' perceptions of school science. The preoccasion instrument asks them to reflect on their prior experiences in science, while the postoccasion questionnaire asks them to reflect on their experiences during their involvement in the project. Additional questions have been added to both that ask students to indicate their intentions post-Grade 12 in relation to areas of future study and potential career paths. A teacher version of the SSSQ that corresponds with the student version is used to collect data on teachers' perceptions of the science they teach at school both before and during their involvement in the project.

An Astronomy Knowledge Questionnaire (AKQ) is also administered to students to collect information on their knowledge of certain astronomical phenomena. It contains 19 multiple-choice items that are mapped to various astronomical concepts, which are meant to be covered in the Science/Physics curriculum in the latter years of elementary school through to Grade 12. The multiple-choice distractors are common alternative conceptions related to each of the concepts. The items in the AKQ comprise two reliable subscales one of which is designed *not be affected* by the intervention (nonequivalent variable; Cronbach's $\alpha = 0.784$). The second scale *is designed* to be influenced by the intervention (equivalent variable; Cronbach's $\alpha = 0.854$). The items in the AKQ have been drawn from the Astronomy Diagnostic Test [Collaboration for Astronomy Education Research (CAER) 1999] and the Star Properties Concept Inventory (Bailey 2007).

Teachers and students complete the questionnaires either online or using paper and pencil. This latter option is provided for those schools that have problems in accessing computers connected to the Internet. We have found that there are often issues associated with the speed of school networks and the stability of their Internet connections.

Interviews are conducted with a sample of participants to explore further their perceptions of science and to elicit student and teacher accounts of what happened in their science class during their involvement in the Space to Grow Project. Data are collected by observing a sample of teachers implementing various components of the materials within their science class. In addition, student work-samples, which may include students' color images, color-magnitude diagrams, and individual/collaborative research projects pursued, are also collected from classes.

3. PRELIMINARY FINDINGS

For the purpose of this paper, only some of the preliminary results of this project are reported to give the reader a flavor of the richness of the data. Subsection 3.1 presents analyses of a subset of the AKQ preoccasion data that focuses on content that can be directly mapped to the curriculum outcomes of the New South Wales elementary science curriculum (Grades 3–6) and which are again covered in the first two years of high school (Grades 7 and 8). Subsection 3.2 reports the pre/post-AKQ analyses for the first wave of participants involved in the Space to Grow project. Subsection 3.3 describes student scientific outputs as a consequence of their involvement of the Space to Grow project. Subsection 3.3.1 of results reports teacher feedback in relation to the professional learning approaches and project materials.

3.1. Preoccasion AKQ Results

For illustrative purposes, this section presents the results of the first four of the nonequivalent dependent variables that are designed *not to be influenced* by project materials. They are chosen because they can be directly mapped to the elementary and junior high school science curricula. That is to say, students *should know* the answers to these questions. The remaining four items of this scale are not included in this analysis because they relate to aspects of Physics not dealt with in the earlier years of high school and not covered by this project. The scale has an internal reliability of 0.854.

The participants in this sample comprise all of the students who have supplied preoccasion questionnaires since the project began collecting data. The bulk of participants come from Grade 10, while many fewer come from Grades 11 and 12 due to the external-examination-driven-nature of the curriculum in this state. The following data should, therefore, be treated with some caution for these senior years of high school.

Table 1 displays a breakdown of students' preoccasion responses in Grades 9–12 to four of the eight items that comprise the nonequivalent dependent variable scale. The items used in these analyses cover the causes of day and night, the phases of the Moon, the seasons, and the apparent movement of the Sun across the sky.

The first item relates to the causes of day and night. Of the 1374 students who provided responses, 51.3% and 50.5% of Grade 9 and 10 students, respectively, offered a correct response. For Grades 11 and 12, the figures were 74.4% and 73.3%, respectively. For Grades 9–12, respectively, 45.7%, 43.7%, 24.8%, and 26.7% of students possessed an alternative conception where the most common one encountered for day and night was that it is the Earth's movement about the Sun that causes day and night.

The second item relates to the phases of the Moon. Of the 1369 students who provided responses, 38.5% and 34.8% of Grades 9 and 10 students, respectively, chose the correct response. For Grades 11 and 12, the figures were 63.6% and 63.3%, respectively. For Grades 9 and 10, the bulk of the responses for this item (55.1% and 61.7%) were classified as alternative conceptions where the most common alternative conception identified was that the shadow of the Earth falling on different parts of the Moon causes the phases of the Moon. Students in the more senior years of high school (Grades 11 and 12) were more likely to offer a correct response for this item, but a significant number still possess alternative conceptions (32.2% and 26.7%).

Less than one third of students in Grades 9–11 ($N = 1345$) were able to offer a correct explanation for the third item on the causes of the seasons (30.6%, 30.4%, and 34.7%), while half of the students from Grade 12 ($N = 30$)

Table 1. **Students' responses to four items from the pre-AKQ that can be mapped to junior secondary science content.**

		Total	Correct responses		Alternative conceptions		I do not know	
Item	**Grade**	**N**	**N**	**%**	**N**	**%**	**N**	**%**
Causes of day and night	9	265	136	51.3	121	45.7	8	3.0
	10	958	484	50.5	430	43.7	44	4.6
	11	121	90	74.4	30	24.8	1	0.8
	12	30	22	73.3	8	26.7	0	0
Phases of Moon	9	264	102	38.5	146	55.1	16	6.0
	10	959	334	34.8	592	61.7	33	3.4
	11	118	77	63.6	39	32.2	2	2.0
	12	28	19	63.3	8	26.7	1	1.0
Causes of Seasons	9	265	81	30.6	167	63.0	17	6.4
	10	959	292	30.4	565	58.9	102	10.6
	11	121	42	34.7	74	61.2	5	4.1
	12	30	15	50.0	14	46.7	1	3.3
Movement of Sun across sky	9	262	49	18.7	177	67.6	36	13.7
	10	915	133	14.5	605	66.1	177	19.3
	11	118	14	11.9	93	78.8	11	9.3
	12	30	4	13.3	21	70.0	5	16.7

provided a correct response (50.0%). The most common alternative conception identified was that the Earth's varying distance from the Sun causes the seasons.

Even fewer students selected the correct option for the fourth item on the apparent movement of the Sun across the sky (18.7%, 14.5%, 11.9%, and 13.3% Grades 9–12, respectively). It is interesting to note that more than 65% of the responses from all grade levels could be categorized as alternative conceptions, viz., that the Sun always rises directly in the East and sets directly in the West.

The majority of students opted to select an answer to these items and very few chose the "I do not know the answer to this question" option. One might conclude that they "think" they "know" the correct answer and have previously covered these concepts in science. The low proportion of students who chose the "I do not know" option may also be able to be attributed to the exam-driven nature of the education system where teachers encourage students to attempt to provide an answer even although they "do not know."

The fact that there are a high number of student responses that contain alternative conceptions, however, might suggest that previous science lessons covering this astronomy content have not resulted in students successfully learning or understanding the concepts. Rather, students appear to retain their alternative conceptions or possess hybrid conceptions about these fundamental phenomena. These data are consistent with data published by Danaia and McKinnon (2007).

3.2. Student Pre/Post AKQ

The sample of students that these results relate to is comprised of the first wave of participants all of whom have been involved in the Space to Grow learning experiences described above. Thus, there is no "control group." Instead, a pretest/post-test longitudinal design is employed to analyze students' responses. There is a major limitation of the current data set related to the time of year when the materials were implemented by teachers. That is to say, teachers decided to leave implementation until after final examinations had been completed and students were anticipating the onset of their summer vacation. In part, this decision may be attributed to some teachers not feeling completely comfortable with the scientific content, while others used the materials to "entertain" students (i.e., keep them occupied) until the end of the school year at a time when there was no threat to student performance. Thus, while a relatively large sample of students supplied preoccasion data ($N = 612$), a much smaller group provided postoccasion data ($N = 235$), and of these only 161 provided both preoccasion and postoccasion data on components of the materials. Of these 161, 70 students in five classes covered the same project materials and therefore their results are directly comparable. Thus, the data can be considered, at best, indicative of the approaches employed.

Consequently, we have chosen to present a series of analyses that reflect the Ns above. First, a between-groups analysis of the equivalent and nonequivalent scale scores is presented. It should be noted that the nonequivalent dependent variables design is employed to improve the attribution of causality to the intervention. That is to say, if students' content knowledge as measured by the nonequivalent dependent variables scale is *not* affected, while the equivalent dependent variables scale is, we are in a much stronger position to be able to claim that the interventions have caused the change. Here, the means and 95% confidence limits of three random samples drawn from the preoccasion data supplied by respondents who did not supply any post-test data (N = 451) are presented graphically in Figure 4. The size of the preoccasion random sample is determined by those who supplied post-test data (N = 235). One-way analysis of variances were computed with the occasion of testing as the independent variable. These results are presented graphically in Figure 4.

Figure 4 shows that there appears to be no impact on the nonequivalent dependent variables here coded in blue from the preoccasion to the postoccasion. There is significant change, however, in the equivalent dependent variables coded in red. The effect sizes of this difference ranged from 0.25 to 0.47.

Table 2 presents the means and standard deviations for students who supplied complete sets of data on both preoccasions and postoccasions *and* who completed the same project content. Here, a multivariate analysis of variance with repeated measures on the occasion of testing was computed. For the nonequivalent dependent variables, there was no main effect due to the occasion of testing, while for the equivalent dependent variables there was highly significant main effect [$F(1,68) = 33.423$, $p < 0.0001$] and a moderate to strong effect size (ES = 0.66).

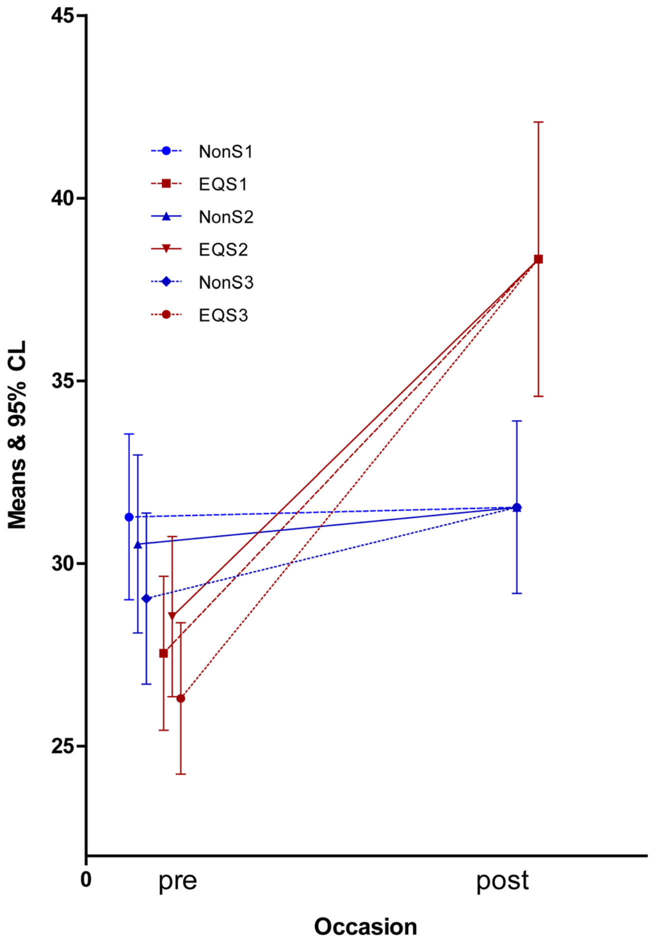


Figure 4. Graph of the equivalent and nonequivalent mean scale sores with 95% confidence levels.

Table 2. Means and standard deviations for equivalent and nonequivalent dependent variables.

	Pre			Post					Cohen's d
Scale	**n**	**M**	**SD**	**n**	**M**	**SD**	**F**	**p**	**ES**
Nonequivalent	70	36.79	12.57	70	37.86	17.42	0.185	0.668	0.07
Equivalent	70	39.55	17.17	70	51.90	20.18	33.423	< 0.0001	0.660

The authors acknowledge that improvements still can be made to students' knowledge outcomes. As teachers acquire familiarity with the new pedagogical approaches embodied within the materials used in the Space to Grow Project, and as students undertake additional projects, it could be argued that the knowledge outcomes are likely to increase.

Of additional interest, students report changes to the practices commonly found in their science classrooms. A total of 643 students provided data on the preoccasion and 177 on the postoccasion. Similar analytic approaches were employed as reported above for the astronomy content knowledge. For the sake of brevity, there is a highly significant reduction in the amount of time students reported that they copied notes prepared by the teacher, a massive increase in the use of computers and a significant reduction in frequency of teacher demonstration of experiments. It is also interesting to note that while they reported they found the science more challenging, they also reported that the content of the projects was not too hard. A fuller analysis of the changes to the conduct of science classes will be the subject of a future paper.

Things may well change as 2012 unfolds when subsequent waves of participants become involved thereby increasing the number of teachers and students who supply complete sets of data. Nonetheless, these preliminary findings indicate the approaches adopted seem to have had a moderate impact on improving students' knowledge outcomes on curriculum topics that are addressed by the project.

3.3. Scientific Outputs

It is also interesting to note the scientific outputs that have been obtained by groups of students who have engaged in the Space to Grow project. To date, there are three groups of students from three different schools who have pursued group projects that have led or are leading to publications in the professional literature.

In the early stages of Space to Grow, prior to the development of the curriculum materials described above, a group of ten female students at a metropolitan high school undertook aspects of a study of a little known planetary nebula (PN), K1–6, where they worked in collaboration with their teacher and project astronomers to analyze and publish their results in the astronomical literature (Frew *et al*. 2011). Students were responsible for generating the color image of the PN, using the Virtual Observatory (VO) tools to retrieve various archival data, and generating the light curve of the PN central star.

A second publication (Fitzgerald *et al*. 2012) has resulted from the work of two male Grade 11 students from a second metropolitan high school who undertook an independent research project on a previously little studied Globular Cluster, NGC6101. Students received guidance from their teacher and worked closely with one of the authors (MF). Students assumed responsibility for measuring, identifying, reclassifying, and updating the periods of the RR Lyrae population contained within it (Fitzgerald *et al*. 2012). Students also made an independent estimate of the reddening toward this cluster and found one, as yet unclassified, new variable star. Figure 5 shows a photograph of the two students together with MF presenting their work at their school's Science Fair.

A third publication is underway that involves high school students in a regional high school collaborating with students from a Canadian metropolitan high school. This has resulted from an initial trial of the current materials with a teacher in Canada who received no training. (He could not attend any teacher professional learning sessions.) Two groups of students chose to undertake further open inquiry studies on clusters of their own choice. Students were presented with details of potential clusters to examine. One pair of students from the Canadian class chose to investigate an open cluster that previously only had been examined with photographic methods in the late 1950s: NGC2215. During the same period, a Year 10 class in Australia also had chosen to look at the open cluster. It was suggested by project personnel that there would be the potential for these students to collaborate. As a result, a pair of students from the Canadian class collaborated with one of the Australian

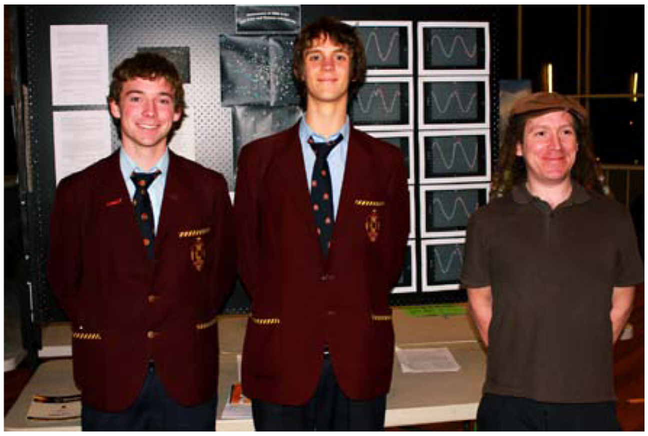


Figure 5. Two students (Josh Criss and Tom Lukaszewicz) together with project team member Michael Fitzgerald displaying their work on the RR Lyraes in NGC6101 at a school Science Fair.

students who assumed the role of lead investigator. They used email extensively to communicate and to jigsaw the task. The students have added significantly to our understanding of the main physical parameters of this open cluster: the distance, age, metallicity and reddening. They explored whether an apparently more distant stellar population was a true stellar cluster or just a photometric coincidence. The results have been submitted for publication to an astronomical journal.

3.3.1. Teacher Feedback on Materials and Professional learning

As indicated above, data are also collected from teachers to obtain feedback on both the teaching and learning materials used and the professional learning approaches employed. The development of the materials in light of feedback supplied by teachers is of special interest.

It appears that their interpretation and implementation of the professional learning materials has had a major impact on their attitudes toward what the project team was trying to achieve. For example, when a head of a science department who had provided feedback on an earlier version saw the latest materials and the changes that had been made, she made the comment “Oh! So you *actually* do listen to what we tell you.” The increase in “street credibility” that this generated led to a number of new teachers wishing to become involved.

Preliminary, anecdotal feedback from teachers, on both the materials used and the suggested pedagogies for implementation, reveals that the approaches adopted are “different” (in a positive way) to what they “normally” do in secondary science. That is to say, the inquiry-based nature of the materials and the fact that that they are implementing “real” science is different from how they would normally cover this content (such as using a prescribed textbook). Some of the teachers who have experienced the face-to-face professional learning sessions also have indicated that being able to work in collaboration with teachers from other schools, and the trialing of materials with a group of students before implementing them within their own science classes, are invaluable features of the project’s new professional learning approach. It will be interesting to track what happens with the first wave of teachers as they develop greater levels of expertise not only with the project materials but also with inquiry science approaches that involve backward-faded scaffolding.

4. CONCLUSIONS

Through being involved with the Space to Grow project and using astronomy and the images and data acquired from the LCOGT.net, the authors hope to engage students more in the exciting world of science. Teachers are a key element and need to be supported in implementing inquiry-based science that makes scientific use of the images and data acquired from these robotic telescopes. Consequently, the different teacher professional learning approaches that are being trialled and implemented are fundamental to the success of this project. It will be interesting to assess the impact of these different professional learning approaches and document the modifications made to them based on the needs of participating teachers. It is anticipated that the data collected from teachers will help identify the worthwhile features of the different models to inform future teacher professional learning not only in science but perhaps more generally.

The preliminary AKQ findings highlight that a number of the students who have tendered prequestionnaires appear to have low levels of knowledge or hold alternative conceptions about fundamental astronomy concepts that are supposed to be covered in elementary and the first three years of the high school science curriculum in the educational jurisdictions from which the participants have been drawn. The high number of students who are not able to offer a correct response, or who provided alternative or hybrid conceptions, raise questions about the way in which these concepts were taught in the junior years, if indeed, they were covered at all. Students' difficulty in retaining these concepts also suggests that perhaps we need to visit how these concepts are taught and redress the pedagogical deficits of the transmissive model that, perhaps, have given rise to them.

The pre/post AKQ results presented indicate a moderately sized learning effect for the equivalent dependent variable scale, while there was no change for the nonequivalent dependent variable scale. These knowledge gains appear to be accompanied by positive changes in students' perceptions of what is happening in their science classrooms. As the project gains momentum, and additional schools and classes become involved, it will be interesting to see what happens in relation to students' knowledge outcomes and also their perceptions of the science they experience at school during their involvement in the project.

To date, various student investigations have led to two scientific papers being published (Fitzgerald *et al*. 2012, Frew *et al*. 2010) and a third that has been submitted with students as co-authors. This suggests that students and teachers can make scientific use of the data obtained from telescopes provided that they have access to appropriate resources and professional learning to help facilitate their analyses. It also indicates that some of the students have become highly engaged by these learning experiences to reach and undertake open inquiry at this level.

In July 2012, the Space to Grow project will expand into the junior years of high school to also include Grades 7 and 8. The research team hope that by broadening the project to span all grades of high school, students' interest in science will be captured much earlier and, in addition, retain them in the study of scientific subjects during the postcompulsory years of secondary school (Grades 11 and 12).

Acknowledgments

The authors acknowledge Carolyn Dow for liaising with schools and teachers to organize professional learning sessions and for her role as Project Manager. We also thank each of the jurisdictions, the schools, the teachers and the students involved in this research.

This work was supported by the Australian Research Council (Grant No. LP0989264); Las Cumbres Observatory Global Telescope Network, the Catholic Education Offices of Parramatta and of Bathurst, and the NSW Department of Education and Communities Western Region.

This research was conducted with ethics approval from Charles Sturt University (Protocol No. 2009/025), NSW Department of Education and Communities (SERAP No. 2008298) and approvals from each school involved in the two Catholic Education Office Dioceses.

References

American Association for the Advancement of Science (AAAS). 1989, *Project 2061: Science for all Americans*, Washington, DC: AAAS.

Ainley, J., Kos, J., and Nicholas, M. 2008, "Participation in Science, Mathematics and Technology in Australian Education, ACER Research Monograph 63," retrieved October 31, 2011, from http://research.acer.edu.au/acer_monographs/4/.

Aronson, E., Blaney, N., Stephan, C., Sikes, J., and Snapp, M. 1978, *The Jigsaw Classroom*, Beverly Hills, CA: Sage.

Bailey, J. M. 2007, "Development of a Concept Inventory to Assess Students' Understanding and Reasoning Difficulties About the Properties and Formation of Stars," *Astronomy Education Review*, 6, 133.

Barmby, P., Kind, P. M., and Jones, K. 2008, "Examining Changing Attitudes in Secondary School Science," *International Journal of Science Education*, 30, 1075.

Bybee, R. W. 1997, *Achieving Scientific Literacy: From Purposes to Practical Action*, Portsmouth, NH: Heinemann.

Bybee, R. W., and DeBoer, G. 1994, “Research on the Goals for Science Education,” in *Handbook of Research on Teaching and Learning of Science*, ed. D. L. Gabel, New York: Macmillan, 357.

Bybee, R. W., and Fuchs, B. 2006, “Preparing the 21st Century Workforce: A New Reform in Science and Technology Education,” *Journal of Research in Science Teaching*, 43, 349.

Collaboration for Astronomy Education Research. 1999, *Astronomy Diagnostic Test*, http://solar.physics.montana.edu/aae/adt/. Modified for Southern Hemisphere 2002 by the University of Sydney, further modified 2004 by Charles Sturt University.

Danaia, L., and McKinnon, D. H. 2007, “Common Alternative Astronomical Conceptions Encountered in Junior Secondary Science Classes: Why is This so?” *Astronomy Education Review*, 6, 32.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., and Orphanos, S. 2009, *Professional Learning in the Learning Profession: A Status Report on Teacher Development in the United State and Abroad*, United States: National Staff Development Council and The School Redesign Network, Stanford University, retrieved November 28, 2011, from http://www.learningforward.org/news/NSDCstudy2009.pdf.

European Commission. 2007, *Science Education Now: A Renewed Pedagogy for the Future of Europe*, Brussels, Belgium: European Commission, Directorate General for Research.

Fitzgerald, M. T., Criss, J., Lukaszewicz, T., Frew, D. J., Catelan, M., Woodward, S., Danaia, L., and McKinnon, D. H. 2012, “RR Lyrae Stars in the Globular Cluster NGC 6101,” *Publications of Astronomical Society of Australia*, 29, 72, early online edition http://www.publish.csiro.au/?act=view_file&file_id=AS11046.pdf.

Frew, D. J., Stanger, J., Fitzgerald, M., Parker, Q. A., Danaia, L., McKinnon, D. H., Yean, V., Guerrero, M., Hedberg, J., Hollow, R., Bor, Y., Colman, I., Graham-White, C., Li, Q., Mai, J., Papadakis, K., Picone-Murray, J., and Vo Hoang, M., 2011, “K 1–6: An Asymmetric Planetary Nebula with a Binary Central Star,” *Publications of Astronomical Society of Australia*, 28, 83.

Goodrum, D., Druhan, A., and Abbs, J. 2011, *The Status and Quality of Year 11 and 12 Science in Australian Schools*, Canberra: Australian Academy of Science.

Goodrum, D., Hackling, M., and Rennie, L. 2001, *The Status and Quality of Teaching and Learning of Science in Australian Schools*, Canberra: Department of Education, Training and Youth Affairs.

Harris, K. L., Jensz, F., and Baldwin, G. 2005, *Who’s Teaching Science? Meeting the Demand for Qualified Science Teachers in Australian Secondary Schools*, Melbourne, Australia: Centre for the Study of Higher Education, University of Melbourne.

Millar, R., and Osborne, J. 1998, *Beyond 2000: Science Education for the Future*, London: King’s College London, School of Education.

National Research Council. 1996, *National Science Education Standards*, Washington, DC: National Academy Press.

Organisation for Economic Co-operation and Development Global Science Forum (OECD). 2006, *Evolution of Student Interest in Science and Technology Studies Policy Report*, retrieved November 28, 2011 from http://www.oecd.org/dataoecd/16/30/36645825.pdf.

Osborne, J., and Collins, S. 2000, *Pupils’ and Parents’ Views of the School Science Curriculum*, London: King’s College London.

Osborne, J. and Dillon, J. 2008, *Science Education in Europe: Critical Reflections*, London: Nuffield Foundation.

Pandey, A. K., Upadhyay, K., Ogura, K., Sagar, R., Mohan, V., Mito, H., Bhatt, H. C., and Bhatt, B.C. 2005, “Stellar Contents of Two Young Open Clusters: NGC663 and 654,” *Monthly Notices of the Royal Astronomical Society*, 358, 1290.

Prince George's County Public Schools. 2012, "A Guide to Cooperative Learning," retrieved February 21, from http://www.pgcps.org/~elc/learning1.html.

Rosing, W. 2010, "LCOGT Part 1," retrieved March 25 from http://www.youtube.com/watch?v=KwYDvbuluKw.

Sjøberg, S., and Schreiner, C. 2010, *The ROSE Project: An Overview and Key Findings*, http://roseproject.no./network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf

Slater, S. J., Slater, T. F., and Lyons, D. J. 2010, *Engaging in Astronomical Inquiry*, New York: W.H. Freeman Publishing and Company.

Slater, S. J., Slater, T. F., and Olsen, J. K. 2009, "Survey of K-12 Science Teachers' Educational Product Needs from Planetary Scientists," *Astronomy Education Review*, 8(1), 010101.

Slavin, R. 1986, *Using Student Team Learning*, 3rd ed., Baltimore: John Hopkins University Press.

Stocklmayer, S., Rennie, L., and Gilbert, J. 2010, "The Roles of the Formal and Informal Sectors in the Provision of Effective Science Education," *Studies in Science Education*, 46, 1.

Tytler, R. 2007, *Re-imagining Science Education: Engaging Students in Science for Australia's Future*, ACER Monograph 5, Camberwell, Victoria: Australian Council for Educational Research Press.

Tytler, R., Osborne, J., Williams, G., Tytler, K., and Cripps Clark, J. 2008, *Engagement in STEM Across the Primary-Secondary School Transition: Opening up Pathways*, Canberra: Australian Department of Education, Employment and Workplace Relations.

ÆR
010106-1–010106-14

PART B: BLOCKING FACTORS AND PERCEPTIONS

Blocking factors inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters.

Michael Fitzgerald, Department of Physics and Astronomy,*
Macquarie University, North Ryde NSW 2109, Australia

Lena Danaia and David H. McKinnon, School of Teacher Education,
Charles Sturt University, Bathurst, NSW, 2795, Australia

(*) Corresponding author: mfitzasp@gmail.com, Phone: +61 431 480 007

Abstract

In recent years, the adoption of inquiry-based pedagogies in the classroom form a part of important recommendations of calls for large-scale high school science reforms. However, these pedagogies have been problematic to implement on a large scale. In this study the perceptions of issues surrounding inquiry-based pedagogies of 34 positively inclined early adopter teachers involved in an Australian large-scale high school intervention project based around astronomy are probed. In particular the blocking factors that prevent these teachers from undertaking pedagogical transformation away from traditional transmissive teaching are uncovered from a series of semi-structured interviews. The most important blocking factors identified include the extreme time restrictions on all scales, the poverty of their common professional learning experiences, their lack of good models and definitions for what inquiry-based teaching actually is, and the lack of good resources enabling their capacity to implement change.

Keywords: school science, secondary/high school, teacher beliefs, inquiry-based science teaching

Introduction

Inquiry-based learning has been both a buzz term and a key focus for 21st century science teaching reform. For the most part, however, this approach to learning and teaching in school is rarely undertaken in the typical science classroom (Danaia et al., 2013; Goodrum & Rennie, 2007; Tytler, 2007; Goodrum, Hackling & Rennie, 2001; Millar & Osborne 1998), which Osborne (2006) depressingly characterises as *“.... provid[es]*ing *uninteresting answers to questions* [students] *never asked”*.Tytler (2007) stated that science education in Australia was in a state of crisis and argued that science education needed *re-imagining*. It could be argued forcefully that *re-imagining* is now an imperative since the world surrounding the school has dramatically changed while the content and educational approach have remained largely unchanged over the last five decades.

There are some, such as Settlage (2007), who consider inquiry-based learning, particularly of the open-inquiry variety, to be an unrealistic mythology rather than a practical approach to high school science education. There is also the problematic understanding of the term. The term ‘inquiry’ can be perceived by some to mean simply “hands-on learning” while others regard it as an approach that involves students generating questions, designing the method of inquiry, conducting the investigation and answering their original question and, in the process, finding out that even more needs to be considered.

Flagging this potential confusion, but also noting that both interpretations share much common ground, research into the professional development (PD) of teachers about the topic of inquiry-based teaching and learning has generally painted a fairly bleak picture (Capps et al. 2012). Teachers from across the world have continued to be largely dissatisfied with the experiences presented to them (e.g., Dillon et al. 2000, Penuel et al. 2007). In addition, while national bodies have taken the necessary step of making PD a requirement of teacher accreditation (e.g., Commonwealth, 2007), it is unlikely to make a difference on the ground that the provision of the PD itself is of inferior quality. For example, the hypodermic approach is often employed involving a one day face to face session where teachers are ‘talked at’ and expected to go away and ‘implement’ approaches talked about.

Even when science teachers’ PD experiences have been perceived in a positive light, they generally get the rug swept out from underneath them by more pressing concerns in the classroom upon their return to the school (e.g., Lumpe et al., 2000). With the reality of time constraints imposed by the context of available contact hours, teachers generally find it hard to translate their PD experiences into the reality of the classroom. This difficulty can also make it hard for intended improvements to spread naturally throughout the population of science teachers where large-scale uptake relies heavily on the perception of success of an approach before trialing it themselves (Hall & Hord, 2001).

In this paper, we explore the barriers and issues that teachers perceive as preventing them from undertaking inquiry in the classroom. We begin by explaining the context and aims of an intervention within which this study is situated and define the sample of teachers that we have interviewed. We then explain the nature of the interview process itself as well as exploring the two separate analytic methods used to extract conceptual and relational meaning from the qualitative data. We then explore and explain the links and concepts identified through this analysis before discussing their implications for inquiry-based interventions and the extent to which these findings can be extrapolated beyond our Australian context.

RESEARCH CONTEXT AND AIMS

Project Context

This research was undertaken in the context of a large-scale $2.4 million high-school astronomy project implemented in the state of New South Wales (NSW), Australia called *Space to Grow* (Danaia et al., 2012). The project was co-funded by the Australia Research Council (ARC) and the educational jurisdictions of the Catholic Education Offices of Paramatta and Bathurst and the NSW Department of Education and Training (DET) Western region. It was jointly run through Macquarie University and Charles Sturt University with the Las Cumbres Observatory Global Telescope Network (LCOGT) also providing significant monetary and organisational input in the form of access to their telescopes.

The project's official start-date was in July 2009. First estimates of the number of participants were around 40 schools, 200 science teachers and 9000 students in Grades 9-12. By mid 2010, it was clear that the number of teachers interacting with and using the project materials originally created in an earlier investigation was far fewer than anticipated. There appeared to be factors which were not being addressed leading to the lack of uptake by science teachers. At this stage, the project focus was changed significantly. Two of the project team undertook an extensive rewrite of the educational materials used. In addition, the PD model was reconceptualised and the approach to recruiting teacher participants was addressed through the preliminary analysis.

Participants

The participants in this research are an opportunity sample of 34 science teachers within the three educational jurisdictions who were willing to engage with the intervention project and commit to either three or five days of funded PD. These teachers could be described as being positively disposed towards the project simply by the fact that they replied to correspondence. As is commonly known, and further illuminated by this study, if teachers are not interested in something, they will generally attempt to ignore it.

Table 1 presents the demographic data of the participants involved in this research. All teachers were employed full time with most (58%) in the Catholic sector. The majority (30) held a Bachelor of Science or Bachelor of Applied Science degree as their main science background. Of these 34 teachers, only two had not implemented due to their perception that the materials and the investigative projects were “inferior” and only one teacher was prevented by external factors from implementing the project materials in any way. The main batch of interviews was conducted over the period 2011-2012. There was also an earlier, less rigorous but more open-ended series of interviews undertaken in mid-2010 to get an initial feel for the potential issues. These earlier interviews were not recorded and are not included in this analysis.

TABLE 1: Demographics of participants in this research

Demographic		N
Gender	Male	19
	Female	15
Type of School	Independent	6
	Catholic Systemic	20
	Government	8
Age	Under 30	2
	30-40	12
	40-50	8
	50+	12
Position	Classroom Teacher	20
	Head of Department	14
Educational Backgrounds	Bachelor of Education (Applied Science)	7
	Bachelor of Science, Diploma of Education	24
	+ Grad Certificate of Education	2
	+ PhD.	1
Years Teaching Science	Less than 1 year	1
	4-7 Years	5
	8-12 Years	4
	13-25 Years	11
	25 Years+	13
Years Teaching at that school	Less than 1 year	5
	1-3 years	7
	4-7 years	5
	8-12 years	8
	13-25 years	7
	25 years +	2
Any Astronomy in science degree?	Yes	10
	No	24

METHOD

Interviews

Interviews were conducted with 34 teachers at their respective school campus during one of their free periods and recorded with the respondent’s permission. The median length of an interview was one hour, with the shortest 40 minutes and the longest two hours. The interviews were semi-structured in the sense that broad themes had been chosen beforehand with the interviewer having a list of potential questions from which to choose if a lull in the conversation occurred. Thus, the interviews progressed in a naturalistic conversational fashion with the teacher's responses being allowed to run open-ended with the respondent addressing topics at will, rather than being led. The main themes guiding the interview were:

1) General background in terms of the teacher's employment, education and general life history.
2) How teachers became involved in the project and why?
3) The nature of previous PD experiences and what style of PD they preferred.
4) Their experiences and reactions to the way in which the PD was conducted in *this* project.
5) An exploration of general contextual factors about what influenced their and other teachers' abilities to improve or change their practice.
6) General questions about their perceptions of their students and of inquiry-based learning.

All interviews were transcribed by an independent transcription agency. Each interview was read in detail and two actions were performed on the data initially. First, any irrelevant off-topic or social-conversation text was removed and second, sections of text that were perceived to be on a general overarching topic, e.g., student motivation, were sorted and copied into a separate file. These paragraphs were tagged with the interviewee's name for later cross-reference, if required, as well as keeping the interviewer/interviewee identification tags to separate this text in later analyses. The final text of on-topic interview conversation totaled just over 200,000 words for the 34 interviews. Two methods of analysis of these textual data were undertaken. The first was undertaken manually, and the second, semi-automatically using Leximancer (www.leximancer.com).

Textual Analysis

The manual analysis method involved reading and re-reading the text. The purpose of this was to identify any *apparent* general concepts discussed with examples of the representative text recorded in a separate document for later elaboration. The apparent links amongst these concepts/topics were identified together with the number of teachers who had made that particular link was quantified using a simple frequency count. These concepts and linkage frequencies were recorded and represented visually in a network diagram using Microsoft Visio^{TM}.

In order to generate a visual representation of the relationship amongst the concepts and the frequency of their links, these data were subsequently imported into Gephi, an open source graphical visualization and manipulation package (https://gephi.org/). The data were organised using a "force-based algorithm" (Jacomy et al., 2011) designed to allow a rigorous qualitative interpretation of the data.

The resulting Gephi network representation is presented in Figure 1. Here, the circles represent the individual concepts identified. The size of each circle is proportional to the total number of links made with all of the other concepts. The width of the lines connecting each circle is directly proportional to the frequency count of teachers who made the link between the two concepts. For example, the *size* of the *Good PD Design* circle is directly proportional to all of the links with *other* concepts. The *thickness* of the lines drawn between this concept and the smaller circles are directly proportional to the *number of teachers* who made connections between the *Good PD Design* concept and each of these other concepts, e.g., *collaboration with other teachers, barriers due to distance* etc.

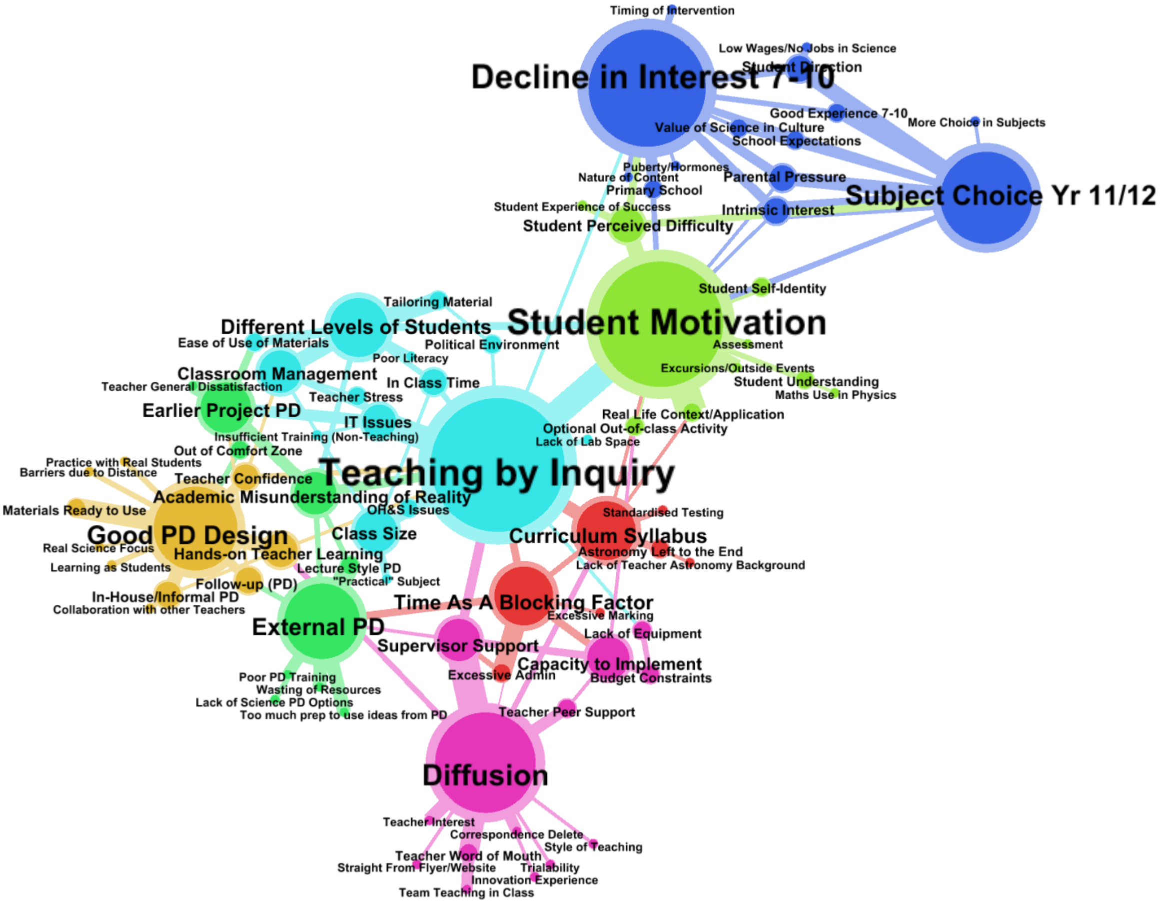


Figure 1: Gephi communities of concepts.

"Communities of concepts" within the graph were also explored. A "community" is defined as a set of concepts that are broadly connected. They may also be termed "themes". Thus, the different colours in the graph represent these broader themes comprised of inter-related concepts. The general principle behind this technique, using the in-built algorithm outlined in detail by Blondel (2008), is to progressively define increasingly larger themes from the initial nodes with the goal of finding the local maxima of modularity for each community. In this sense, it is somewhat like a k-means cluster analysis commonly employed in the Statistical Package for the Social Sciences (SPSS). Using this approach, seven distinct themes were identified and are outlined in Table 2. Each of these themes is represented by a separate colour in Figure 1.

Table 2: Identified *Community of Concepts* as broad themes.

Theme	Gephi Theme
1	Diffusion-related
2	Curriculum/School factors
3	External/Early Project PD
4	Good PD Design
5	Teaching by Inquiry
6	Student Motivation
7	Decline in Interest over 7-10

As a comparative and confirmatory analysis, a separate method was used to explore the same interview data. Leximancer, a text analysis tool, was used to identify the underlying conceptual and thematic structure without any human intervention. Leximancer has one major advantage as it avoids human bias and interpretation of words and looks purely at the relationships of words within sentences to identify concepts and themes. Concepts and themes are identified using Bayesian probabilities based on the distance between words in a sentence. That is to say, Leximancer identifies a “concept” when two or more words continue to occur within a certain distance (set in the rules) within a sentence. “Themes” are similarly identified when “concepts” occur within a certain distance of each other.

The size of a theme in Leximancer is set by the user. That is to say, by trial and error the number of concepts within a theme can be adjusted to something that “makes conceptual sense”. In contrast, Gephi calculates the themes purely from the data. Thus, the themes identified in Gephi are perhaps more representative of the *true* theme size encoded within the data. In Figure 2, the Leximancer generated map of concepts represented as small circles and a word are colour-coded within the Leximancer-identified themes represented by the larger ellipses.

The areas that correspond to the Gephi-identified themes are overlaid as black lined polygons for comparison. While the correspondence is not exactly one-to-one, there is a high degree of agreement on the broad issues. There is a single group identified in the Leximancer analysis that was not apparent in the Gephi data: the theme associated with 'astronomy, telescope and stars'. The reason for this is quite simple: this is the core theme of the Space to Grow project itself and was not coded by the authors in the initial textual analysis.

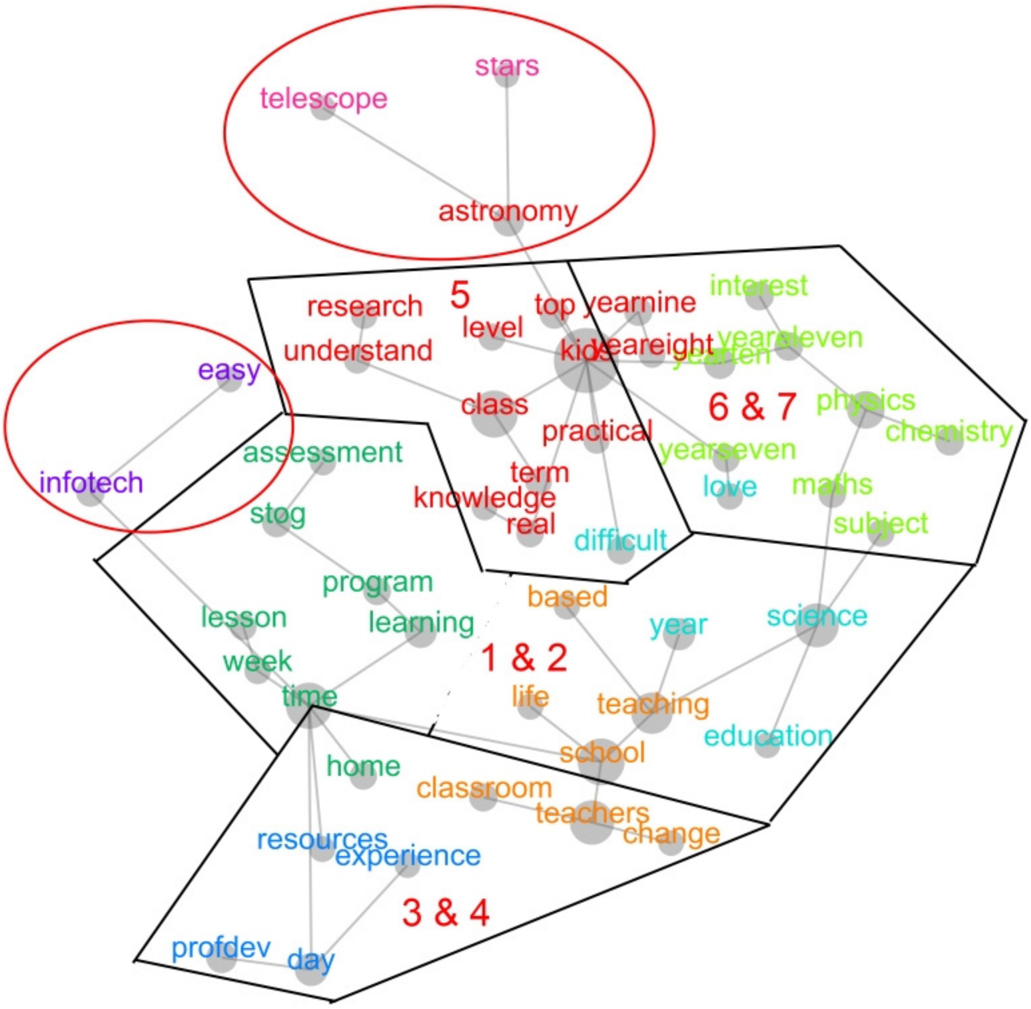


Figure 2: Leximancer VS Gephi representations

As can be seen in Figure 2, in the Gephi analysis there are two distinct super-groups of Communities of Concepts, that of the teachers to the upper right and those concerning the students on the lower left with 'Teaching by Inquiry' forming the major link between the two. While not as pronounced, the Leximancer graph is also two sided with the students to the top right and the teacher issues largely to the lower left. As these two super-groups deal with two easily separable groups of concepts, we chose to focus on the teacher-focused group of concepts in this paper and deal with the issues related to students in a later paper.

In exploring the broad themes, we have split the following set of results up into two distinct sections. The first deals with major inhibiting factors that teachers perceive as stopping them from implementing inquiry-based science in the classroom. The second focuses more on what teachers perceive as working for them in allowing them to implement inquiry-based science and of helping them to spread the innovation amongst their fellow teachers.

FACTORS INHIBITING INQUIRY IN THE CLASSROOM

Teaching by Inquiry

The teacher themes all revolve around inquiry-based approaches to teaching and learning. This not surprising given that it is one of the core educational goals of the project. It seems, however, that teachers are not confident in what ‘inquiry-based learning’ actually means or what it involves. For some, it is a synonym for *hands-on learning*, while others are simply not quite so sure.

> *Well we’ve all heard about it [inquiry based instruction]. What we really need is just some models...some examples...and some training on how to write the activities and how to structure them. If I had that basic tool kit I’d be able to do it myself...confidently. At the moment I’m like... I don’t know how to do it. I wish I could go to a few workshops or something and learn how to... how to construct these things. I think it’s probably quite simple. I just... it’s probably more of a confidence thing.*

The nature of class size, which tends to be about 30 students for a typical Yr 7-10 high school classroom, is perceived to be an impediment to inquiry-based learning. In such large classes it is less likely that the teacher can provide individual and/or small group help with their experimental skills, an area identified as particularly necessary for modern Australian students (DEST 2006). This is despite the fact that other subjects with a heavy hands-on aspect, such as Visual Art, Industrial

Technology or even Information and Software Technology classes, being classified as practical subjects and often have their maximum class size capped at 24. The larger the class size is, the less safe the laboratory environment will be.

> *Well one of the biggest glaring problems that comes up is trying to do experiments and practical work. If you had a class of 24 that's three kids to a bench. Three kids in a group is a good number of kids so that everybody has a job to do. As soon as you get four kids at a group you've got somebody doing nothing. And if there's a kid doing nothing, that's generally when accidents and mistakes will happen. And so what happens is whenever my classes are doing experiments, I'm not helping them with their experiments. I'm standing back trying to manage the whole class and keep a very close eye on safety.*

The opportunity to do hands-on work has also been reduced due to the high level of organizational overhead due to Occupational Health and Safety (OH&S) issues. This applies to all sciences but it is particularly acute in Chemistry where the safety requirements have become stringent and prevent the use of chemicals and equipment easy accessible in previous eras leading to some teachers having to show You-tube video clips rather than perform the actual experiments. OH&S issues also impact on the capacity to run excursions, such as field-trips to a planetarium and observation nights where risk assessments need to be undertaken for every external opportunity offered. This adds another layer to the administrative loads teachers appear to be faced with..

> *See, for every prac we do a - oh god, it just escapes me - we do an awareness... an OH&S sheet. We do the same experiments every year, yet we're forever writing out the same OH&S sheet. I mean, to me it seems ridiculous ....for every prac you attach your OH&S sheet. It's just what you do but that's another time-consuming thing.*

Information Technology (I.T.) issues also figured prominently in the interviews. In the context of astronomy, all image data are digital and are transported, manipulated and measured on computers. What little capacity there is to take visual non-computational measurements can only be done out of school hours, i.e., at nighttime. So, perhaps more than other sciences, astronomical measurements depend heavily on reliable functioning software. All of the teachers expressed significant frustration at achieving stable functionality with the I.T. hardware and software at their schools. These issues caused a great deal of stress to those teachers who encountered problems in the interviews. Many also commented that insufficient training was generally provided for the new IT that was rolled out to schools, both hardware and software. During the period of this research, funding for laptops for each student in Australia was provided by the Australian government, but no IT support or funding was provided.

> *So, we like the idea of I.T. and the kids have all got laptops and we thought they might have been an opportunity to use the laptops for proper learning and the potential was there of course, but in practice they are very limited to them because you can't put any* [additional] *software on them.*

Earlier/External PD

The typical approach suggested to promote inquiry-based learning is the provision of high quality “professional learning experiences”. However, this approach is hampered by the typical style of External Professional Development that teachers generally experience. One teacher’s description of a typical PD day is a *‘bunch of lectures and a nice lunch in between’*.

> *Very few presenters practise what they preach. I can’t even think of ever going to a workshop about some sort of active learning where we actually did some active learning. Most people stand up and talk about it, and say how much of a good idea it is, but they’re not actually doing it with the teachers.*

The teachers in this study largely had low opinions of the quality of the training they had previously been exposed to and consider some of them to be a significant waste of resources, with respect to both time and money. More specifically, their general experience is that while attending a PD day the focus or content covered inspires them and they leave with good intentions and momentum but once they return to the reality of the school there is little chance to incorporate any of the ideas garnered from the day. This is largely because these sessions commonly do not give teachers something concrete they can take directly back to their classrooms. Rather, any content or materials to be implemented require significant preparation involving both time and resources. There also seems to be little science-focused PD for teachers in comparison to more generalized pedagogical, legal or administrative professional development.

> *Professional learning, what I'm finding with people is that they've reached saturation point… the first day back next term, we've got to do professional learning. We've got to do three sessions. And the choices, like a lot of them, are basic computing skills. Sorry, I don't want to spend an hour learning something that I'm not going to use straight away because I can work things out for myself anyway and to waste an hour of my time when I'm not going to be using it straight away, when I will forget, to me, is a waste of my time.*
>
> *And,*
>
> *I hate going on PD days. I hate them, because they're usually educational based. I like going to PD days where you learn some science, and then you learn how to fit the science into education, rather than "this is how you teach" and then you've got to try and fit your science into the teaching method, and it's usually a day that you sit there and think you could have done a lot more with it.*

In general, the PD provided in the 'earlier' (pre-August 2010) project suffered from the same problems illustrated above. There was expression of widespread teacher dissatisfaction with the PD and project as a whole, but there was one specific and important area that emerged from this theme. This was that the concept of academics' *Misunderstanding of Reality* which in this earlier phase of the project, appears to have been particularly pronounced. Some teachers commented that the nature of what the project expected from both them and the students was "light years away" from what would actually be achievable in their classrooms.

A significant proportion of this tension was due to the teachers being asked to go far beyond their comfort zone and without sufficient scaffolding or support being provided. The teachers felt that they, and their students, were being asked to “actually be astronomers”, which neither they, who at best had a broad generalist science expertise, nor their students, who typically did not even know what a galaxy was, could undertake a real piece of scientific research in the very limited class-time available to astronomy. While some (very few) teachers thrived on this expectation, the vast majority thought it was an implausible and unachievable approach.

> *Initially it* [the PD] *assumed too much knowledge for the teachers. They do know stuff, but they don't know all the stuff that the astronomy department of M- University knows as part of their cultural knowledge and you know I think it was too high. The expectation was that you astronomers are there* (points slightly high) *the kids are there* (points to the middle) *, you think we are there* (in between the astronomers and teachers) *and you want us to go there* (where the astronomers are) *but we are really there* (points very low) *and the kids are really there* (even lower)*, so the gap was a lot higher than what you thought.*

Teachers also see quite distinct contrasts between what they were taught during their teacher education degrees e.g., constructivism, inquiry-based methods, and the reality, e.g., transmission, tick the box teaching methods, when they were thrust into in their mainstream teaching careers. They also see this distinction between what they can achieve in their classrooms and what gets presented to them by academics.

> *…. you know our feeling, probably amongst teachers, is that academics couldn't teach if their life depended on it. That's our feeling as teachers and she* [reference made to an academic] *did everything in her power to confirm that. We still talk about it because it was meant to be about quality teaching and we all went to the hall and sat there and listened while she stood at her lectern and lectured us for six hours. Half the teachers didn't even turn up after lunch. You know, that's pretty poor isn't it?*

> *My first couple of years* [of teaching], *it was like … this is not what I've been learning at university in some ways, the new way of facilitating learning and all of that. So I've been six years down the track. I feel like I'm now a teacher in one of those schools. To be honest, I think I've lost touch with what I have learnt, a bit, at university in the whole constructivist type approach to learning. And now I follow a program and tick the outcomes off and that's kind of my focus, it seems.*

Curriculum related blocking factors

Even if adequate support is provided, "time" is the most commonly stated single factor preventing project implementation. A large amount of time is actually spent teaching the students (five out of every six periods), which leaves one period for preparation per day. This single period is usually spent catching up on administrative tasks while the class preparation work is generally left until home at nighttime or at the weekend.

> [Time as an issue]*…look it is, but it's not enough to say that time is an issue because it's becoming a more significant issue and the way schools are going at the moment with the expectations from the Department* [of Education]*, teachers are going to have less and less available time. They are chasing their tails on often pointless administrative bloody crap, you know, and they are using their energy arguing with resistant dysfunctional kids. And that's not a good environment to be trying to generate a sense of inquiry or wanting to get out there and learn more, or improve your teaching. People pull back when those sorts of pressures start to mount and they are mounting significantly.*
>
> *It* [time] *is a big issue and the workload is actually the thing that people complain about. It's not necessarily doing something new, it's how much work is involved. Well I was just saying the other day like I get in here about quarter past seven and I'm often here till after five and then I go home and do a couple of hours work. So I guess a 12-hour day and the weekends, it's a big ask… it's, yeah, not getting any easier. So yeah, it's very time consuming and yeah*

> *that's why I didn't really want to take on something new* [the project] *that would take up even more of my time.*

While teachers do not so much mind the out-of-hours preparatory work, they have found that the amount of administration and paperwork to be completed has been steadily increasing as outside agencies want them to become more accountable. However, some teachers pointed out that this additional "administrivia" either generates an elaborate system of *lying*, or simply taxes a teacher's time and intellectual resources with no actual benefit either to the teacher or to the student. Even mandatory content is sometimes simply not being undertaken as a coping strategy for teachers. Marking and the provision of feedback are seen as major time sinks but the lesser of the two evils. Some teachers commented that it would help a great deal to have someone actually do some of the more mundane tasks such as enter the assessment marks into the computer for them.

> *The thing I just don't like about teaching is the administration part of teaching. We are getting really bogged down with that these days. So, at the moment, many teachers are spending a lot of hours doing work to be compliant for an audit. So taking work samples from students' work, a lot of fiddling around with* [the science*] programs and a lot of the stuff is bureaucratic stuff. I don't mind doing stuff if I see a positive for it, like if, for example, if you are doing all this stuff for the audit and someone comes back and says I don't agree with these activities you are doing, or the way you are teaching this, here are some other strategies, then that's fine. But if you just do all this work and there is no response you think, what's the point?*
>
> *Well it's impossible. It's impossible to do everything that's asked of you. I've never been able to do the job, but I'm relaxed about that because I know there are things I'm not doing, as long as somebody else doesn't know I'm not doing it. Well, everybody is doing it. The only difference is generally that I'm being honest about it and say I'm not doing it all. But, there are plenty of teachers that like to give you the impression that they're on top of it. So we are*

> *creating an environment where you can't do it, but you can only be rewarded if you make it look like you are doing it all. It's another stress isn't it. It's very poor management that one.*

The administration and preparation pressures are intertwined with the overcrowded nature of the curriculum and national testing regime that structure the school program and which dictates the nature of the use of scheduled class-time. In terms of astronomy, the topic is generally left until the end of the year in the school program. As some teachers claimed, this means that it is just not done. In general though, if the project cannot be adequately and easily fitted into the school's program, which is usually very tight, it is unlikely to be taken up.

> *First of all is the nature of the science syllabus. It's huge and there's like heaps and heaps of stuff in there. And although the science syllabus is described that you would spend 50 per cent of your time on pure skills and only really 25 per cent of your time on just straight up knowledge content, in reality there's so much content to get through that it's very easy sometimes to spend all your time on content. So, the first thing is of course there's so much to get through that we don't get the time to actually do proper experiments, and we don't get the time to do more interesting and fun things. We really don't…like I haven't been on an excursion for science in my teaching career. I haven't been on one because there's no time. The schools just don't have the time to put aside a day for science. And that's significant.*

FACTORS PROMOTING INQUIRY-BASED SCIENCE IN THE CLASSROOM

Good PD Design

While teachers, apart from a small number of trailblazers, lacked the confidence to undertake the project in its previous form, the teachers were uniformly very positive about the confidence the reformed 'later' (post-August 2010) project provided them. In this format, teachers also commented about being out of their comfort zone, but noted it as a positive rather than a negative.

> *I found them* [the PD days] *extremely useful and I got more and more confident. As you know, I was the one who was like, "I can't get this" and it sort of made me learn too…and then I learnt a lot from my mistakes. So when a student actually did make a mistake in class, I remembered doing it during the professional development and I knew how to resolve it.*

The particular nature of the later professional development design was that it was much slower paced than the typical PD sessions teachers had experienced and on which they had commented. The PD sessions focused heavily on getting the teachers to undertake directly the same process, using the same materials, as the students. There was also a heavy science content focus as well. The majority of the session times were spent with the teachers actively using the materials as learners with time for reflection about how they would undertake this in *their* class. During these periods, various pedagogical approaches such as guided inquiry and jigsaw methods, were modeled for the teachers. A further benefit of the newer design was that it involved multiple face to face sessions with collaborative homework undertaken in an asynchronous fashion online. This allowed the teachers' feedback to be incorporated towards a follow-up built on the previous PD session. These allowed the teacher to return to the material again with the benefit of more experience and with some reflection about their previous session.

> *Because I could see I could use it, and that's what matters in teaching because in teaching the worst thing… people give you all these great ideas and then it just... nothing ever happens with it. Whereas with this, I could implement this tomorrow, I've got the material….and I've done it all myself too. It's not like I'm coming from a theoretical point of view. I can do this, I've done it in class, I was the naughty boy at the back* [during the PD], *so that's cool. I can do it.*

> *I just think unless there's follow-up, then you tend to, well I tend to go...Okay that's nice... and then it gets put to one side. There's no change in* [my] *behaviour. You might think it's all well and good, but then it all gets put aside because you've got these commitments to get work done to a timeframe and it just gets put aside, even though what you've done might be*

> *relevant, might be great. Unless you've spent the time to actually adapt it, you're not going to do it. But for me, if there's follow up, you're going to make some effort to adapt.*

One particular aspect of note that teachers found useful about the newer PD design was that the materials provided were ready to use in the classroom. After each training day, the teacher was capable of taking the material directly into their classroom, and some of them did, to use with their students because the authors provided all of the in-class materials necessary. These materials required only minor modification for a particular context/classroom. This was an important issue on which teachers commented frequently. As indicated earlier, they criticized as a lot of typical PD experiences where "adequate" resources or pedagogical approaches ready for classroom use were not provided.

> *...and particularly things with resources and new sort of ideas. They give you the resource but no real...they don't tell you anything about how to implement it or how to use it. So generally, they just give you a resource and then you go away and work out how you're going to structure* [it] *into lessons what the kids* [are to] *do and what you'll need to do, etcetera. Whereas* [with] *this package, it's already designed and set up for us to implement.*

In general, and in contrast to the earlier much criticized approaches, teachers seem very positive about in-house and informal PD and its increased benefits over the traditional approaches. As one teacher said, "Sometimes a five-minute chat over the coffee table can improve your teaching much better than an entire PD day". One teacher involved in the project has constructed his own PD website to provide a forum for teachers to share their ideas and to collaborate with other teachers over the implementation of the Space to Grow materials. In one sense, this is almost like having that five-minute chat over morning coffee.

> *... here in the past our teachers have delivered* [In-house PD sessions] *them, especially on different educational projects that they've delivered and that's been good. Everyone's engaged because they're your colleagues and it's what's working in their classroom so you're interested in it. They've done it with our kids, the same sort of kids that we would have in*

> *our room, and it's worked, and they've got measurable improvements that are actually real to us, and I'm sure the other ones are real as well but when we know the kid and they can say, "Look, he's gone from here to here by doing a few of these tasks," well then it's real, and so everyone's engaged.*

Diffusion

Parts of the discussions revolved around what aided or hindered other teachers and initially themselves from getting on-board with the project. While fellow teachers can form a strong support social group as well as providing a source of information through personal conversations, it is generally a person in a supervisory position who is a key facilitator for that teacher to participate in the project. In contrast, there were teachers who said they specifically asked for certain allocations or classes in order to be able to incorporate the project but were denied their requests.

> *Yes, and a few administrative issues, like I had specifically requested to be on [particular classes] this year, I also specifically requested to teach Year 10 this year to really get it embedded, but that didn't happen, …neither of those requests. So it will be a challenge to take it beyond where we were last year.*

Being the only person interested in the project at a school has also been perceived as a negative factor. Having another teacher at the same school to share resources, to have conversations with, and to show support makes implementation much easier. Some teachers who have had previous positive experiences with the project have invited other teachers into their class, or have gone into other teachers' classes to show them how the project works in reality. This provides the new teacher with some experience of what is required and an ability to undertake a particular project in a trial-based manner.

> *I would've been happy to go with it if someone else on my staff had been interested, and no one was. I just felt like "it's just another thing I've got to do" and I was already drowning and*

> *having trouble keeping my head above water. So that's the reason, it's not a very exciting reason and each time something's come up but no one wants to be involved.*

Only very occasionally did a teacher become involved from encountering an information flyer or the project website. Generally, it was more likely for a teacher to become involved through the recommendation of a trusted peer or supervisor. Typically, teachers are swamped with correspondence aimed at getting them to be involved in all manner of projects or for enticing them to make any number of purchases. Usually this correspondence is ignored or discarded due to the time constraints alluded to earlier.

> *Well yeah, look, that's... I undoubtedly delete some stuff that I might vaguely be interested in, just because of the sheer quantity. It's personal recommendation; it's like anything, isn't it? If you want to go and buy a phone it's nice to be able to see someone who's had it and, yeah, and knows all the ins and outs about it. So a personal recommendation is much more useful. So, I think it's that personal side. We often listen to each other more than we read every email that comes across our desk.*

A teacher's inherent interest is not enough by itself to provide capacity to implement. With the earlier materials, some teachers who were particularly interested in astronomy were put off from undertaking the project, and sometimes by the lack of supervisor or peer support. In contexts other than this astronomy project where most of the materials are computer-based and free, budget constraints and lack of adequate equipment have prevented inquiry-based project implementation.

> *That doesn't mean we don't want to teach* [that] *boring science. We'd like to, my budget to run the science faculty is $9000 a year. You go back to your astronomy department and ask them how much they've got to run their department ...$9000 a year... that's for all the textbooks, all the equipment, all the stationery for 400 kids. That's not much money.*

SUMMARY AND DISCUSSION

This research has drawn on teachers' perspectives to identify factors that they perceive prevent them from implementing inquiry-based learning and teaching approaches in secondary school science classes. The interviews revealed that while teachers were familiar with the term *inquiry-based learning*, some of them were not sure about what it would involve in the reality of their own classrooms. The interviews revealed that they lacked the confidence and competence to implement inquiry approaches within their science classes. Teachers also indicated that they have little time to implement inquiry-based, investigative approaches given the breadth of the curriculum that had to be covered. There were also a number of organizational issues that were identified by teachers such as large class sizes, limited resources and space, tighter occupational health and safety regulations and excessive administrative loads within the school context. Teachers perceived such factors as preventing them from implementing inquiry-based science in their classes. The interviews also revealed that typical professional development experiences fail to model the behaviours at which they are directed such as inquiry-based learning or constructivist pedagogies. Rather, they are transmissive in nature and appear to have little, if any, impact on teachers' classroom practices. Many of these concerns have been consistently reported in the literature together with numerous calls for change to the way in which secondary school science is delivered (e.g., Goodrum et al., 2001; Goodrum & Rennie, 2007; Tytler, 2007).

All of the factors identified have implications for both pre-service teacher training and in-service teacher professional learning. It would seem that teachers not only need extensive support and guidance on how they could implement inquiry-based instructional approaches within their classrooms, they also need examples, models or actual experience in implementing such approaches before attempting to undertake it within their own science classes. In the Space to Grow project, all of the teachers who had experience at implementing such approaches during the professional learning sessions later implemented these inquiry-based investigative approaches in their classroom and continue to do so. It is also worth noting that some are applying inquiry-based approaches to science content to be covered not just astronomy.

Curriculum developers and policy advisors may conclude from these findings that if inquiry-based approaches are to be implemented in the delivery of secondary school science, the breadth of the curriculum needs to be reduced to allow teachers time to drill deeply into the content and focus on implementing it using inquiry-based approaches. More importantly, and perhaps centrally, teachers need to be engaged in professional learning that both models and involves them in investigative, inquiry-based approaches.

Similar to other Western countries, Australia now has a set of *National Professional Standards for Teachers*. One of these standards requires teachers to engage in continued-professional learning. Within Australia, state- and territory-based educational bodies exist that require teachers to be accredited. To be accredited, and to maintain accreditation with the regulating body, teachers must undertake a specified number of hours of professional learning within a particular time frame. This is happening at a time where Australian teachers are also confronted with the roll out of a National Curriculum. The new National Science Curriculum calls for investigative science and inquiry-based learning approaches to be adopted and teachers are to commence implementation during 2014 and 2015.

Given these circumstances, now is an opportune time to examine current models of science-teacher professional learning in light of the factors identified above and transform the more traditional, transmissive instructional approaches commonly adopted in secondary school science classes to ones that involve students and their teachers investigating and engaging in inquiry-based learning. This is a major issue for inquiry-based approaches where teachers who do adopt and implement are those who are willing to take risks and self-organise within schools where such activities are actively supported by their administration (Songer et al., 2003). Even so, for these teachers, their opinions of what PD facilitators ask them to do are negative with many of the demands placed on them being regarded as completely unrealistic.

Even when the claims are potentially realistic, the quality, and nature, of the training provided is often problematic, lacking in the five key broad characteristics of effective PD identified by Ingvarson (2005), i.e., content focus, active learning, feedback, collaborative examination of student work, and follow up, the teachers interviewed in this study counted themselves lucky to have seen even one of these in their common PD experiences. Similar lists of quality characteristics by other authors, such as Suppovitz (2000), Banilower (2007), Loucks-Horsley (2003), Garet (2001), Meiers (2003) differ little in their substance as to what constitutes “good” PD and in their claims about their lack of presence within the typical teacher experience in this study.

Professional learning, however, does not exist in a vacuum. While addressing the quality of the PD, even more attention needs to be paid to contextual factors such as the primacy of “teachers’ time” and its relation to the stress levels reported by science teachers and the quality of work they produce. Inquiry-based learning, almost by definition, takes more time, preparation and expertise by the teacher, than traditional transmissive teaching. Regardless of the nature of the PD, if the teacher exists within a context that prevents adequate translation of what was learnt from the PD into the classroom, then it was all for naught. The current, seemingly common, culture of science teachers where there is insufficient time to implement approaches that are absolutely required by the curriculum is not an environment conducive to implementing sophisticated inquiry-based projects in class.

ACKNOWLEDGEMENTS

We acknowledge the project from which the teacher data are drawn: Space to Grow Australian Research Council Linkage Grant (grant number: LP0989264). MF acknowledges receipt of MQRES PhD scholarship from Macquarie University.

REFERENCES

Banilower, E., Heck, D., Weiss, I., (2007), “Can Professional Development Make the Vision of the Standards a Reality? The Impact of the National Science Foundations’s Local Systemic Change Through Teacher Enhancement Initiative”, Journal of Research in Science Teaching, 44 (3) 375-395.

Blondel, V.D., Guillaume, J-L, Lambiotte, E., Lefebvre, E. (2008), “Fast unfolding of communities in large networks”, Journal of Statistical Mechanics, P10008

Capps, D.K., Crawford, B.A., Constas, M.A., (2012), “A Review of Empirical Literature on Inquiry Professional Development: Alignment with Best Practices and a Critique of the Findings”, Journal of Science Teacher Education, 23(3), 212

Commonwealth Government (2007), “Top of the Class: Report on the inquiry into teacher education”. Canberra.

Danaia, L., Fitzgerald, M., McKinnon, D., (2013), “Students’ Perceptions of High School Science: What has Changed Over the Last Decade?”, Research in Science Education, 43, 1501

Danaia, L., McKinnon, D. H., Parker, Q. A., Fitzgerald, M. F., Stenning, P. (2012). “Space to grow: LCOGT.net and improving science engagement in schools.” Astronomy Education Review 11(1): 010106.

Department of Education, Science and Training (DEST) (2006), “Summary report of the science, engineering & technology skills audit.”, Canberra: Commonwealth of Australia.

Dillon, J., Osborne, J., Fairbrother, R., Kurina, L., (2000), "A study into the professional views and needs of science teachers in primary and secondary schools in England." Kings College London

Garet, M., Porter, A., Desimone, L., Birman, B., Yoon, K. (2001). "What Makes Professional Development Effective? Results from a National Sample of Teachers." American Educational Research Journal 38(4): 915-945.

Goodrum, D., Hackling, M., & Rennie, L. (2001). The status and quality of teaching and learning of science in Australian schools: A research report. Canberra: Department of Education, Training and Youth affairs.

Goodrum, D., Rennie, L., (2007), “Australian school science education national action plan 2008-2012”, Canberra: Department of Education Science and Training.

Hall, G., Hord, S., (2001), “Implementing Change: Patterns, Principles, and Potholes”, Allyn and Bacon, Needham Heights

Ingvarson, L., Meiers., M., Beavis, A., (2005), “Factors Affecting the Impact of Professional Development Programs on Teachers’ Knowledge, Practice, Student Outcomes & Efficacy”, Educational Policy Analysis Archives, 13:10

Jacomy, M., Heymann, S., Venturini, T., Bastian, M., (2011 DRAFT), “ForceAtlas2, A graph layout algorithm for handy network visualization”, DRAFT ONLINE :http://www.medialab.sciences-po.fr/publications/Jacomy_Heymann_Venturini-Force_Atlas2.pdf

Loucks-Horsley, S., Love, N., Stiles, K., Mundry,S., Hewson, P., (2003). “Designing Professional Development for Teachers of Science and Mathematics.” London, Sage Publications.

Lumpe, A., Haney, J., Czerniak, C., (2000), “Assessing Teachers’ Beliefs about Their Science Teaching Context”, Journal of Research in Science Teaching, 37:2, 275

Meiers, M., Ingvarson, L., (2003), “Investigating the links between teacher professional development and student learning outcomes”, Millar, R., Osborne, J., (1998). Beyond 2000: Science Education for the Future (The report of a seminar series funded by the Nuffield Foundation). London: King’s College London, School of Education.

Osborne, J. (2006). Message from the President E-NARST News, 49, 1–2.

Penuel, W., Fishman, B., Yamaguchi, R., Gallagher, L., (2007), “What Makes Professional Development Effective? Strategies That Foster Curriculum Implentation”, American Educational Research Journal, 44:921

Settlage, J., (2007), “Demythologizing Science Teacher Education: Conquering the False Ideal of Open Inquiry”, Journal of Science Teacher Education, 18, 461

Songer, N., Lee, H., McDonald, S., (2001), “Research Towards an Expanded Understanding of Inquiry Science Beyond One Idealized Standard”, Science Education, 87:4, 490

Supovitz, J., Turner, H., (2000). "The Effects of Professional Development on Science Teaching Practices and Classroom Culture." Journal of Research in Science Teaching 37(9): 963-980.

Tytler, R., (2007), “Re-imagining science education: engaging students in science for Australia’s future.”, Camberwell: Australian Council for Education Research.

Differences in perception of high school science:

Students’ and Teachers’ views.

Michael Fitzgerald, Department of Physics and Astronomy,*
Macquarie University, North Ryde NSW 2109, Australia

Lena Danaia and David H. McKinnon, School of Teacher Education,
Charles Sturt University, Bathurst, NSW, 2795, Australia

(*) Corresponding author: mfitzasp@gmail.com, Phone: +61 431 480 007

ABSTRACT

The science teacher in the modern high school acts not only as the teacher but also generally the designer and customizer of the in-class practice at the smallest scale. In this role, the teacher must translate the content into a form that the pupils will understand and adequately present the materials at an appropriate level in an adequate fashion. This, of course, would rely on some accurate self-knowledge of how they act in class and impact their students’ learning. In this study we explore these issues by comparing the difference in responses of teachers and their students to an instrument that probes their perceptions of their in-class practice. We find two dramatic findings. First, not only do teachers constantly positively overrate their in-class practice compared with their pupils, but secondly, these perceptions are completely unrelated to how their students see their classrooms. This implies that using teachers as sources of evaluation about their own classrooms is heavily problematic and that evaluation should always be endeavoured to be undertaken at the level of the student. Ideally, evaluation should be undertaken at both levels.

INTRODUCTION

In the developed world, high school student interest in science has been waning for decades and, in response, have led to many national reports and working groups calling for substantial reforms. (e.g., AAAS 1990, Millar & Osborne (1998) International Bureau for Education 2001, Drury & Allen 2002, Committee for the Review of Teaching and Teacher Education 2003, Lyons & Quinn 2010, Goodrum et al. 2012). Concurrently, a large body of research has been undertaken into students’ opinions of their experiences of school science and independently of their teacher. A recent review by Osborne et al. (2009) provides an in-depth overview of recent work and the main points of interest for this field. In particular, they focus on the instruments in the literature used to measure students’ attitude towards science, the generation of questions from new datasets, the work on identity as well as the impact of age and gender.

Little research has been undertaken that directly compares students’ and teachers’ perceptions of their science classroom in terms of those aspects identified as specifically important for inquiry-based science learning. This is the case even though student and teacher perceptions of their classrooms and their interaction have been shown to form an important factor in the socio-psychological makeup of the classroom (Myers & Fouts 1992).

Previous research has been focussed on the perceptions of teacher-student interpersonal relationships in the classroom. The history of this research field is summarised well in Wubbels and Brekelmans (2005). The central instrument, and theoretical structure, of this field has based around the quantitative 'Questionnaire on Teacher Interaction' (Wubbels et al., 1985). The QTI questionnaire can be reliably reduced to eight scale scores: admonishing, strict, leadership, helping/friendly, understanding, student responsibility/freedom, uncertain and dissatisfied.

The QTI questionnaire has been used to probe students’ perception of their teachers, the teachers’ perception both of themselves and the ideal. For those that have looked at interpersonal behaviour, they have generally found great differences between student and teacher perceptions (den Brok et al. 2006). In general, the teachers’ perceptions have been "positively" skewed in comparison to the students’ perceptions. The teachers rate such aspects as 'leadership', 'helpful' and 'understanding' behaviours as higher than their students, while conversely rating such as aspects as 'uncertain', 'dissatisfied' and ' admonishing' lower than their students. These differences are also generally linked to certain instructional behaviours and tend to be correlated with higher student motivation and understanding.

Most importantly, only a small number of studies showed non-significant differences between teacher and student perception, but overall, generally moderate to strong effect size differences are found and these tend to be positively skewed. (Weubbels, 2005) This is generally seen as a symptom of wishful thinking on the teacher's behalf. In general, teachers' perception of themselves is typically (66% of cases) less than their perception of the ideal. In turn, students' perceptions of teachers are lower than the teachers' perceptions of themselves. For some teachers (33% of cases), the teachers' perception is lower than the students' perception, which can be seen as the teacher protecting themselves from confrontation with negative student perceptions.

In an endeavour to improve the experience of the science education experience of students, it is via the teacher that any of these changes are undertaken. The teacher is well-known to have the largest impact on student learning within the classroom (Rowe 2003). In the classroom, it is the teacher who must actively monitor the level to which their classroom matches, or diverges, from the ideal classroom and with this information decide on a corrective course of action, if one is available. If the teachers' perception of the classroom is inadequate or skewed, matching their in-class practices to what students need and perceive becomes problematic.

In this paper, we seek to compare the teacher and student perceptions of their science classroom with a focus on those elements identified as important to high school science education in a similar manner. The instrument we use, the Secondary School Science Questionairre (SSSQ) is a slightly modified version based on the initial work of Goodrum et al. (2001), and used over the last decade by others (Danaia 2006, Goodrum 2007, 2012, Danaia et al. 2013). The SSSQ has significant overlap with the QTI in conceptual content while containing science specific items as well.

We begin this paper with a demographic definition of our teacher and student samples and comparison to the general Australian context. We then describe the instruments themselves before undertaking two main avenues of analysis. First, we explore the mean differences overall between the teacher and student cohorts. Second, we crossmatch the student and teacher databases such that we can compare individual teachers' responses to the mean scores of the aggregated data for each class of students. We then discuss the implications of these results for science education.

TEACHER AND STUDENT SAMPLE

Teachers

Our sample consists of 86 science teachers who were all involved in the Space to Grow astronomy intervention project (Danaia et al. 2012) in NSW, Australia. Each teacher undertook our Teacher Secondary School Science Questionairre (TSSSQ) survey in the period 2010-2012. The survey was administered via two means. The first was via an online survey using Surveygizmo (http://www.surveygizmo.com/) and the second was via the traditional paper survey. Each teacher was mailed the paper version but given a web-link to undertake the survey online if they so choose.

In our sample there were 38 females (44%) and 48 males (56%). The age range distribution of our teachers is similar ($X^2(8)=12.356, p=0.089$) to that found in the 2007 Staff in Australian Schools SiAS study (McKenzie et al. 2008), shown in Figure 1. The average-age category in our sample, the 41-45 year old age range, is similar to that also found in the SiAS report.

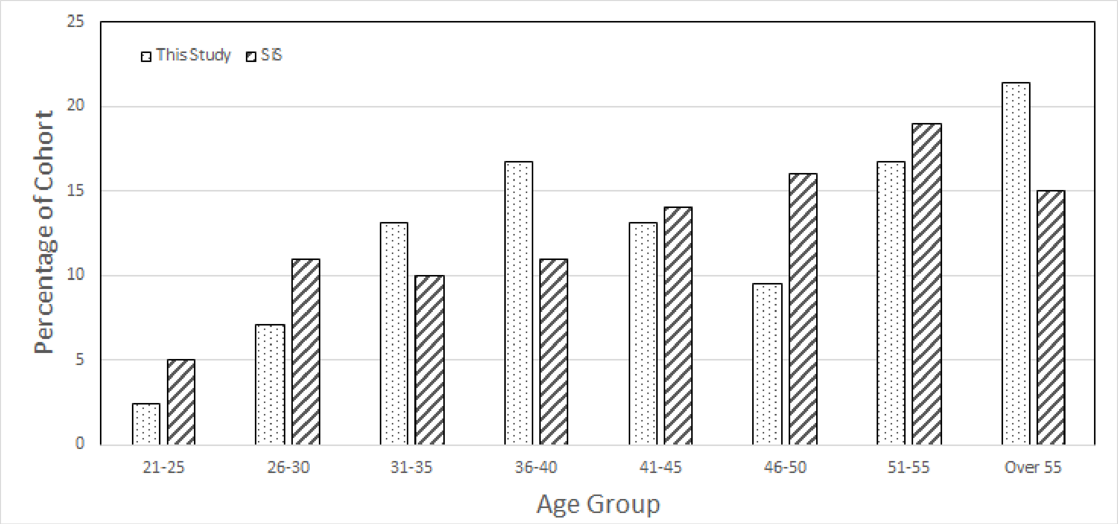


Figure 1: Age distribution of teachers in our sample compared to that in the Staff in Australia's Schools 2007.

Most teachers in this sample were classroom teachers (70%) while a substantial fraction were Heads of Departments or Subject Co-ordinators (28%) with one assistant principal. The majority were employed on a full-time permanent basis (91%), with the rest being casual, temporary or part-time. In the SiS report, 82% of teachers are employed full-time. Most teachers in our sample taught in a Catholic Systemic school (58%) or in Government schools (32%) with 7% in Catholic Independent schools and 3% in Independent schools.

The number of years the teachers had been teaching science at their school was compared to the SiAS report in Figure 2. The values are statistically significantly different, with a ($X^2(6)=15.213,p=0.009$). The differences seem to be in the lower age ranges and show an excess of beginning teachers and less teachers in the 1-3 year braket in our project, although the values of both the SiS and our sample would agree very well overall if we simply considered the two lowest categories together as 0-3 years at about 40% of the sample each.-There was no information on how long teachers had been in teaching in total in the SiS report, so we only present our own results for this in Figure 3.

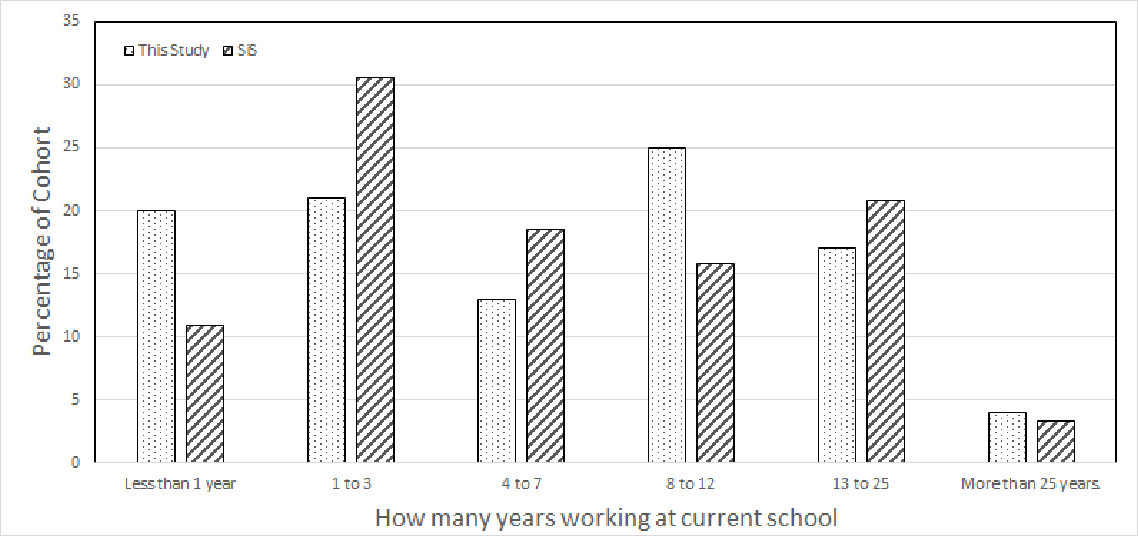


Figure 2: Years spent teaching at current school.

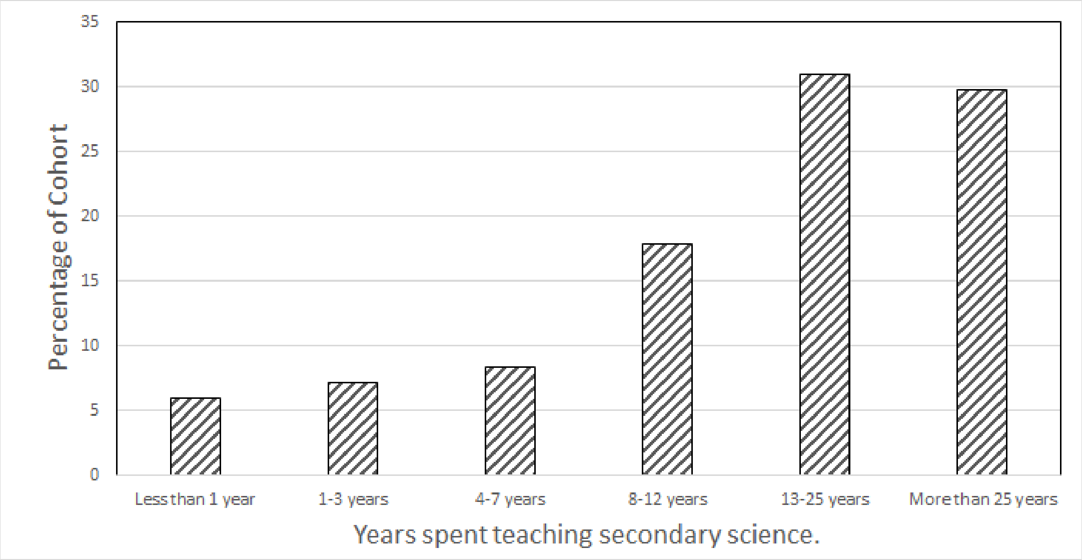


Figure 3: Years spent teaching overall.

The majority of teachers (70%) had a Bachelor of Science as their science qualification, although only 2% took this to the Honours Level, a level which normally requires a research project to be undertaken and a report generated. The next most common degree was a Bachelor of Applied Science (9%), followed by an Integrated Bachelor of Education degree with a specialisation in Science and Education (5%). Data on the nature of their major streams of study, was only collected later in the project, so only 25% of the teachers provided this information. For those that did, the fields of scientific study were, Biology (32%), Other (23%), Chemistry (18%), Physics (14%), Geology (9%) and Mathematics (4%). About a quarter (28%) of the teachers stated that they had undertaken astronomy, other than within the Space to Grow project, at some formal level, whether through a university subject in their degree, or through professional development or other type of course such as a Master of Science (Astronomy) studied by distance education.

The Diploma of Education (58%) was the most common educational qualification, with a Bachelor of Education (20%) being the second most common while some had a Master of Education (8%) degree, and one with a Master of Teaching and one with a PhD degree. The vast majority (98%) were qualified to teach junior science (Grades 7-10). In the senior science areas, the majority were qualified to teach Chemistry (85%), Physics (71%), and Biology (69%) with lower rates for the Earth and Environmental Science (43%) and Senior Multi-Strand Science (40%) courses.

The median ordinal category of class size reported for Grade 7 science classes was 26-30, for Grade 8 to Grade 10 it was 21-25, Grade 11 it was 11-15 and for Grade 12 was 1-10 students. In 41% of the schools, teachers reported that only 10-20% of students pick physics to study in Grades 11 and 12. Perhaps more worryingly, less than 10% of students picked physics in 41% of schools. In contrast, 16% of teachers reported that in *their school* the proportion of students who studied physics was 20-30% and only one school (2%) reported a rate above this. One is left to conclude that the uptake of physics in the senior high school is low.

Students

The student sample is comprised of students who have undertaken the survey either in the paper-based or electronic forms in the Space to Grow project until the end of 2012. While data were collected from students in other grade levels, we focus primarily on the responses from students in Grade 10 (N=1770) and Grade 9 (N=742), the two years immediately prior to students making their subjects choices for senior high school. These students can be described as an opportunity sample due to the nature of the research being embedded within a project bounded by educational jurisdictions which involved intact class groups taught by a teacher who either volunteered to become involved or who was nominated by the school.

INSTRUMENTS USED

In this research, two modified versions of the Secondary School Science Questionnaire (SSSQ; Goodrum et al., 2001) were used. These instruments have been previously used to examine student attitudes and perceptions of school science over the course of an innovation (Danaia 2006) and over time (Danaia et al., 2012). The first instrument is a slightly modified version of the original SSSQ as reported in Danaia (et al., 2012). The second, termed the *Teacher Secondary School Science Questionnaire* (TSSSQ), is a modified form of the student-SSSQ survey which is used to probe the teacher's perceptions of the school science that happens in their classroom. It closely mirrors the student survey. That is to say, the items are phrased to reflect the role of the respondent: for the students, the stem was “In my science classes, my teacher...” and the teacher responded to “In this science class, I...” and the remainder of the items were identical. The teacher questionnaire was constructed to allow direct comparisons of the perceptions of teachers and students. Beyond the Likert-scale items, teachers also provided demographic information on age, employment, scientific and educational background, and their qualifications as well as their broader opinions on schools, school science and their roles within science in the community.

The results in the individual items for students and teachers are presented to allow comparisons of each individual item on the survey rather than try to amalgamate the 40 items into scales using an exploratory or confirmatory factor analysis. There are four reasons for adopting this approach. First, we are not looking for any latent variables that drive students’ or teachers’ responses to the items. Second, we are not looking for any relations amongst such latent variables; we are looking solely at the raw difference in *perception* between teachers and students. Third, while presented in sets of related items, which we have also replicated here, the original source of the questionnaire (Goodrum et al., 2001) presented no theoretical basis for any underlying factor structure. Consequently, we adopt the same approach. Fourth, rather than the traditional "Strongly Agree through Strongly Disagree" Likert scales, all of the SSSQ items actually represent *perceptions* of *rates of particular experiences* in the science classroom. This makes it more difficult to create “scales” that reflect the “optimum value” for any given experience. For example, a statement in the teacher questionnaire is "Students find science lessons challenging" may not be at the top end of the ordinal scale (i.e. Almost always), but may be somewhere in the middle (i.e. "Often"). This item is a description of that teacher’s experience with that particular class in that particular year. While we can, and do, make broad assumptions about the direction of 'positivity' for some of the ordinal items, there is little information on what the true *optimal* answer for any item should be. Hence, any factor structure that creates reliable scales may act to muddy the general picture rather than provide more clarity.

OVERALL MEAN COMPARISON BETWEEN TEACHER AND STUDENT PERCEPTION

In this first section of the results, we compare the distributions of responses provided by teachers and students for each individual SSSQ item. These comparisons represent the convergence or divergence between the teacher and student population perceptions of their science classes overall. Table 1 presents the cross-tabulation, the Chi-Square statistic and the calculated p-value. Given that 39 Chi-squares are being computed, it is not reasonable to accept a p-value of 0.05 below which a significant difference in the pattern of responses of students and teachers can be claimed (Simes 1986). We thus employ a modified-Bonferroni correction to the p-value using the average inter-item correlation of 0.247. We employed the online Simple Interactive Statistical Analysis calculator to compute the modified p-value. The new p-value below which significance is indicated is 0.0031.

The individual items are grouped together into the same groups originally presented by Goodrum et al. (2001). The population response of the teachers is presented together with the population response by students. A chi-square statistic is computed for each item and the modified Bonferroni correction applied to the p-value obtained from the cross-tabulation. Only those items with a p-value that falls below the computed value of 0.0031 are highlighted as significant.

This first set of items (1-9), shown in table 1, deals with the types of learning activities experienced in the classroom. All of the items, apart from Item 3,'I work out explanations in science with my friends', show statistically significant different patterns of responses between students and teachers. In addition, all of the items except for item 5, 'read a science textbook' are biased towards the teachers painting a more favourable picture and that these events happen frequently as experienced by the students. The results for item 5 are somewhat hard to interpret. In the original Goodrum et al. (2001) paper the distribution was peaked at each extreme (Never and Always), as were the dataset used in Danaia et al. (2012). In our data, the student data is effectively evenly spread across the whole range, while the teacher's responses peak at about once per week. .

Table 1 *Learning activities --- dealing with content in science in the secondary school*

		% Response					
Item	Population	*Never (%)*	*Once a Term (%)*	*About Once a Month (%)*	*About Once a week (%)*	*Nearly every lesson (%)*	*Sig p.*
In my science class							
1. I copy notes the	Students	2.6	2.7	7.4	21.5	65.7	**5.2E-19**
teacher gives me	Teachers	3.6	7.2	13.3	54.2	21.7	**
2. I work out explanations in	Students	5.7	8.5	23.4	39.2	23.2	**3.2E-05**
science on my own	Teachers	1.2	0.0	16.9	42.2	39.8	*
3. I work out explanations in	Students	4.9	5.5	16.1	38.1	35.5	3.4E-02
science with my friends	Teachers	1.2	0.0	14.5	41.0	43.4	ns
4. I have opportunities	Students	9.1	10.0	23.0	29.2	28.7	**4.2E-10**
to explain my ideas	Teachers	1.2	3.6	4.8	36.1	54.2	**
5. I read a science	Students	20.2	16.5	20.8	22.8	19.6	**6.1E-07**
textbook	Teachers	6.0	10.8	28.9	42.2	12.0	**
6. We have class	Students	5.8	6.0	14.0	27.0	47.1	**2.0E-04**
discussions	Teachers	1.2	0.0	6.0	26.5	66.3	*
7. We do our work	Students	5.5	9.3	28.0	36.6	20.6	**7.3E-10**
in groups	Teachers	1.2	2.4	4.8	56.6	34.9	**
In science, we							
8. Investigate to see if	Students	10.4	12.8	27.2	31.9	17.6	**5.3E-04**
our ideas are right	Teachers	2.4	15.7	42.2	31.3	8.4	*
My science teacher							
9. Lets us choose our own	Students	47.4	25.2	16.9	7.3	3.3	**1.1E-16**
topics to investigate	Teachers	8.4	55.4	30.1	3.6	2.4	**

The next set of items (10-12), shown in table 2, deals with practical work in the school science classroom. One could argue that a teacher demonstrating experiments is better than doing no experiments at all, but this is, in turn, worse than the students undertaking experiments themselves via following instructions. It is likely that there is a confound variable where the teacher thinks that experimental work is undertaken more often than the students and perhaps takes into account all of the opportunities for experimental work leading to the teachers recording a more frequent response than the students who have a different set of criteria about what constitutes "experimental work". Nonetheless, and with this caveat in mind, these results can be interpreted as the teachers' perception is that there is a higher rate of experimental work being done overall than the students perceive.

Table 2 *Learning activities --- practical work in science in the secondary school*

Item	Population	% Response *Never (%)*	*Once a Term (%)*	*About Once a Month (%)*	*About Once a week (%)*	*Nearly every lesson (%)*	*Sig p.*
In my science class							
10. I watch the teacher	Students	7.9	14.4	32.5	29.7	15.5	**1.4E-04**
do an experiment	Teachers	2.4	7.2	31.3	49.4	9.6	*
11. We do experiments by	Students	4.2	6.1	19.5	38.5	31.7	**1.8E-05**
following instructions	Teachers	2.4	0.0	6.0	59.0	32.5	*
12. We plan and do our	Students	28.2	25.0	23.3	15.6	7.9	**1.3E-10**
own experiments	Teachers	6.0	16.9	49.4	21.7	6.0	**

Items 13-16, shown in table 3, probe what teachers and students perceive about the nature of school science in terms of how often students need to undertake deeper thinking about the science itself. For all of the items, it is clear that the teachers have a much more positive view of the depth of thinking required in the science classroom than do the students.

Table 3 *What students need to be able to do in science in secondary school*

Item	Population	% Response *Almost Never (%)*	*Sometimes (%)*	*Often (%)*	*Very Often (%)*	*Almost Always (%)*	*Sig p.*
In science we need to be able to							
13. Think and ask questions	Students	5.2	13.4	25.6	25.7	30.1	**2.3E-09**
	Teachers	1.2	0.0	12.0	31.3	55.4	**
14. Remember lots of facts	Students	5.4	13.8	25.9	28.6	26.3	**1.0E-15**
	Teachers	4.8	38.6	37.3	16.9	2.4	**
15. Understand and explain	Students	5.3	14.4	25.5	29.4	25.5	**2.1E-04**
science ideas	Teachers	1.2	1.2	24.1	37.3	36.1	*
16. Recognise science in	Students	6.3	15.2	25.4	26.8	26.3	**5.8E-08**
the world around us	Teachers	1.2	1.2	15.7	34.9	47.0	**

Items 17-25, shown in table 4, represent a variety of ideas surrounding the quality of science teaching. It is clear that teachers perceive the quality of feedback and guidance they give to happen more frequently than the students. Two exceptions to this are item 21, "We have enough time to think about what we are doing" where students seem to think they more frequently have enough time than the teachers and item 23, "makes it clear what we have to do to get good marks" which is not statistically significant. The high stakes standardised testing environment of modern schooling possibility is the explanation for why teachers and students both have fairly accurate assessments of the frequency of being told how to get good marks. It is not clear why students think they have more time to think about what they are doing than the teachers, perhaps due to the teacher's perception of (their own precious) time more than an accurate assessment.

Table 4 *Teacher feedback and guidance in science in the secondary school*

		% Response					
Item	Population	*Never (%)*	*Once a Term (%)*	*About Once a Month (%)*	*About Once a week (%)*	*Nearly every lesson (%)*	*Sig p.*
My science teacher							
17. tells me how to	Students	10.1	15.6	25.8	29.8	18.7	**2.0E-15**
improve my work	Teachers	1.2	3.6	4.8	48.2	42.2	**
18. gives us quizzes that we	Students	16.5	25.4	36.6	16.1	5.3	**3.3E-10**
mark to see how we	Teachers	8.4	4.8	44.6	37.3	4.8	**
are going							
19. talks to me about how	Students	18.7	25.0	28.5	19.5	8.3	**1.5E-26**
I am getting on in science	Teachers	1.2	2.4	19.3	53.0	24.1	**
20. shows us how new work	Students	8.7	9.0	21.5	33.2	27.6	**1.2E-15**
relates to what we	Teachers	1.2	0.0	8.4	25.3	65.1	**
have already done							
During science class							
21. We have enough time to	Students	7.5	22.4	31.8	24.7	13.6	**9.6E-04**
think about what	Teachers	2.4	16.9	47.0	28.9	4.8	*
we are doing							
		Almost Never (%)	*Sometimes (%)*	*Often (%)*	*Very Often (%)*	*Almost Always (%)*	*Sig p.*
My science teacher							
22. marks our work and	Students	9.6	16.2	28.9	33.2	12.2	**9.8E-08**
gives it back quickly	Teachers	1.2	2.4	50.6	38.6	7.2	**
23. makes it clear what we	Students	5.3	8.4	18.2	33.5	34.6	4.5E-02
have to do to get	Teachers	1.2	2.4	16.9	41.0	38.6	ns
good marks							
24. Uses language that is	Students	5.6	6.2	15.2	27.3	45.6	**3.8E-14**
easy to understand	Teachers	1.2	0.0	2.4	9.6	86.7	**
25. Takes notice of	Students	7.0	9.5	17.3	29.2	37.1	**3.8E-13**
students' ideas	Teachers	1.2	0.0	2.4	22.9	73.5	**

The pattern of responses for the next two items (26-27), shown in table 5, are both statistically significant. It is not clear, however, whether more frequent use of computers and the internet can be necessarily regarded as a good thing. Nonetheless, it is clear that teachers reported a significantly more frequent use of computers and the internet in science. In the original Goodrum et al. (2001) report, the frequency of use were very low. Over a decade later, however, computer use is the classroom has become much more common. Whether this is a good or a bad thing remains debatable.

Table 5 *Computer use in science in the secondary school*

		% Response					
Item	Population	*Never (%)*	*Once a Term (%)*	*About Once a Month (%)*	*About Once a week (%)*	*Nearly every lesson (%)*	*Sig p.*
In science, we							
26. Use computers to do our science work	Students	6.5	14.3	34.4	29.4	15.4	**2.4E-06**
	Teachers	2.4	2.4	26.5	51.8	16.9	**
27. Look for information on the Internet at school	Students	7.6	12.6	33.5	32.5	13.9	**1.5E-04**
	Teachers	1.2	4.8	27.7	51.8	14.5	*

Items 28-30, shown in table 6, probe students' perceptions of their enjoyment of, and curiosity in, science classrooms. In general, teachers perceive students to be less bored and more excited than the students report. It is very clear that teachers vastly overestimate how excited and/or bored students are in the science classroom. However for item 29, "I am curious about the science we do", the students are fairly evenly spread across the range, some are always curious and some are never curious in equal parts, whereas teachers seem to largely interpret their students as often being curious.

Table 6 *Enjoyment and curiosity in science in the secondary school*

		% Response					
Item	Population	*Almost Never (%)*	*Sometimes (%)*	*Often (%)*	*Very Often (%)*	*Almost Always (%)*	*Sig p.*
During science class							
28. I get excited about what we do	Students	21.7	34.8	21.0	12.6	9.8	**1.1E-13**
	Teachers	2.4	24.1	38.6	31.3	3.6	**
29. I am curious about the science we do	Students	14.3	26.1	23.4	19.8	16.5	**4.6E-09**
	Teachers	2.4	20.5	47.0	25.3	4.8	**
30. I am bored	Students	17.1	38.4	14.4	12.6	17.4	**2.7E-16**
	Teachers	6.0	79.5	13.3	1.2	0.0	**

Items 31-34, shown in table 7, attempt to measure the extent to which science is perceived to be difficult and challenging. It appears that teachers perceive that students find science to be much harder than students perceive. Students tend to feel that they rarely don’t understand the science presented in class or that it is too hard and more frequently perceive it as too easy than teachers do. The comparative distribution between teachers and students on the question of the level of challenge is more evenly spread and only borderline statistically significant.

Table 7 *Perceived difficulty and challenge of science in the secondary school*

		% Response					
Item	Population	*Almost Never (%)*	*Sometimes (%)*	*Often (%)*	*Very Often (%)*	*Almost Always (%)*	*Sig p.*
During science class							
31. I don't understand the science we do	Students	25.6	44.8	14.2	8.1	7.3	**1.1E-08**
	Teachers	7.2	73.5	16.9	1.2	1.2	**
32. I find science too easy	Students	34.3	38.8	16.0	6.5	4.4	**7.2E-05**
	Teachers	39.8	54.2	2.4	3.6	0.0	**
33. I find science challenging	Students	7.5	32.8	26.8	20.4	12.5	**1.8E-03**
	Teachers	2.4	26.5	37.3	28.9	4.8	ns
34. I think science is too hard	Students	32.8	34.5	15.3	7.8	9.6	**1.6E-10**
	Teachers	8.4	48.2	22.9	19.3	1.2	**

In the final set of items (35-39), shown in table 8, the relevance of school science to the students’ life is probed. Teacher's perceived that the science they teach is more relevant to students' lives than the students do. This is not unexpected.

Table 8 *Perceived relevance of science in the secondary school*

		% Response					
Item	Population	*Almost Never (%)*	*Sometimes (%)*	*Often (%)*	*Very Often (%)*	*Almost Always (%)*	*Sig p.*
The science we learn at school							
35. is relevant to my future	Students	24.5	33.0	19.9	12.5	10.1	**6.7E-14**
	Teachers	1.2	21.7	44.6	24.1	8.4	**
36. is useful in everyday life	Students	22.4	38.2	20.5	11.3	7.6	**1.5E-11**
	Teachers	1.2	26.5	43.4	20.5	8.4	**
37. deals with things I am concerned about	Students	27.5	35.9	20.1	10.0	6.5	**9.2E-10**
	Teachers	2.4	37.3	39.8	16.9	3.6	**
38. Helps me make decisions about my health	Students	27.4	33.7	20.3	12.0	6.7	**3.8E-06**
	Teachers	6.0	38.6	32.5	19.3	3.6	**
39. Helps me understand environmental issues	Students	12.0	26.3	27.8	21.6	12.3	**4.4E-04**
	Teachers	4.8	22.9	43.4	25.3	3.6	*

To more directly illustrate the broad differences, Figure 4 graphically demonstrates this difference in students' (black) and teachers' (grey/hatched) responses showing the mean ordinal score for each item. Here the mean scores for each item are presented as an overlaid horizontal bar chart. For all of the statistically significant different patterns of responses, teachers express a more positively skewed view of their in-class practices compared with those expressed by the students. The three exceptions to this pattern are Item 1 'students copy notes in class', Item 14 ‘remember lots of facts’ and Item 30 ‘are bored’ where students views are more positively skewed. It may be observed that in these latter three items, if they were to be recoded in the reverse direction, the same pattern would persist and one could claim that teachers paint a more positive picture of their classroom than do their students.

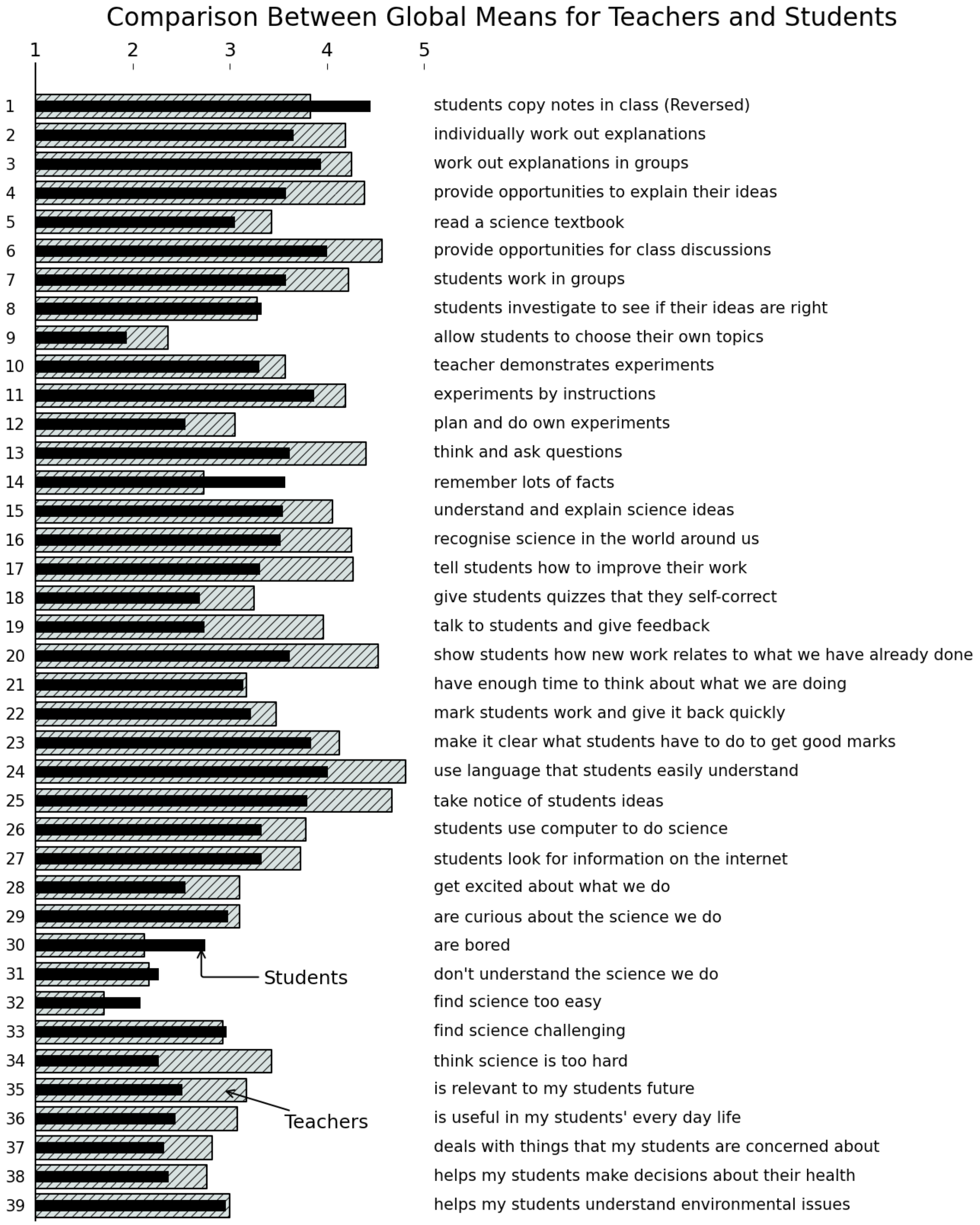


Figure 4: Comparison of teacher and student means.

TEACHER VS STUDENT AGGREGATE BREAKDOWN

In the previous section we concentrated on the comparing the responses of teachers and students for the entire sample. In this section we examine the same items but break them down into paired student and teacher groups in which 64 of the 86 teachers were able to be reliably matched to their students. Each student was required to name their teacher during the survey for matching purposes. Thus, the student data were aggregated to produce a mean and standard deviation for each item before the student data were merged and matched for each teacher with their discrete ordinal response. Thus, each teacher's ordinal response is able to be compared to the mean value of the students' ordinal responses in their class.

For each item, the teachers were grouped into batches representing a given ordinal response. For instance, the teachers were sorted into those teachers who said "Almost Never", "Sometimes", "Often", "Very Often" and "Almost Always'. The mean responses of each of the student groups corresponding to each teacher were then further averaged to represent the average response of student groups to teachers who responded with that particular ordinal response (e.g. "Sometimes or Often") choice.

One-way ANOVAs were performed to determine the statistical significance of each relation. Taking the previously calculated modified Bonferonni corrected significance value of 0.0031, none of the relations were found to be statistically significant. As there are a lot of items, with a lot of teachers, a lot of students, and a lot of relations, a simple table cannot hold all of this information in any simple manner. To represent the data, we have created a graph for each item that holds the multiple dimensions and adds value with a number of calibration lines. We present a sample of one of these graphs, which represents one of the most clearly borderline significance, for explanation purposes in Figure 5. The entire sample of item represented by smaller graphs are presented in Figure 6 and Figure 7.

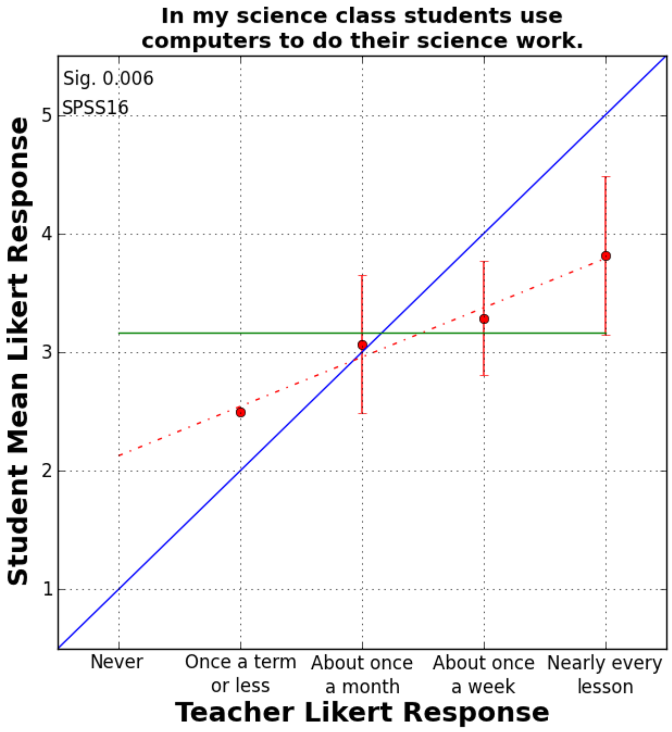


Figure 5: Closeup of Example Figure

In Figure 5, the x-axis represents the ordinal teacher response, while the y-axis represents the mean values of the student groups for all teachers who responded with that response. The error bars on the points represent the standard deviation of the student group mean responses. If there are no error bars, such as in the 'Once a term or less' category in Figure 5, it means there was only a single teacher who responded in that manner and hence there is no variance in response. The blue line represents what would be expected for perfect agreement between the teachers and student groups. This blue line is, by definition, never likely to be achieved or approximated unless all students in all groups answered with the same response as the teacher.

If we are searching for correlations, then what we are looking for in the pattern of responses is a definite slope in the data of the student responses compared to the teacher response. If the slope in the student responses is positive (in the same direction tending higher to the right) and statistically significant, it means the students relatively agree with the teachers. That is to say, the more the teacher thinks X about a class and the more the students also think X, the more alike their perceptions of what is happening in that particular class. If the slope in the student-response line is negative (in the opposite direction tending lower to the right) and statistically significant, it means the more the teacher thinks X about a class, the *less* the students think X.

While it must be remembered that Figure 5, just like ALL other figures are technically statistically insignificant, a slope can be identified in the red dotted line fit between the points on the graph. This slope was fit with a traditional non-weighted least square linear fit to the data. The main reason for insignificance is due mainly to the very large standard deviation in the student groups' responses.

In the graph there is another line, the solid green line. This represents what we would assume if there were zero dependency in the student responses upon the teacher responses. This is a representation of the null hypothesis case that all of the charts statistically agree with. It is the case for the charts provided in Figure 6 and 7 that there is minimal difference between the best dotted line fit (assuming a difference) and the best solid line fit (assuming the null hypothesis). This leads us to the conclusion that the perceptions of teachers of classroom activity on all probed items from the SSSQ have little or no relation to the perception of the students of the activity in their classroom.

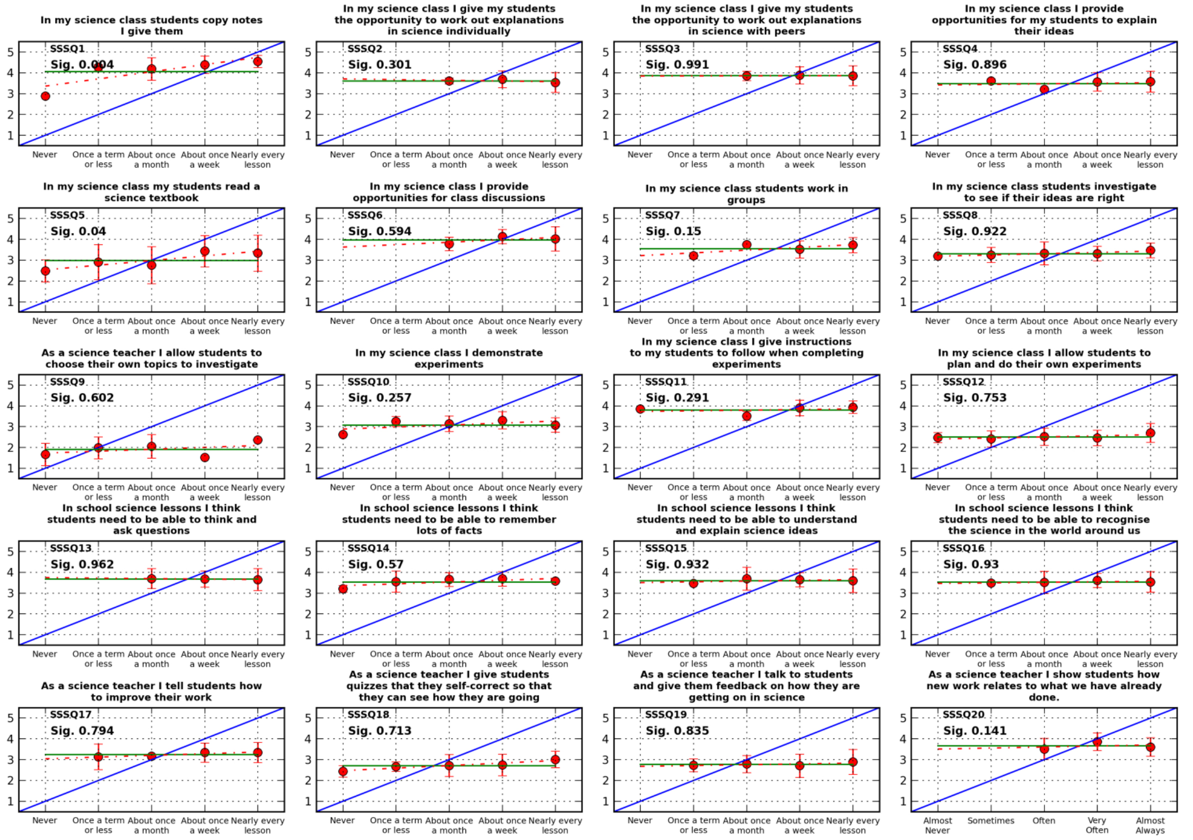


Figure 6: Comparison of teachers perceptions to students' perceptions

for first 20 items on the SSSQ.

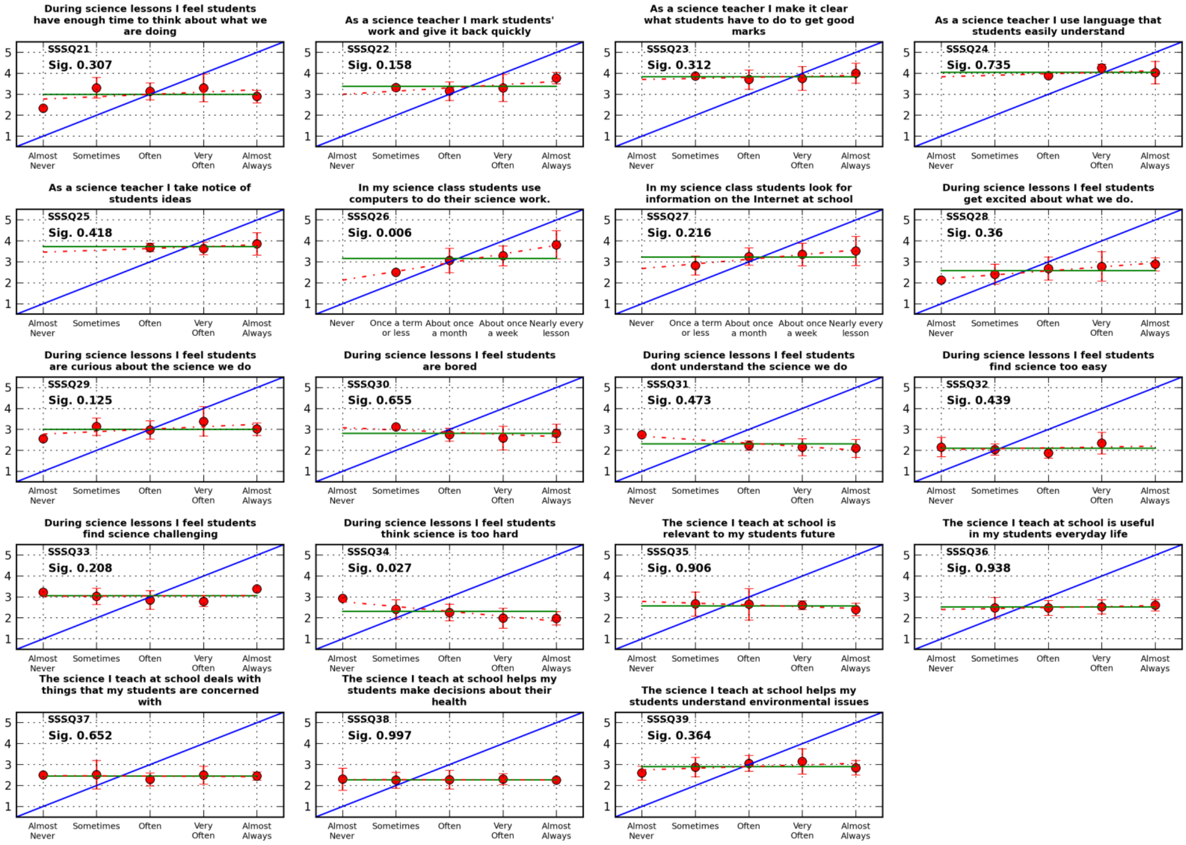


Figure 7: Comparison of teachers perceptions to students' perceptions for second 19 items on the SSSQ.

CONCLUSIONS

This paper has compared the perceptions of students and teachers of their classrooms on the same metrics via two methods. First, the responses of the entire student and teacher sample are compared using Chi-square analysis. By doing so, we find statistically significant differences in the patterns of responses of teachers and students on most of the items in the SSSQ survey. For those with significant differences, most are interpreted as the teacher having a more positive view of that aspect of their classroom or of their teaching than do the students, although there are a number of items with less clear interpretations.

The second analytic approach involved matching the teachers with the aggregated mean scores of their respective students. This allowed us to examine the relationship between teachers' differing perceptions of their classrooms compared to their students’ perception. Overall, there appears to be no statistically significant relationship between what the teacher perceives and what the students perceive. Regardless of any response by a teacher, the students’ responses hover very closely around a global mean.

Whether these perceptions represent actual differences in classroom behaviours rather than a simple difference in perception would require an observational study. What is clear is that 1) teachers overall perceive that which occurs in their classroom in a more positive light and 2) Students in general seem to perceive their science classrooms similarly regardless of the perceptions of their teachers. This has a variety of impacts on the nature of school science education.

These results suggest that there is little point in using the teachers to evaluate an educational approach or intervention. On quantitative measures such as the one presented in this paper, it seems that teachers will generally paint a much more positive picture than their students will. Hence, the final evaluation of any educational endeavour needs to be undertaken at the level of the student. This also means that teachers are perhaps under the impression that their classrooms are running in a generally more positive fashion than they actually are, leading to a lack, or an underestimate, of any required remediation of in-class practices. This may be quite a bitter pill to swallow by teachers who are already generally pushed to the limits of their resources (Fitzgerald et al. 2014a), but in reality it is probably more a function of the situational context that the teacher has to work within.

The SSSQ is a very useful research tool to plot changes in student perception over small time scales (Fitzgerald et al. 2014b), long time scales (Danaia et al. 2013) as well as comparing the difference between student and teacher perceptions in their classrooms as a whole. As yet, however, the SSSQ, similarly to the QTI tool (Wubbels et al., 1985), it has yet to be adequately tested as a diagnostic tool for improvement for individual teachers in their science classroom. It is not clear that showing an individual teacher their convergence or divergence in perceptions with their students may cause anything other than an increase in stress on the part of the teacher when a large proportion of their current practice is driven by their context and school situation.

The most general conclusion that can be taken from this paper is that it is the students, and not their teachers, who are likely to provide the most realistic appraisal of what is occurring in their classrooms. Decisions about what occurs in the classroom are usually undertaken by their teachers and outside ‘experts’ rather than through listening to the student voice (Osborne & Collins 2000). The most efficient way to get a good picture of multiple science classrooms within any limited educational context, such as a school or jurisdiction, is to talk to the teachers directly. It must be kept in mind though that the person asking the questions will be given a rosier picture (even if the picture is dark) than what would be elicited from the students. The students, and their achievement and motivation, in any educational endeavour are after all the ultimate sources of evaluation in which teachers can only be at best a vague proxy.

References

American Association for the Advancement of Science (AAAS), (1990), “Science for all Americans: Project 2061”/ New York, Oxford University Press.

den Brok, P., Bergen, T., Brekelmans, M., (2006), “Convergence and divergence between students’ and teachers’ perceptions of instructional behaviour in Dutch Secondary Education” in Fisher, D., Khine, M., “Contemporary Approaches to Research on Learning Environments”, Singapore: World Scientific

Committee for the Review of Teaching and Teacher Education (CRTTE). (2003), “Australia’s Teachers: Australia’s future advancing innovation, science, technology and mathematics agenda for action.”, Canberra: Department of Education, Science and Teaching.

Danaia, L., (2006), “Student experiences, perceptions and performance in junior secondary school science: An intervention study involving astronomy and a robotic telescope”, PhD Thesis, Charles Sturt University

Danaia, L., McKinnon, D., Parker, Q., Fitzgerald, M., Stenning, P., (2012), “Space to Grow: LCOGT.net and improving science engagement in schools”, Astronomy Education Review, 11(1)

Danaia, L., Fitzgerald, M., McKinnon, D., (2013), “Student Perceptions of High School Science: What Has Changed Over the Last Decade”, Research in Science Education, 43:4, 1501

Drury, C., Allen, A., (2002), “Task force on the physical sciences: report and recommendations”, Department of Education and Science, Ireland. http:/www.sciencetaskforce.ie/. Accessed September 2005.

Fitzgerald, M., Danaia, L., McKinnon, D., (2014a), “Blocking Factors Inhibiting Inquiry-based Science Teaching and Potential Solutions: Perceptions of Positively-inclined Early Adopter Science Teachers.”, International Journal of Science Education, Submitted.

Fitzgerald, M., Danaia, L., McKinnon, D., (2014b), “A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science.”, Research in Science Education, Submitted.

Goodrum, D., Hackling, M., Rennie, L., (2001), “The status and quality of teaching and learning of science in Australian Schools”. Canberra: Department of Education, Training and Youth Affairs

Goodrum, D., Rennie, L., (2007), “Australian school science education national action plan 2008-2012”, Canberra: Department of Education Science and Training.

Goodrum, D., Druhan, A., Abbs, J., (2012), “The status and quality of year 11 and 12 science in Australian schools”, Canberra: Australian Academy of Science.

International Bureau for Education, (2001), “Science Education for contemporary society: problems, issues, dilemmas.”, Geneva: International Bureau of Education, UNESCO.

Lyons, T., Quinn, F., (2010), “Choosing Science: understanding the declines in senior high school science enrolments”, Research Report to the Australian Science Teachers Association (ASTA).

University of New England, Australia: Naitonal Centre of Science, ICT and Mathematics Education for Rural and Regional Australia.

McKenzie, P., Kos, J., Walker, M., Hong, J., (2008), “Staff in Australia’s Schools 2007”, Commonwealth of Australia: Department of Education, Employment and Workplace Relations.

Millar, R., Osborne, J., (1998), “Beyond 2000: science education for the future (The report of a seminar series funded by the Nuffield Foundation)”, London: Kings College London, School of Education.

Myers, R., Fouts, J., (1992), “A Cluster Analysis of High School Science Classroom Environments and Attitude toward Science”, Journal of Research in Science Teaching, 29:9, 929

Osborne, J., Collins, S., (2000), “Pupils and parents views of the school science curriculum”, London: King’s College London.

Osborne, J., Simon, S., Tytler, R., (2009), “Attitudes Towards Science: An Update”, Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, California, April 13-17

Rowe, K., (2003), “The Importance of *Teacher Quality* as a Key Determinant of Students’ Experiences and Outcomes of Schooling”, A context and discussion paper prepared on behalf of the *Interim Committee for a NSW Institute of Teachers*, Feburary 2003

Simes, R. J. (1986). An improved Bonferroni procedure for multiple tests of significance. *Biometrika, 73*(3), 751-754.

Simple Interactive Statistical

Analysis, http://www.quantitativeskills.com/sisa/calculations/bonhlp.htm, visited 27/11/2013.

Wubbels, T., Brekelmans, M., (2005), “Two decades of research on teacher-student relationships in class”, International Journal of Educational Research, 43, 6

Wubbels, T., Creton, H., Hooymayers, H., (1985), “Discipline problems of beginning teachers. Interactional teacher behaviour mapped out”, Paper presented at the AERA Annual Meeting March 31-April 4

PART C: EDUCATIONAL DESIGN AND EMERGENT STUDENT ACHIEVEMENT

Inquiry-based educational design for large-scale high school astronomy projects using real telescopes.

Michael Fitzgerald, Department of Physics and Astronomy,*
Macquarie University, North Ryde NSW 2109, Australia

David H. McKinnon and Lena Danaia, School of Teacher Education,
Charles Sturt University, Bathurst, NSW, 2795, Australia

(*) Corresponding author: mfitzasp@gmail.com, Phone: +61 431 480 007

Abstract

In this paper we outline the theory behind the educational design used to implement a large-scale high school astronomy intervention project. This design was created in response to the identification of an ineffective educational design in the initial early stages of the project. The new design follows an iterative improvement model where the materials and general approach can evolve in response to solicited feedback. The improvement cycle concentrates on avoiding overly positive self-evaluation while addressing relevant external school and community factors and concentrating on backward mapping from clearly set goals. Limiting factors, including time, resources, support and the capacity for undertaking risk, are attempted to be dealt with as much as possible in the large-scale design allowing teachers the best chance of successful implementation in their real-world classroom. The actual approach adopted following the principles of this design is also outlined which has seen success in bringing real astronomical data through access to research-grade telescopes into the high school classroom.

Introduction

Inquiry-based, and a more student-centered, curriculum design has been called for by numerous national bodies and educational experts presenting guidelines for reform in science education over the last few decades (e.g. AAAS 1990, NRC 1996, NRC 2000, Lawrence & Palmer, 2003, Tytler, 2007, Goodrum et al., 2001, CRTTE, 2003, Goodrum & Rennie, 2007, Hackling, Goodrum & Rennie, 2001). As noted by Obsorne (2006) and Bennett (2001), these calls are not a recent development but has a long history back to the work of Dewey in the early parts of the 20th century. For some who are more critical of this style of teaching, the continued, relatively unsuccessful, attempts at inquiry over the past century could be seen as “some zombie that keeps returning from its grave” (Mayer, 2004).

Even with a sample of positively inclined early adopting teachers who have considerable experience in science teaching, there is a lot of confusion over what the term ‘inquiry-based learning’ means (Fitzgerald, 2014a). Even when the concept of ‘inquiry-based teaching/learning’ can be explicitly defined, further issues are encountered with the quality of implementation of the approach and the spectrum of practice it engenders. With these issues in mind, the theoretical and actual design of any science-education approach needs to be very clearly defined in order to enable judgments of efficacy together with guides to others intending to adopt and implement a similar approach.

The positive efficacy of inquiry-based learning is also not a universally held claim. It is claimed by some, such as Kirschner et al. (2006), that inquiry-based learning is an inefficient and ineffective approach to teaching. They state that major theoretical problems have been encountered when compared to what is known about working memory and long term memory from modern cognitive science. Their general claim is that most science educators find inquiry-based learning impossible to implement in the classroom and are likely either to ignore it completely or, at best, simply pay lip service to it.

Dunkhase (2003) points out that over the last 70 years, inquiry-based learning has only rarely been successfully implemented on a large-scale over the long term. Even when it seemingly has been undertaken on a wider scale, where the curriculum materials were being used, they were typically used trivially (Andersen, 2002). A large contributor to this trivial usage is frustration and difficulties into attempting to implement inquiry teaching as the curriculum intended.

The criticism of inquiry-based learning that it is not borne out by empirical studies on its efficacy is contradicted by a very large meta-analysis of teaching strategies that impact on student achievement (Schroeder et al., 2007). For inquiry-based strategies, the effect size of the impact was 0.69, which is moderately large. In another later meta-analysis focusing more on inquiry-based learning itself (Alfieri et al. 2011), it was found that open inquiry with no scaffolding seemed to be much less effective than direct instruction. However, in turn, scaffolded-inquiry was much more effective than other forms of instruction. This shows that the impact will be very sensitive to the style and design of an inquiry-based implementation.

Truly effective educational design goes beyond simple instructional design to incorporate all of the issues that affect the quality of learning and the possibility of that design succeeding in a real-life context, that is to say, in the science classroom. This does not just include the nature of the provided instructions and supports, but also the psychology of the teacher and students and the factors that impact on the classroom such as the school context, parents and the community as a whole. Simple provision of a new teaching technology/pedagogy is not enough. Making a website providing simple instructions is not enough. An adequate understanding of all of the impacting factors surrounding the design must be taken into account. Not only must curriculum developers make sure that their design is effective in producing student learning and motivation gains, but they must make it plausible and workable such that a regular classroom teacher could implement it in their classroom as intended.

In this paper, we describe such an educational design that the authors have used to facilitate student motivation and learning utilizing real astronomical data from real astronomical telescopes in the high school science classroom. There are many different interacting factors that make educational design equally as much of an art as a science, but we attempt to cover the major elements that were considered in the design. As all elements do interact, considering one element separately to another may result in the attribution of faulty conclusions to a particular design decision. Concomitantly, there is a real possibility that one of the major elements may be missing from our analysis. Consequently, the authors have attempted to present as complete a design case as possible.

Background

The initial context of our design was situated within the Space to Grow secondary science astronomy education project (Danaia et al. 2012). This was a $2.4 million dollar funded project based significantly around an Australian Research Council Linkage grant which initially began in July 2009 and concluded in June 2012. The original educational design used the project was taken from an earlier Federal Government project funded by the Department of Education, Science and Training (DEST) under the Australian Schools Innovation in Science technology and Mathematics (ASISTM) project called ‘Deep Space in the Classroom’. The fundamental rationale of both projects was to get students in high school science classrooms to undertake real research using the 2-metre class Faulkes Telescopes based in Hawaii, USA and Siding Spring in Australia. Involvement for schools and teachers in the Space to Grow project was initially mandated in a top-down fashion by the decision makers in three educational jurisdictions.

Early in the Space to Grow project (2009 to early 2010), little was occurring in terms of implementation by the intended population of teachers. There were only five teachers actively working out of a stated potential of approximately 200 teachers, and those active teachers were generally not following the 'intended' design. The rest of the teachers, presumably, were hiding and waiting for the innovation to disappear as is common when the innovation is not perceived to be of positive benefit rather than yet another time-consuming task to add to their already saturated schedules (e.g., Hall & Hord 2001). There was little understanding on the part of the project team as to why the rate of implementation was so poor. Neither was there any active endeavour to remediate the project as the educational design was perceived as “excellent” even though what evaluation existed suggested otherwise. This is not an uncommon phenomenon with regards to innovation where, in the absence of effective evaluation or appraisal, the default stance is that everything is positive and working fine (Rogers 2003).

The second major large-scale project design flaw was that the focus on who was "to blame" for the failings of the project was more directed at the teachers and/or the schools than at any flaw within the approach of the project itself. In an attempt to understand the situation and teachers’ perceptions of the educational design and to uncover the blocking factors issues, informal discussions were held with a small number of teachers, most of whom had not implemented the project, to gain some understanding about their perspectives. The issues identified from the teachers that provided the context around which the design was created both from the earlier informal interviews and later formal qualitative research (Fitzgerald et al., 2014a) is outlined in the *Design Knowledge* section of this paper. First, however, we discuss the broader design approach we have taken before going into more detail about these issues as well as the educational theory, goal setting and development of the educational materials.

Design Goals and Principles

The core of the design presented here involves an *iterative improvement model*. Traditional textbook design is predicated on the design model where a single 'completed' product is possible both theoretically and practically. The 'textbook' approach to science education was a functional compromise in the era of large-scale printing and minimal revision costs during the 20th century. There is an implicit assumption here that there exists an expert (the 'author or authors') who knows enough about the subject matter content, how classrooms function (typically other peoples' classrooms), how widely varying students will react to the textbook, and has such near-perfect prescience that all of the information can be collated neatly into a single tome or series of tomes.

The end product, in reality, is usually quite poor and not pedagogically effective, acting more as a method of crowd control than as a true aid to learning. The poverty of these textbooks has been outlined most effectively in various reports from Project 2061 (Kesidou & Roseman 2002, http://www.project2061.org/publications/textbook/) and is a common claim in both informal and formal conversations with teachers. It is the case that the early-adopter teachers involved in the Space to Grow project had given up on textbooks entirely and had chosen to use their own material garnered from a variety of disparate sources.

Modern-day communication and desktop-publishing technologies allow for a different model compared with the traditional one-shot textbook model. With the rise of print-on-demand books or simply not printing at all and distributing materials electronically, the format, contents and structure of a given instructional document need not be static. These fluid educational materials have the capacity to evolve in response to feedback from users, to changes in the mandated curriculum or school programs as well as to developments in instructional design theory. Instead of the "get everything right at the start" approach, a more efficient, evolutionary approach can be made with an "eternal trial and error" approach where the design continues to evolve in response to outside pressures from users and to react to the changing contexts in which they exist. This is the model we use for the development of our materials and general approach. This model is outlined schematically in Figure 1.

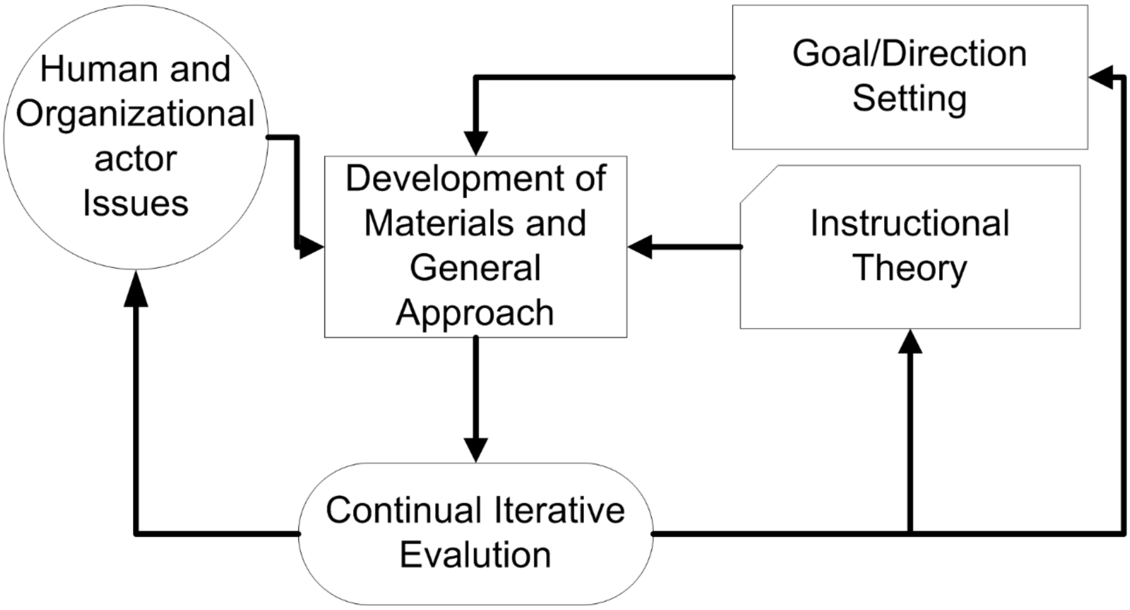


Figure 1: Outline of general educational iterative design model.

Continual feedback is gathered from the teachers in a generally informal manner. Typically the sources are from discussions and interactions with teachers on professional development days as well as from conversations, classroom observations and co-teaching by the designers themselves. While there is a more formal route for teacher reporting of the success, or otherwise, of the design, most feedback so far has been informal. This feedback generates a better understanding of the issues surrounding the people and organisations using the materials. The aim of this approach is to provide more clarity in the goals of instruction and the direction and content of the materials. In addition, it also updates our knowledge on how well our chosen instructional theory operates in the real-world science classroom.

Quantitative evaluation of the materials is a more detailed process and while necessary to provide important weight to claims of efficacy, only indirectly influences the design process itself as it only provides a very broad brush picture. This is both its strength and its weakness. While teachers can provide suggestions and feedback about their perceptions of how the design could be improved, their perceptions do tend to be skewed positively in comparison to the students' perceptions (Fitzgerald et al. 2014b). Thus, the final measure of quality or success of the materials has to come from the students.

The quantitative measures used are an attitudinal questionnaire called the Secondary School Science Questionnaire based on an earlier national study (Goodrum et al., 2001, Danaia et al. 2013) and a knowledge questionnaire named the Astronomical Knowledge Questionnaire comprising items from the traditional Astronomy Diagnostic Test (CAER, 2001), three items adapted from Dunlop (2000) , The Test Of Astronomy STandards (TOAST, in Slater et al. 2010a) and the Star Concept Inventory (Bailey et al., 2011). Details about the functional use of these questionnaires in the design can be found in Fitzgerald et al. (2014d).

The feedback, both qualitative and quantitative, from teachers and students serves to illuminate the obstacles that need to be overcome in the pathway of least resistance to implementation. Many of these obstacles are unlikely to be known in advance. In this respect, the materials follow the general principle of maximizing implementation-opportunity outlined in Diffusion of Innovations theory (Rogers, 2003). This theory suggests that the *nature* of the intended innovation needs to change in response to the changing needs of the increasing population of users if it is to be the driver of a successfully growing implementation. Hence, the focus of change efforts by the authors is on changing the *nature of the innovation*, which is relatively easy in comparison to changing the nature of the implementers, which is relatively difficult.

As time goes on and more people become involved, the requirements, issues and level of general approval of the general population of implementers change. For each differing group, decision points are encountered where the individual teacher will try the particular innovation in the first place and whether, after initial experience, s/he will continue to utilize it. The general principle of diffusion over time is represented by an implementation curve, as shown in Figure 2. Each different group represented in this figure, as well as their own subgroups, will have a different set of criteria against which they judge the innovation's utility and hence the likelihood of them implementing. What works perfectly well for the innovators and early adopters is highly unlikely to work without significant alteration with the less positively inclined, but much larger, mainstream population. This substantial gap between the two groups is a fairly well documented 'chasm' that needs to be overcome on the route from early predisposed users to the majority of users who generally require significant alteration of the innovation itself (Moore, 2006).

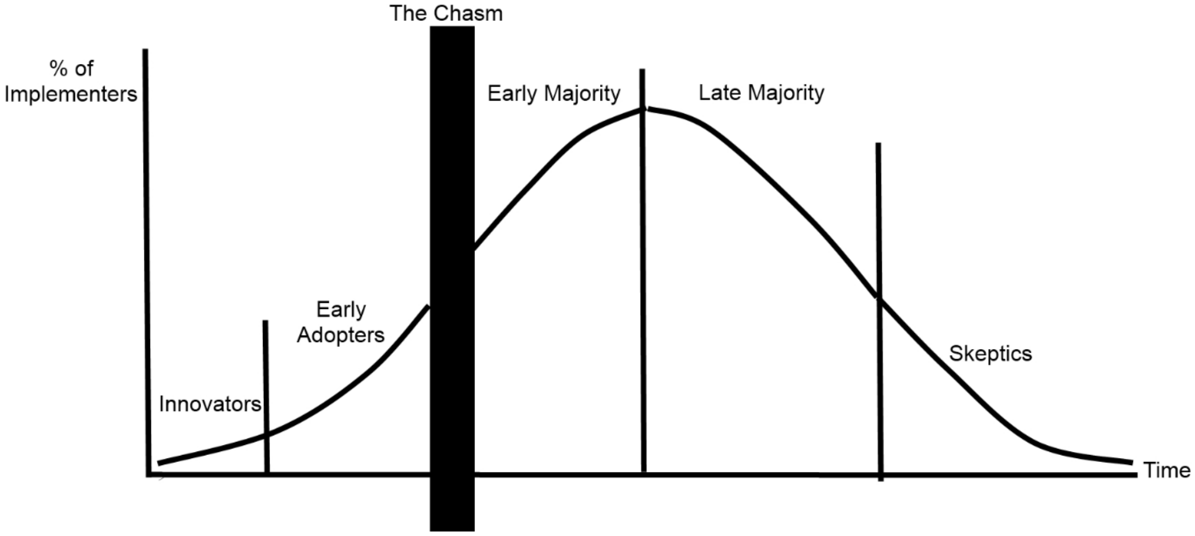


Figure 2: Implementation Adoption curve based on Rogers et al. (2003)

Another key issue related to this iterative design process is a conscious and serious attempt to avoid pro-innovation bias. This is where, due to personal emotional involvement in the design, false-positive evaluations of the project are perceived (Rogers, 2003). It is part of human psychology to positively colour self-appraisal such as that typified by the idea of 'illusory superiority' (Hoorens, 1993). While a certain amount of positive bias is adaptive and necessary for normal everyday human life, it becomes a significant hindrance in situations where the human is both a designer and appraiser of that same design. Not being able to accept the reality of flaws in a design leads to stagnation, and in more extreme cases, pro-innovation bias can lead to the avoidance of evaluation at all.

While it is not simple to detach one's self emotionally as a designer from the process of adoption and implementation, it is equally difficult for an independent outsider to have deep insight into the design. The optimal approach is to accept that this bias exists and also that criticism is both intrinsically and highly important to design development but may also be offensive to one's sensibilities at times. While this may sound slightly vague, it was a very important issue in the Space to Grow project because one of the major flaws of the earlier iterations was the false self-appraisal that the provided resources and approach were "excellent". To add further complication, similar bias is also apparent in the interpretation of teacher feedback which must be considered and for which corrections must be applied (Fitzgerald et al. 2014b). In the following section, we outline the three main areas we use this particular set of evaluation criteria and corrections to improve the quality of the curriculum materials that constitute the innovation.

Human and Context Issues in the Design

The first major issues that we consider in our design process are those broader issues surrounding the people and their environment as they impact on the success of implementation. These are related to the particular nature of high-school students' understanding and motivation coupled with the primary importance of the teacher as the primary actor within a larger social, political and economic context. These issues are outlined in the diagram presented in Figure 3. We choose to locate the student at the center of our educational design concerns, but what the student does is heavily influenced by what the teacher is capable of undertaking in the classroom. Furthermore, the teacher's capacity to control and implement what they would like in the classroom is heavily impacted by a number of issues related to the school and larger community.

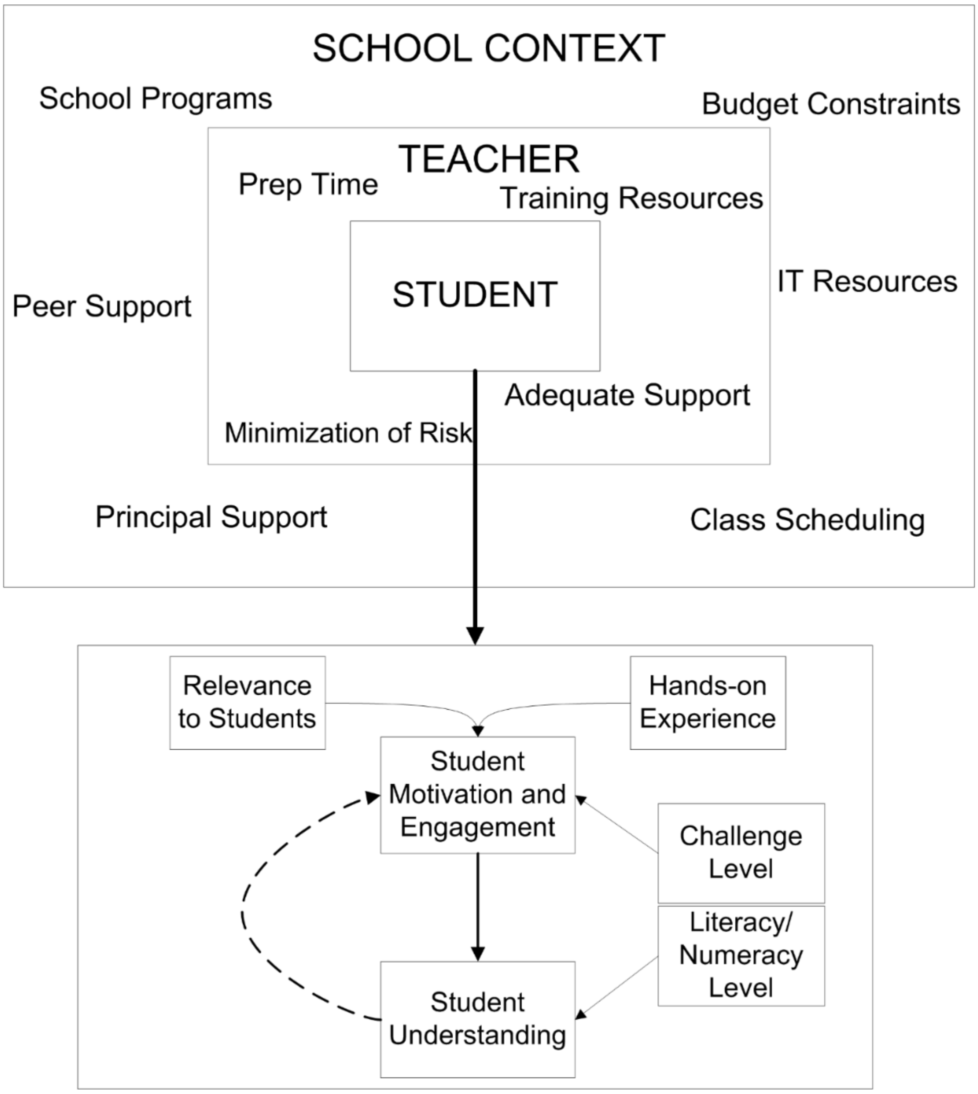


Figure 3: Outline of the various issues to be considered in the educational design.

Student Issues

Most high school students do not have a strong extrinsic or intrinsic motivation to study science and tend to consider it relatively boring (Osborne et al., 2003). The assumption that a significant fraction of students find the idea of science dull due to their prior experience is well reported in the research literature (e.g., Goodrum et al., 2001; Tytler, 2007). While astronomy does seem to hold more intrinsic fascination for some students (Osborne 2000) than do the other sciences, it would be a mistake to assume that this is the default position for most students. While some students may become interested in the big questions asked by astronomy, such as where we are in the universe and how we got here, this is not true for most students.

Astronomy is also one of the more abstract and less tactile observational sciences and hence can act as a negative if the students feel too detached from the material. This is problematic as engagement is best achieved when there are significant links between what they are learning and their direct experience. Besides the Sun and the seasons and, for some, the night sky, there is always some layer of abstraction between the student and astronomy. Removing as much of this layer as possible is of great benefit to sustaining engagement and motivation through the materials.

The quickest route to the removal of this layer is to provide 'photon-eye contact' through the use of a telescope on a local observing night to view astronomical objects such as Jupiter or Saturn, the Orion Nebula and the Moon. However, observing nights are problematic to organize in schools with the rise of more stringent Occupational Health & Safety (OH&S) regulations, the necessity of undertaking a risk analysis, as well as managing supervisory and transport requirements (Fitzgerald et al. 2014a). These barriers, coupled with the lack of availability of a telescope or an expert operator, often result in observation nights not being considered by the teacher.

One alternative approach is to get students to control a telescope remotely during their class-time. The telescope is at another conveniently located (dark) part of the globe and students use it to photograph objects of their choice. There also exist robotic instruments that can be scheduled to collect images requested by the students and return them to the school in raw FITS format as quickly as possible. This lacks a significant amount of the hands-on experiences in comparison to remote observing but, in the absence of other options, is at least a minimalist approach to students acquiring their own images. This approach, using robotically controlled telescopes, is the method we have so far employed due to resource constraints. We are, however, now trialing remote observing sessions with our educational materials with a variety of observatories. Even when not directly related to the narrower scope of the content, experiences such as this appear to be vital for developing initial student engagement.

Students typically ask the question and teachers need to answer it: "Why are we doing this?". There are two separate components to this question. The first is "Why is what I am doing relevant to me at all?" The second is "Is what we are doing in anyway realistic or is it just a made up recipe-driven classroom activity?" Neither question is truly independent of the other. By stressing the authenticity of the activities undertaken by the students as well as always attempting to link the activity to their immediate and future lives, we hope these questions will be minimized. Ultimately, however, students will ask the questions and the teacher should have a convincing answer ready.

Once the motivational components have been addressed, the educational design needs to be targeted at the abilities of the students within the classroom. Obviously, the teacher has the most relevant knowledge of their students and hence is the best person to make the call about what in-class activities are most appropriate to their students. Students of differing abilities require differing approaches. This means that the overall design must be sufficiently flexible for it to engage the majority of students rather than just the gifted and talented. If the materials are too hard for the students, they will become disengaged; if it is too easy, they will become bored. In both cases, classroom management issues may surface.

It is hoped that if the optimum level of challenge and difficulty is achieved then students will achieve the ideal state of 'flow' (Csikszentmihalyi, 2008; Shernoff et al., 2003). If the intended task requires little skill or challenge in their perception then it is likely the student will be ambivalent about the whole procedure. If they perceive it to be far too challenging to their perceived skill level, it will be a cause of anxiety. The key, therefore, is to push the challenge and difficulty levels to the students' optimum levels.

There are also considerations to be made about literacy levels and its application to the science classroom. While it is true that all students "should" achieve high standards of literacy, a good experiential grasp of the concepts of science can be acquired without the use of excessive literacy requirements or reliance on scientific jargon. Yet again, this is a line-call decision that only the teacher can make. Nonetheless, the teacher should cater for different levels of student literacy in the design as much as possible, especially for the less advanced curriculum materials. There are limits on both extremes of the educational design and its materials. Ten A4/Letter sized pages of dense text is simply far too much to be reasonable for any student or teacher to follow while a simple picture/cookbook approach is obviously too directed.

With respect to numeracy levels, in cases where a certain level of mathematical understanding is required, the designer and the teacher cannot assume that students will be able to apply what they have learned in the mathematics classroom to the science investigation. Even if they have learned it, they may have forgotten it or not be able make the conceptual link between the mathematics and its scientific application. This is especially true since the use of mathematics in physics and astronomy is distinctly different compared with the mathematics offered in high school (Redish, 2005). In addition, designers cannot assume that students are able to understand, generate or read graphs to the extent that teachers do.

Only a relatively small fraction of students can truly work quickly in the very abstract. Most students have more success working with concrete activities eliciting concrete understandings that can later be recontextualised into different situations (e.g. Tao & Gunstone 1999). If a student can work directly with a concept, the necessity for generating abstract analogies, such as is done in Content Representations (Loughran et al. 2006) is minimized. The principle here is to keep all of the experiences as direct and authentic as possible so that all students can extract some meaning from the content in the most realistic manner, modeling actual scientific procedures, as possible. Of course, not all concepts can be modeled in an adequate manner in the classroom but, the closer to an authentic direct experience that the curriculum design can accommodate, the better.

Teacher related issues

A core aspect of the design is being able to enable the teacher, who will not necessarily be an expert or even pro-amateur in the field of astronomy, to be able to let the intended experiences driven by the educational design play out in their classroom. It is the teacher who largely determines in-class activity and thus recognized as the primary actor and decision maker within the educational design.

The first major issue is dealing with the preparation time. Teachers are extremely time-poor. Thus, expecting teachers to prepare material from scratch in an area in which they are not an expert demands too much of a time investment. Innovations generally fail where only the instructional technology (i.e. a laptop, a telescope or an interactive whiteboard) is provided because teachers do not have the time to develop their own curriculum materials to surround the raw technology provided. Similarly, providing multiple disconnected worksheets on many different topics within the overall design also translates into the classroom teacher having to spend significant preparation time organizing them into a coherent sequence.

The simplest guideline to address this time issue is to provide as much of the in-class material as possible in an editable form as a coherent sequence so that the teacher can customize it in a very short time for his/her own classroom context to minimize their preparation time. The centralized nature of in-class material creation and provision also has a cumulative time-saving effect on the education system. That is to say, consider that a teacher may roughly spend one to three hours on preparing a lesson. If there are 100 teachers using the materials but were expected to create their own in-class materials, there would be a loss of 100-300 productive human hours from the system that could have been spent on something much more beneficial to individual students. There is no reason to have teachers reinventing wheels that have minor contextual differences. Rather, the teacher should be able to use their preparation time concentrating on how to *customize* the material for *their* students and school context rather than designing them from scratch. Having the in-class material centralized also allows a level of quality control that is not possible for a single teacher. There is also the added benefit of a much reduced improvement and development-iteration time because in a single year many teachers will use, and provide feedback on, the materials.

The second major component is the financial cost for teacher training. Professional Development (PD) is an expensive endeavor and, some would say, not cost effective with respect to the general low quality of PD provision as identified by the teachers in Fitzgerald (et al. 2014a). However, there seems to be little research on the balance of resource cost versus PD efficacy to substantiate this claim. In fact, while millions of dollars have been spent on PD programs focusing on inquiry-based teaching and learning, there are many questions remain to be answered related to PD focused on this area of science education (e.g., Capps et al., 2012).

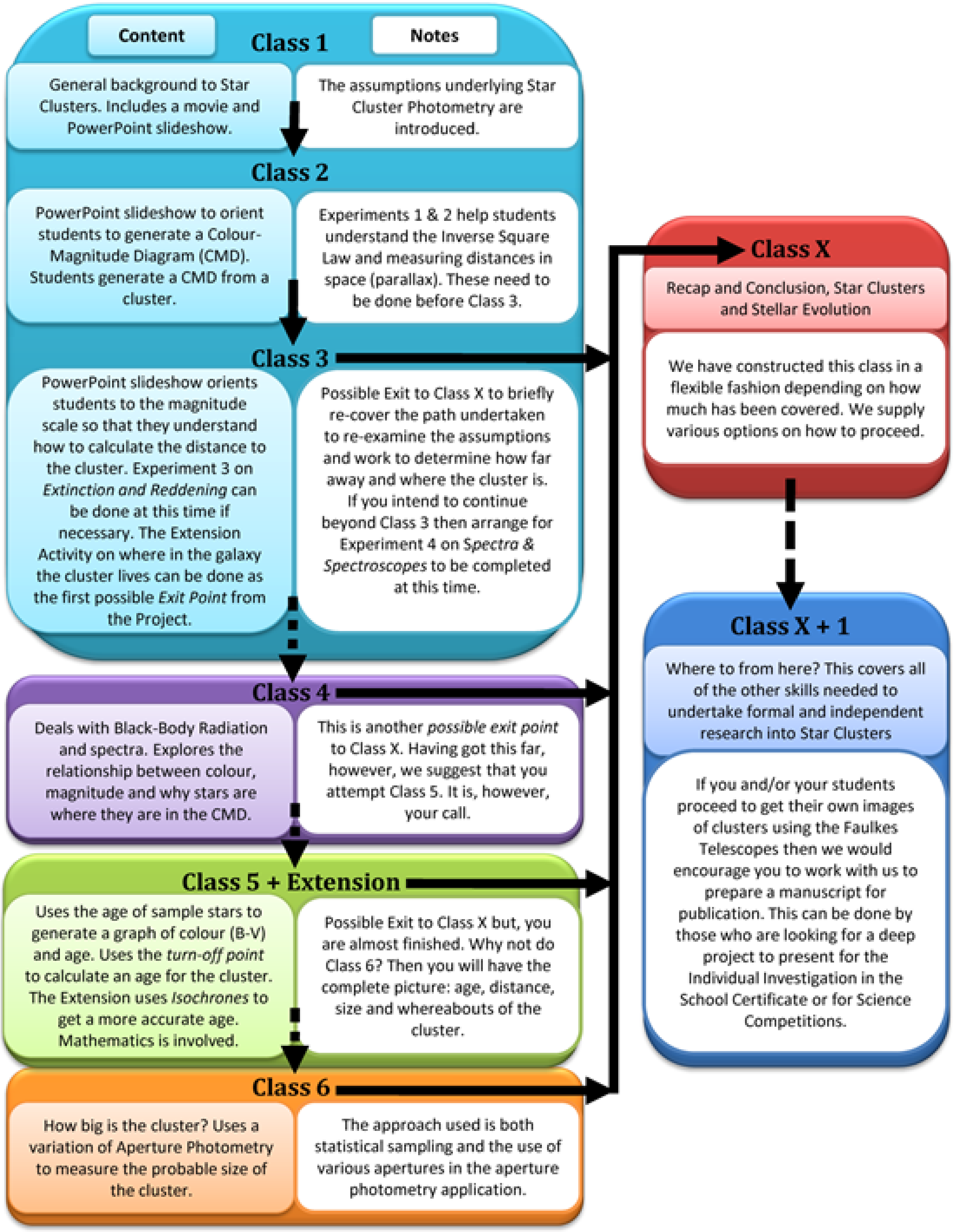
Nonetheless, regardless of the cost, it is necessary to provide training and support at some level for the teacher. We have embedded the PD experience as much as possible within the materials developed following these design principles. The embedding takes the form of a conversation between the authors and the teacher that walks them through the steps and the things they need to consider for a successful implementation. The teacher resources developed for the project are large, voluminous and cover all possible aspects and common problems while providing a clear structure about the nature, direction and goals of the project. While some may regard the volume of materials as a threat, we have provided all materials as hyperlinked digital documents. This overcomes any threats that may be created by seeing a large volume of paper-based content.

For those face-to-face PD experiences that are run with teachers, there is a heavy focus on having the teachers follow the same path that their students will take, albeit at a slower pace and in greater detail. Time is intentionally allocated within the PD sessions for reflection on their immediate learning experience of the educational design. In this sense, the teachers are required to wear two hats. First, they wear the student hat and experience the materials as if they were the student. At each natural stopping point in the materials, they are asked to wear their teacher hat to reflect critically on what they have just experienced and to discuss as a group how this approach would (or would not) work in their own classrooms.

Once teachers have completed the formal component of the PD, whether that be face-to-face with the curriculum developers or self-driven, they are required to trial and test the materials with one of their science classes. Due to the size and scope of what is trying to be achieved with this design, it is only feasible to implement the material in small and incremental steps, and, in the process, to increase in a measured way the scope and magnitude of implementation over a number of repetitions.

If managers mandate teachers to undertake the entire innovation on their first attempt, however, it is likely that the implementation will be *trivial* rather than a mirror of the *intended* use of the innovation (Hall & Hord 2001). Consequently, in an attempt counter this threat, the materials are designed so that the teacher has a number of coherent exit points throughout the material. Figure 4 shows a schematic of the sequence of classes and the possible exit points tracking to the final class named Class X where "X" is a variable depending on the exit point determined by the teacher.

While the details of the content of these materials are described later in this paper, the general principle that teachers can exit the materials at a variety of locations is clearly shown in Figure 4. This alleviates the teacher's potential fear by allowing expansion of the *scope* of the intervention to be at a rate determined by the teacher as they gain confidence. It should be emphasized that exit to Class X is determined by the teacher on the basis of her/his appraisal of the content knowledge as well as an appraisal of the class's interest and engagement and the teacher's determination of the students' ability and motivation to deal with the concepts. Class X is named thus because it *could be* Class 4 if the teacher determines that the class should exit after determining the distance to the cluster of stars in Class 3 etc.



Class 1

General background to Star Clusters. Includes a movie and PowerPoint slideshow.

The assumptions underlying Star Cluster Photometry are introduced.

Class 2

PowerPoint slideshow to orient students to generate a Colour-Magnitude Diagram (CMD). Students generate a CMD from a cluster.

Experiments 1 & 2 help students understand the Inverse Square Law and measuring distances in space (parallax). These need to be done before Class 3.

Class 3

PowerPoint slideshow orients students to the magnitude scale so that they understand how to calculate the distance to the cluster. Experiment 3 on *Extinction and Reddening* can be done at this time if necessary. The Extension Activity on where in the galaxy the cluster lives can be done as the first possible *Exit Point* from the Project.

Possible Exit to Class X to briefly re-cover the path undertaken to re-examine the assumptions and work to determine how far away and where the cluster is. If you intend to continue beyond Class 3 then arrange for Experiment 4 on *Spectra & Spectroscopes* to be completed at this time.

Class 4

Deals with Black-Body Radiation and spectra. Explores the relationship between colour, magnitude and why stars are where they are in the CMD.

This is another *possible exit point* to Class X. Having got this far, however, we suggest that you attempt Class 5. It is, however, your call.

Class 5 + Extension

Uses the age of sample stars to generate a graph of colour (B-V) and age. Uses the *turn-off point* to calculate an age for the cluster. The Extension uses *Isochrones* to get a more accurate age. Mathematics is involved.

Possible Exit to Class X but, you are almost finished. Why not do Class 6? Then you will have the complete picture: age, distance, size and whereabouts of the cluster.

Class 6

How big is the cluster? Uses a variation of Aperture Photometry to measure the probable size of the cluster.

The approach used is both statistical sampling and the use of various apertures in the aperture photometry application.

Class X

Recap and Conclusion, Star Clusters and Stellar Evolution

We have constructed this class in a flexible fashion depending on how much has been covered. We supply various options on how to proceed.

Class X + 1

Where to from here? This covers all of the other skills needed to undertake formal and independent research into Star Clusters

If you and/or your students proceed to get their own images of clusters using the Faulkes Telescopes then we would encourage you to work with us to prepare a manuscript for publication. This can be done by those who are looking for a deep project to present for the Individual Investigation in the School Certificate or for Science Competitions.

Figure 4: General pathways through the curriculum materials.

Curriculum developers must also remember not to have unreasonably high expectations of teachers. Teachers are not and cannot be, in most cases, research scientists mentoring their students towards a scientifically publishable finding. It is impossible for the normal classroom teacher to gain enough expert knowledge in a single scientific field to guide a piece of valid research to such a conclusion, let alone in the multiple scientific fields that they must teach. This would still be very difficult even when the teacher is an amateur astronomer. Science teachers generally have expert teaching knowledge of their own and cannot be expected to be experts in the multiple scientific disciplines that comprise the high school science curriculum. However, teachers should be expected to extend their own curriculum content knowledge and pedagogical expertise but there needs to be a realistic yet achievable limit. Once a teacher perceives themselves as having reached this limit, the students need to be teamed with scientific mentors to conclude their scientific investigation or perhaps to produce a scientific paper.

School Context issues

While teachers' concerns and students' interest are obviously primary considerations, there are other contextual factors involved that need to be addressed. Here, we explore those issues most relevant to the educational design. In astronomy, all of the images are in digital format and their analysis must be undertaken using specialised software. Thus, the most frequently fatal contextual factor that affects implementation is the Information Technology (I.T.) infrastructure in the school. There are four major elements involved in this issue that must be met. First, the software needs to be free as schools have little disposable budget to invest on single-use software. Second, not all software works on all types of computers: some of the available software works only on Windows, so solutions allowing use also on Apple Operating Systems had to be developed for schools using this platform. Third, certain educational jurisdictions block the running of certain software on their computers as well as blocking certain functions on the school network. All of these can cripple the use of any software. Finally, even if the software can run successfully, it is either user-unfriendly, scientifically invalid or a combination of both. Thus, the software has to be failsafe, idiot-proof, simple, yet produce scientifically valid data. At the beginning of our project, there was only one piece of software identified that met all four of these criteria.

The school timetable is a second contextual factor that has to be considered. The materials and approach need to fit into the in-class time available for the content area. There is only a small of time available within the NSW/Australian curriculum for astronomy that spans two to four weeks or 12-24 x 40 minutes periods. Some educational systems around the world may have even less time for astronomy, or none at all. The availability of in-class time is further compromised by the average class-size, which, in the schools of our sample, is almost 30 students. This can lead to even greater pressures on the in-class time to deal with the time-intensive inquiry-based approach.

The in-class time issue thus drives the principle that the design should be as concise as possible and avoid any unnecessary additional factors that may not add educationally or motivationally to the students' experience. For example, in the earlier version of the project, there was the need to submit a *competitive* telescope-time proposal to acquire imaging time on the robotic instruments. The construction of this proposal would have taken up a large fraction of the *available* class-time to complete, let alone wait for approval from a telescope-time committee and then to await the data generated by the robotic telescope. By the end of this process, the in-class time left would be minimal. Identification of this blocking factor, and its removal, resulted in a much more productive use of in-class time.

A third contextual factor involves the science department's budget which tends to be heavily constrained. Any attempt to charge for services provided in the design must be very cost-effective, or free. While there is an argument that the school or jurisdiction treats funded innovations, which are underwritten by external grants, more seriously, these innovations that have significant costs associated with them are far more likely not to be adopted.

The final, and most important, implementation factor apparent in our research is the fact that supervisory support is crucial and that science-teacher peer support is very helpful in getting the innovation implemented in the classroom. A supervisor who is negative towards the project, or a science staffroom environment where the teacher is the only one interested makes life very hard for the individual who intends to implement. Providing outside peer support from teachers in other schools who have already implemented is also useful although the best model of how to do this efficiently is still being explored.

Backward Mapping of Goals and Direction

The first step in the design process is to focus on what the goals of the educational design are to be. Once these goals have been constructed, then the choice of general pathway, approach, activities and assessment can then be clearly defined. If there are no stated goals, if the goals are only vaguely stated and/or if methods to achieve such goals are not clear, then the educational design will be poor at best and will generally lack coherence and structure. It is very clear that the clarity of goals themselves and the means by which to achieve these goals must be strongly aligned and transparent.

Input into the selection of these goals comes from various sources as outlined in Figure 5. The actual selection of these goals, in practice, must include at least some, and preferably a high, level of alignment to the mandated curriculum if teachers are to be convinced to adopt and implement the approach. Goals that diverge significantly from the mandated curriculum are far less likely to be adopted as the nature of modern schooling restricts extra-curricular activities. Without some goal attachment to the curriculum, the struggle for implementation would become an implausibly difficult battle.

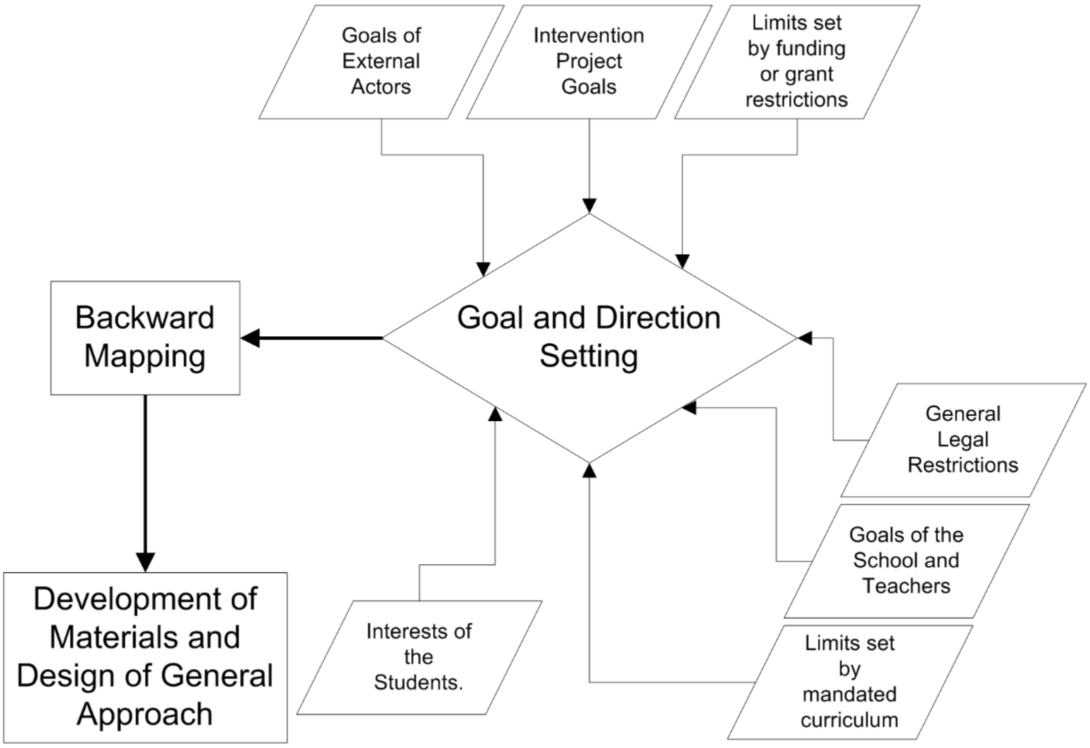


Figure 5: Schematic showing major inputs into the goal and direction setting process.

To address the limits set by the mandated curriculum, the theme of the *lifecycle of stars* was chosen. This topic mapped directly to content strands of the then NSW state junior and senior high-school curricula and now, to the new Australian Science Curriculum. The design of the materials also covers various less prescriptive but bigger picture areas of the Australian Curriculum, such as aiming to increase interest in and understanding of science content as well as science inquiry, providing a historical and cultural context within which the science sits, as well as developing generic problem-solving abilities (http://www.australiancurriculum.edu.au/).

Other constraints place additional limits on what goals or directions can be constructed. In the context of the Space to Grow project, the funding came from specific jurisdictions limiting the delivery to schools within those jurisdictions. In addition, there were specific budgetary limits on what can and cannot be done using funds from the Australia Research Council. There are also the legal restrictions such as those presented by OH&S laws as well as laws guarding the interests of children.

Outside of the strategic goals, the deeper goals stemming from the intervention project itself need to be outlined. These goals have considerable purposeful overlap with the goals of students, schools, teachers and outside actors. In our context, these can be outlined by the following goal statements:

1) Involve the non-trivial use of real astronomical data from a real research grade telescope;
2) Increase students' understanding and appreciation for the universe around them, what it looks like, what its history is and where they are in it as far as we can currently ascertain;
3) Increase students' appreciation for the true methodology and approach of science in contrast to the general, currently poor, students’ perceptions of school science;
4) Increase the probability of students choosing science, other than as a potential personal interest, as a topic for higher level study or as a potential future career path or, at the very least, help them discover they are actually interested in science; and,
5) Enable students, or a smaller subset that so desire, to take their research to a natural scientific conclusion in the form of a scientific publication.

The first goal is relatively easily addressed through the use of the LCOGT.net telescopes and appropriately sophisticated treatments of the resulting data in the classroom. Rosing (2009, personal communication) stated that only 14% of the images taken by the 2-metre class telescopes were ever downloaded as FITS files. That is to say, those classes who had requested time on the telescopes appeared to be happy with a 56-kilobyte colour image displayed on their screen and which had been delivered to them under software control. Thus, the first goal was achieved early and continues to be achieved with most of the FITS images acquired being downloaded and utilised by schools. In fact, preview images (i.e. in a jpeg or even tiff format) are simply not provided to the schools forcing them to interact directly with the FITS images.

Goals 2, 3 and 4 are harder to define clearly without effective continuing evaluation informing the theoretical instructional design that is a component of the design principle. Nonetheless, a key decision point is reached at the end of Grade 10 when students choose subjects for their final two years of schooling. Many teachers have indicated that enrolments in physics have increased on the basis of the introduction of the project in Grades 8 to 10. One teacher claimed that for the first time in his teaching career of ten years at one particular girls’ high school, the enrolments in senior physics outnumbered those in biology after implementation of the project in lower year levels.

Theoretical Instructional Basis of Educational Design

While the focus is on iterative adaptation to the needs of the growing user base, previously trialed theoretical and empirical approaches to education inform the design. Using these materials, students undertake a process similar to that an astronomer would take in understanding the data and using it to gain a better understanding of the universe. The reality is that it can take astronomers excruciatingly long periods of time to undertake this process. This is even prior to factoring the years of skill and knowledge acquisition that have come before this, leading them to have an 'expert' capacity in contrast to the students' 'novice' capacity (Larkin et al., 1980). Therefore, there has to be some, usually significant, compromise between authenticity and plausibility. There also must be significant focused background scaffolding in three general areas, Motivation, Skills and Content, and Scientific Questioning. Figure 6 outlines schematically how the different scaffolding elements change in importance over time.

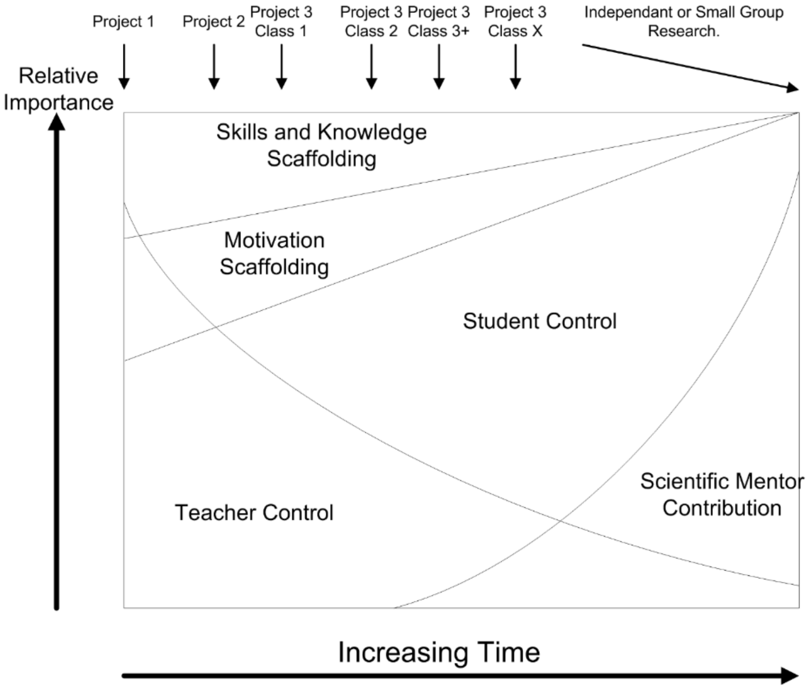


Figure 6: Varieties of importance of control and scaffolding

Motivation scaffolding is necessary to provide engagement and motivation to the student to want to interact with the material at all in the first place. This has to be informed by the social, cultural, economic and political context of the classroom itself, but there are many generic ways of engaging the students (Tytler 2007). Students who have higher levels of interest in the topic, whether intrinsic or situational, also tend to demonstrate improved learning and higher levels of achievement (Pintrich 2003). In this project, we use short commissioned videos to introduce each major topic and to engage the students. Figure 7 illustrates two well-known astronomers presenting in two short videos to engage students. While there is a substantial amount of content within the videos, the focus is on expressing the interesting parts of the content and why the students should be interested in it, rather than using the video as an instructional tool. Further motivational scaffolding is embedded within how the content and knowledge delivery is designed.

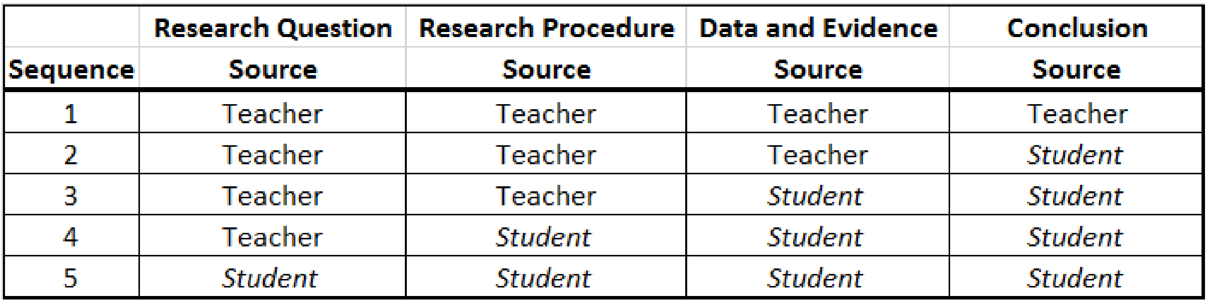
Figure 7: (left) Professor Fred Watson, Astronomer in Charge at the Australian Astronomical Observatory introducing the Life Cycle of Stars, (right) Professor David Malin, AAO introducing Colour and Imaging.

Skill and Content Knowledge Scaffolding is necessary to provide adequate background for students to understand what it is they are actually undertaking. As well as providing functional knowledge, this is also interlinked with motivating the students. It is clear that not only do collaborative learning strategies coupled with embedding them in an important context while undertaking in-class inquiry based and questioning strategies, such as the 5Es (Bybee 1997), improve students’ understanding and learning (Schroder et al., 2007), they also can act to engage and motivate the students to interact with the material.

For a high school classroom, teachers make decisions about the breadth and depth to address particular content and/or skills. While there are some instructional approaches that can increase both, eventually it becomes a limited-sum struggle for the teacher in that the more breadth that is covered, the shallower the treatment. Since the teacher makes the judgment call about the balance, the materials are designed so they can be ‘resized’ to fit the context.

In our project, the materials are presented using a 'just-in-time' approach. Thus, if students require a certain skill or content knowledge prior to undertaking an investigation, an inquiry-based approach that develops that skill or particular content knowledge is provided just prior to the main event where it will be required. The inquiry is always targeted and focused even if the actual interaction with the learning experience by the student is more open. In one sense, the student is always attempted to be placed in a situation where they are in the 'Zone of Proximal Development' (Vygotsky, 1978) where it is plausible for them to solve the problem or do the task with some guidance. While the 'problem' might be new to them, their previous recent experience has set them up to be able to solve it with the conceptual tools they have recently developed. Thus, knowledge development and skill application are cumulative. This means that the initial experiences in the design are much more teacher directed and involve more direct instruction than later experiences to provide the initial scaffolding for students to commence inquiry-based learning. No content knowledge is taught without having a clear application of it or as a deeper treatment of another applied concept.

To scaffold the process, we adopt the Backward Faded Scaffolding (BFS) approach strongly adopted by Slater et al. (2008, 2010b). BFS is in response to the reality that the hardest thing to do for a novice in science is to formulate a reasonable scientific question while generating a conclusions based on good data is relatively easy. In this model, rather than start with the student's attempt to ask a scientific question, they travel in the reverse direction by learning how to draw a conclusion using evidence derived from good data first. They then learn how to design a methodology to collect reliable data. Finally, they learn how to ask a research question. This approach is combined with the principle that initially control should be strongly held by the teacher which is progressively released (Faded) and devolved to the student. The general model is outlined in Figure 8. This approach has a strong resonance with the idea of 'Coupled Inquiry' (Dunkhase, 2003), where it is stated that 'Open Inquiry', while a part of many national science standards, cannot be successful without some more heavily structured or guided inquiry provided first to provide a scaffold for future, more open, inquiry. This is also a major issue identified by those critical of inquiry-based approaches (Kirschner et al., 2006).



Sequence	Research Question Source	Research Procedure Source	Data and Evidence Source	Conclusion Source
1	Teacher	Teacher	Teacher	Teacher
2	Teacher	Teacher	Teacher	*Student*
3	Teacher	Teacher	*Student*	*Student*
4	Teacher	*Student*	*Student*	*Student*
5	*Student*	*Student*	*Student*	*Student*

Figure 8: Backward Faded Scaffolding. (Adapted from Slater et al. 2008)

BFS happens on a number of levels within our design. On the largest time scale, the entire focus of the materials is to take the student on a journey that provides enough scaffolding to enable them ultimately to undertake some type of true open inquiry based on stellar astronomy. This is the basis of the changing importance of the various scaffolds and levels of student, teacher and scientist contributions in the model represented by Figure 6.

On shorter timescales, each class is designed to begin with a short teacher-directed introduction but transition into more student-led explorations of the phenomena at hand. In a sense, an analogous practice for this would be that of the undergraduate studio model, such as SCALE-UP (Beichner, 2000), where a concise introduction is directly followed by in-depth guided exploration, activities or research.

While this is the ideal design of the pathway through the entirety of the materials, the reality is that not all students will be able to maintain interest as they are slowly given more control in the classroom and are expected to interact more deeply with the materials. Any classroom contains students with a mixture of general interests, desires and aptitudes. It is only likely that a small fraction of the students will be interested in pushing further into self-directed research, and of those who are interested, only a fraction of them will still have the drive to take up, and complete, this opportunity. But for that smaller fraction who are interested, they are passed on to a scientific mentor who can then take the student, who by now has had sufficient skills training and motivation scaffolding, to undertake an authentic scientific experience. It is at this point that the student has achieved "Inquiry Escape Velocity", where they have liberated themselves from the classroom into a situation where they are able to undertake inquiry themselves with sufficient guidance.

This concludes our outline of our iterative design model and its major processes. In the next section we briefly outline the materials that two of the authors, Fitzgerald and McKinnon, have independently developed guided by this design approach for general use, although initially developed in response to the Space to Grow project with it's particular contextual issues and requirements.

Description of Materials and Approach

The curriculum materials designed with this approach are broken into three major projects, each of which is deeper conceptually and more student-led than the previous. Each project is further broken up into a series of 'classes', where a class denotes a coherent sequence of activities that may run over a number of class periods depending on the school's timetable. Figure 6 also records where each class would fit in the instructional sequence of our design in terms of teacher control, and motivation and knowledge and understanding scaffolding.

The first, *Introduction to Telescopes and Deep Sky Objects*, introduces students to the fundamental goal of the projects and tries to provide some initial motivational scaffolding. In this class they are given a brief introduction to telescopes and what they do and, using a jigsaw approach, to find out types of objects are up in the night sky. From these objects, students pick five (5) objects in the night sky to be imaged by the telescopes, preferably remotely driven by the students themselves, although, so far, the images have been acquired robotically for use by the students in the second project. This allows students to develop a sense of ownership over their images and to get feedback, and experience success as quickly as possible. In general, the three-filter (BVR) triplet of images are returned to the class within one week during which time they learn how to produce true-colour images in Project 2 in readiness for the return of their images.

The second project, *Understanding the Universe through Colour*, is, again, a scaffolding topic in which students become familiar with the peculiarities of astronomical images, and the software used to analyse them, before they explore the FITS images in more depth in the third project. The core scientific content area behind this project is the nature of colour and colour imaging. The core activity is the creation of an astronomical colour image from the monochrome filtered B, V and R images of their object. They also learn transferable skills in image processing (GIMP or Photoshop). It is also the intention that students with a more artistic focus or visual learning style may become more engaged with astronomy through this approach.

The third project, *Uncovering the Nature and Lives of Stars*, is where student control comes more to the fore. In the first class, students explore images of star clusters and their representative colour magnitude diagrams (CMD) (see Figure 9). This is intended to generate in the students an intuition derived from the imagery for what a CMD actually represents rather than presenting it as a disconnected abstraction. That is to say, they can see and describe the correlation between the shape of the CMD and the colours of the stars in the images they have created from the B, V and R images using the skills developed in the second project.

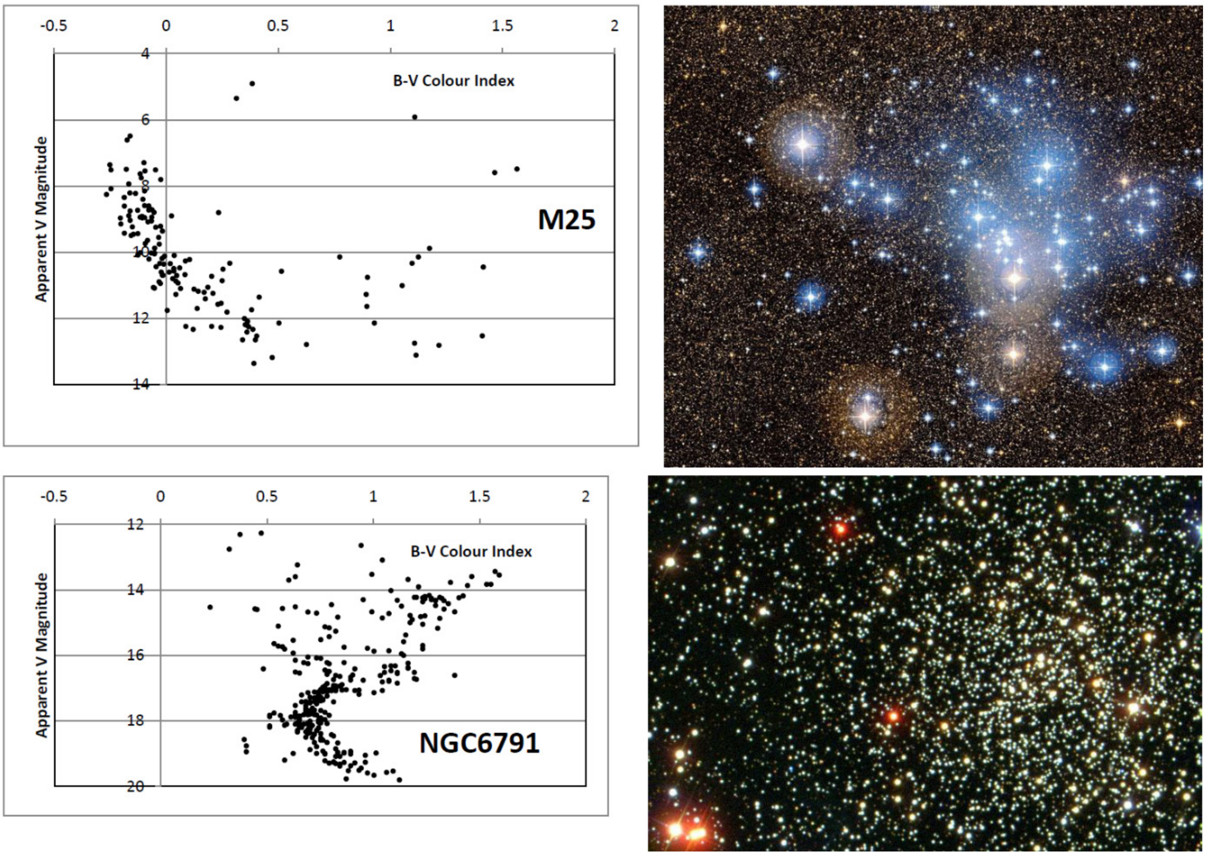


Figure 9: Sample Colour Magnitude diagram and image comparisons of two clusters, a young cluster, M25 (Image from APOD - http://apod.nasa.gov/apod/ap090831.html) and NGC6791 (Image from SDSS image of the week http://www.sdss.org/iotw/). Both sets of data are sourced from Webda (http://www.univie.ac.at/webda/)

In the second class of Project 3, the scaffolding begins to be faded to allow the students to generate their own data from the filtered images by constructing a colour-magnitude diagram of two well known clusters using a given research procedure. In this sense, the inquiry into the first cluster is *confirmatory*, while for the second cluster it is more *structured*. In these investigations, the students develop further skills in manipulating the image processing software to undertake aperture photometry, record the brightness counts of a number of stars in a specially developed spreadsheet. The students, in pairs and in a jigsaw fashion, undertake the analysis of the image. Each pair is assigned a small area of the cluster where they acquire brightness counts of 10 stars in the B-filter and the same 10 stars in the same order in the V-filter. The learn how to export the data and transfer it to the spreadsheet for analysis. Groups exchange their numerical data for the whole cluster online using Google Docs. Thus, at the end of a fairly short period of time (20 minutes), a typical class has data on the brightness's of upwards of 100 stars in both the B and V filters.

In the ensuing classes, students learn the various methodologies and techniques used to examine various properties that can emerge from their own measured data, such as distance, age, reddening, size, proper motion, radial velocity and metallicity. During these explorations, student control, where possible, is progressively increased as they acquire more interpretative skills and content knowledge in the context of their investigation while building their capacity to get to the final stage of asking their own research question or of designing their own research procedure in an authentic open-ended inquiry. When open inquiry begins, students who have reached this stage are mentored by a project scientist rather than by the classroom teacher who has led the students to the launching place from where they can truly inquire.

While the topics can be non-prescriptive and open to student suggestion in terms of the open inquiry that is available them, we provide two broad categories of projects. These involve the characterization of neglected or unstudied open clusters and in contributing to surveys of variable stars in globular clusters. Students can undertake both of these open-ended project categories with the skills, knowledge and inquiry experience developed in Project 3. It must be said, however, that only a substantially smaller fraction of students achieve this level and prosecute the project either as an individual or as a small class group. Nonetheless, along the way a large fraction of all students who experience the design will acquire an appreciation of the processes of science not the least of which involve problem solving, software manipulation and argument based on evidence.

The first examples of outputs from the open-ended inquiry using our materials were the observations of variable stars in a neglected far south globular cluster, NGC6101 (Fitzgerald et al. 2012). Here, two Grade 11 students took V and I band images of known RR Lyrae variable stars in the cluster and derived an independent distance to the cluster. In addition, they found a new variable star. The second example is that of a neglected open cluster, NGC2215, (Fitzgerald et al. 2014c), where one Grade 11 student from Australia collaborated with two Grade 12 students from Canada to significantly refine the major parameters of distance, age, reddening and metallicity of a cluster whose published data had a quite large variance in all previous estimates of these parameters. An image of this cluster and its CMD is shown in Figure 10. Further studies by other student groups are currently underway. Some of these are currently in the paper production stage and involve investigations into other neglected open clusters and variable stars in globular clusters.

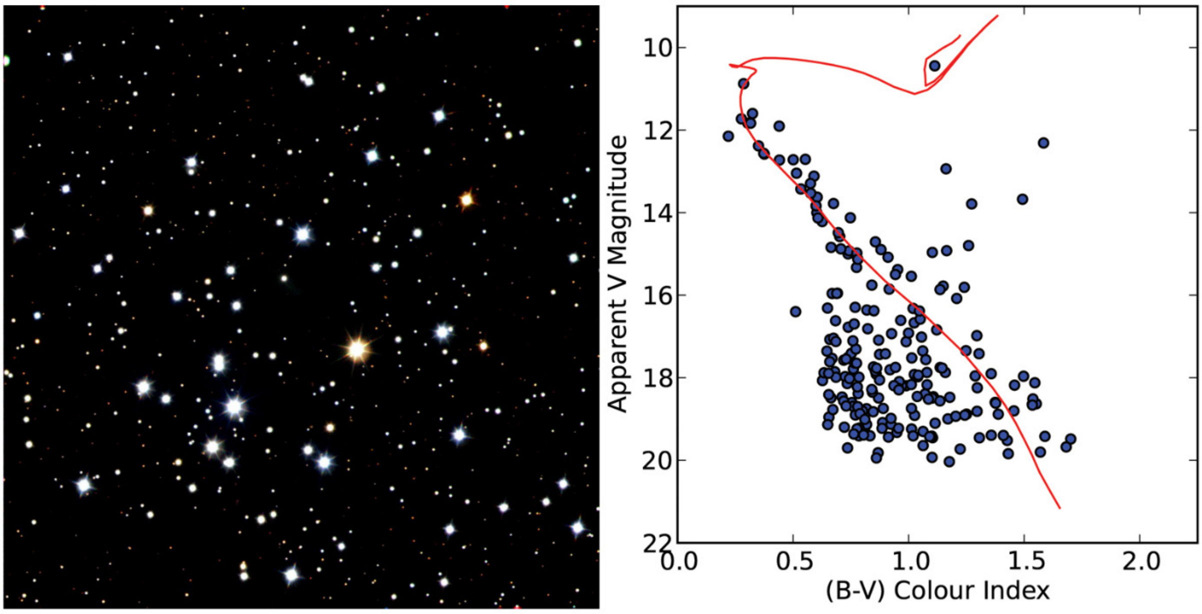


Figure 10: Colour Image of NGC2215 CMD and Colour Magnitude Diagram.

Conclusion

In this paper we described an educational design to facilitate motivation and sciences using real data from real astronomical telescopes in the high school classroom in the context of a large-scale intervention project. This original design originated from an attempt to revolutionize a previously ineffective design that suffered from a variety of systemic problems. The approach is intended to be backward mapped from clear goals and directions as presented.

The new design is based around the rejection of a textbook model in favor of an iteratively improvable model for curriculum materials. These materials have to capacity to evolve in response to all manner of informal input and feedback from schools, teachers, students and project personnel as well as more formal quantitative and qualitative evaluation. Care is taken in the process to avoid false positives due to illusory superiority or pro-innovation bias.

The core of the project centers around making the student’s experience as realistic and as direct as plausible. This also includes flexible consideration of the student’s capacity for challenge, whether it be literary, numerical or scientific as well as minimizing abstractions. It also presents Motivation, Knowledge and Skills scaffolding for the student to be capable of making progress through the project and for some rare students the opportunity to undertake their own astronomical research.

While the final arbiter of success in this model is driven by the student’s motivation and knowledge gains, it is the teacher that is the primary actor in the larger social, political and economic context of the school. The teacher is not expected to be a content knowledge expert in the field. The teacher is enabled by being provided with time-saving pre-prepared materials in a self-teachable format where the PD is embedded in the teacher guide. The design allows for a trial-based incremental approach to implementation which means teachers are not required unreasonably to implement the innovation all at once.

The evaluation of whether this design succeeded from the pre-post quantitative studies will be presented in Fitzgerald et al. (2014d). In Fitzgerald et al. (2014e) we have explored various similar high school astronomy education projects endeavoring to achieve similar aims and have found that in general reporting of the actual design used in the projects and their evaluations are largely missing as well as reports of what was tried and failed or succeeded. With this paper we have endeavored to present our educational design in as transparent a manner as possible, and its evaluation in further research will hope to inform which aspects of the design did or did not work and why.

REFERENCES

Alfieri, L., Brooks, P.J., Aldrich, N.J., Tenenbaum, H.R., (2011), “Does Discovery-Based Instruction Enhance Learning?”, Journal of Educational Psychology, 103:1, 1

American Association for the Advancement of Science (AAAS). (1990), “Science for all Americans: Project 2061.” New York: Oxford University Press.

Anderson, R.D., (2002), “Reforming Science Teaching: What Research says about Inquiry”, Journal of Science Teacher Education, 13:1, 1

Bailey, J., Johnson, B., Prather, E., Slater, T., (2011), “Development and Validation of the Star Properties Concept Inventory”, International Journal of Science Education, 34, 14, 2257

Beichner, R., (2000), “SCALE-UP Project Summary”, North Carolina State University, Raleigh, NC

Bennett, J., (2001), “Science with attitude: the perennial issue of pupils’ responses to science”, School Science Review, 82:300, 59

Bybee, R.W., (1997), “Achieving Scientific Literacy: From Purposes to Practical Action”, Portsmouth, NH: Heinemann

Capps, D.K., Crawford, B.A., Constas, M.A., (2012), “A Review of Empirical Literature on Inquiry Professional Development: Alignment with Best Practices and a Critique of the Findings”, Journal of Science Teacher Education,

Collaboration for Astronomy Education Research (CAER) (1999). Astronomy diagnostic test. Retrieved 20th May, 2009, from http://solar.physics.montana.edu.aae.adt/ modified for Southern Hemisphere 2002 by the University of Sydney, further modified 2004 by Charles Sturt University.

Committee for the Review of Teaching and Teacher Education (CRTTE). (2003). “Australia's teachers: Australia's future advancing innovation, science, technology and mathematics agenda for action.” Canberra:Department of Education, Science and Training.

Csikszentmihalyi, M., (2008), “Flow: The Psychology of Optimal Experience”, Harper Perennial Modern Classics, New York

Danaia, L., McKinnon, D., Parker, Q., Fitzgerald, M., Stenning, P., (2012) “Space to Grow: LCOGT.net and Improving Science Engagement in Schools”, Astronomy Education Review, 11, 010106-1

Danaia, L., Fitzgerald, M., McKinnon, D., (2013), “Students’ Perceptions of High School Science: What has Changed Over the Last Decade?”, Research in Science Education, 43(4), 1501

Dunkhase, J.A., (2003),”The Coupled-Inquiry Cycle: A Teacher Concerns-based Model for Effective Student Inquiry”, Science Educator, 12:1, 10

Dunlop, J., (2000), “How Children Observe the Universe”, Publications of the Astronomy Society of Australia, 17, 294

Fitzgerald, M., Criss, J., Lukaszewicz, T., Frew, D.J., Catelan, M., Woodward, S., Danaia, L., McKinnon, D.H., (2012), “RR Lyrae Stars in the Globular Cluster NGC 6101”, Publications of the Astronomical Society of Australia.

Fitzgerald, M., Danaia, L., McKinnon, D., (2014a), “Blocking Factors Inhibiting Inquiry-Based Science Teaching and Potential Solutions: Perceptions of Positively-inclined Early Adopter Science Teachers”., International Journal of Science Education, Submitted

Fitzgerald, M., Danaia, L., McKinnon, D., (2014b), "Differences in perception of high school science: Students and Teachers views.", Science Education, submitted

Fitzgerald, M.T., Inwood, L., McKinnon, D.H., Dias, W.S., Sacchi, M., Scott, B., Zolinski, M., Danaia, L., Edwards, R., (2014c), "Photometric and Proper Motion Study of Neglected Open Cluster NGC 2215", Astronomical Journal, in review

Fitzgerald, M., Danaia, L., McKinnon, D., Deehan, J., (2014d), "A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science.",, Research in Science Education, Submitted

Fitzgerald, M., Hollow, R., Rebull, L., Danaia, L., McKinnon, D., (2014e), "A Review of High School Astronomy Student Research Projects over the last 20 years.", Publications of the Astronomical Society of Australia, Submitted

Goodrum, D., Hackling, M., Rennie, L., (2001), "The Status and Quality of Teaching and Learning of Science in Australian Schools", Canberra: Department of Education, Training and Youth Affairs.

Goodrum, D., & Rennie, L. (2007). "Australian school science education national action plan 2008–2012." Canberra: Department of Education Science and Training.

Hackling, M. W., Goodrum, D., & Rennie, L. J. (2001). "The state of science in Australian secondary schools" Australian Science Teachers Journal, 47(4), 6–17.

Hall, G., Hord, S., (2001), "Implementing Change: Patterns, Principles, and Potholes", Allyn and Bacon, Needham Heights,

Hoorens, V., (1993), "Self-enhancement and Superiority Biases in Social Comparison", European Review of Social Psychology, 4,1, 113

Kesidou, S., Roseman, J., (2002), "How Well Do Middle School Science Programs Measure Up? Findings from Project 2061's Curriculum Review", Journal of Research in Science Teaching, Vol. 39, No.6, pp. 522-549

Kirschner, P.A., Sweller, J., Clark, R.E., (2006), "Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching", Educational Psychologist, 41:2, 75

Larkin, J., McDermott, J., Simon, D., Simon, H., (1980), "Expert and Novice Performance in Solving Physics Problems", Science, 208, 4450, 1335

Lawrance, G. A., & Palmer, D. H. (2003). “Clever teachers, clever sciences: preparing teachers for the challenge of teaching science, mathematics and technology in 21st century Australia.” Canberra: Department of Education, Science and Training

Loughran, J., Berry, A., Mullhall, P., (2006), “Understanding and developing science teachers’ pedagogical content knowledge”, Rotterdam, The Netherlands: Sense Publishers.

Mayer, R.E., (2004), “Should There Be a Three-Strikes Rule Against Pure Discovery Learning? The Case for Guided Methods of Instruction”, American Psychologist, 5:1, 14

Moore, G., (2006), “Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers”, HarperBusiness, New York

National Research Council. (1996). “National science education standards.” Washington, DC: National Academy Press.

National Research Council. (2000). “Inquiry and the national science education standards.” Washington, DC: National Academy Press.

Osborne, J., Collins, S., (2000), “Pupils and parents’ view of the school science curriculum”, School Science Review, 79:288, 27

Osborne, J., Simon, S., Collins, S., (2003), “Attitudes towards science: a review of the literature and its implications”, International Journal of Science Education, 25:9, 1049

Osborne, J. (2006). Message from the President E-NARST News, 49, 1–2.

Pintrich, P.R., (2003), “A Motivational Science Perspective on the Role of Student Motivation in Learning and Teaching Contexts”, Journal of Educational Psychology, 95:4, 667

Redish, E., (2005), “Problem Solving and the Use of Math in Physics Courses”, Invited talk, World View on Physics Education in 2005: Focussing on Change, Delhi, August 21-26, 2005.

Rogers, E., (2003), “Diffusion of Innovations (5th Edition)”, Free Press, New York

Schroeder, C.M., Scott, T.P., Tolson, H., Huang, T-Y, Lee, Y-H, (2007), “A Meta-Analysis of National Research: Effects of Teaching Strategies on Student Achievement in Science in the United States”, Journal of Research in Science Teaching, 44:10, 1436

Shernoff, D., Csikszentmihalyi, M., Schneider, B., Shernoff, E., (2003), “Student Engagement in High School Classrooms from the Perspective of Flow Theory”, School Psychology Quarterly, 18:2, 158

Slater, S.J., Slater, T.F., Shaner, A., (2008), "Impact of Backwards Faded Scaffolding in an Astronomy Course for Pre-service Elementary Teachers based on Inquiry", Journal of Geosience Education, 56:5, 408

Slater, S.J., Slater, T.F., & Bailey, J.M. (2010a). Discipline-Based Education Research: A Scientist's Guide. New York: W.H. Freeman & Co.

Slater, S.J., Slater, T.F., Lyons, D.J., (2010b), "Engaging in Astronomical Inquiry", New York: W.H. Freeman Publishing and Company.

Tao, P-K. Gunstone, R., (1999), "The Process of Conceptual Change in Force and Motion during Computer-Supported Physics Instruction", Journal of Research in Science Teaching, 36:7, 859

Tytler, R., (2007), "Re-imagining science education: engaging students in science for Australia's future", Camberwell: Australian Council for Educational Research

Vygotsky, L.S., (1978), "Mind in society: The development of higher psychological processes", Cambridge, MA: Harvard University Press

A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science.

Michael Fitzgerald, Department of Physics and Astronomy,*
Macquarie University, North Ryde NSW 2109, Australia

David H. McKinnon, Lena Danaia and James Deehan, School of Teacher Education,
Charles Sturt University, Bathurst, NSW, 2795, Australia

(*) Corresponding author: mfitzasp@gmail.com, Phone: +61 431 480 007

ABSTRACT

In this paper, we present the results from a study of the impact on students involved in a large-scale inquiry-based astronomical high school education intervention in Australia. Students in this intervention were led through an educational design allowing them to undertake an investigative inquiry-based scientific approach to understanding the lifecycle of stars more aligned with the ‘ideal’ picture of school science. Through the use of two instruments, one focused on content knowledge gains, the other on student perceptions of school science, we explore the impact of this design. Overall, students made moderate content knowledge gains although these gains were heavily dependent on the individual teacher, the number of times a teacher implemented and the depth to which an individual teacher went with the provided materials. In terms of students perceptions there were significant global changes in students’ perception of the activities in class and the nature of scientist. However, there were some areas where no change or slightly negative changes of which some were expected and some not. From these results we comment on the necessity of sustained long period implementations rather than single interventions, the requirement for similarly sustained professional development and the importance of monitoring the impact of inquiry-based implementations. This is especially important as inquiry-based approaches to science are required by many new curriculum reforms, most notably in this context, the new Australian curriculum currently being rolled out.

INTRODUCTION

In most developed countries, student interest and participation in secondary school science has been declining for many years (AAAS 1989; Ainley, Kos & Nicholas 2008; Chubb, Findlay, Du, Burmester, & Kusa, 2012; Dekkers & De Laeter, 1997; Lyons & Quinn, 2010; Millar & Osborne 1998; Osborne; Simon & Collins, 2003). Science in high school is often taught in a transmissive, teacher-directed way where students tend to be passive in their learning and spend their time copying notes and memorising facts that they will need to recall on an end of topic test (Lyons 2006; Goodrum et al. 2001; Osborne & Collins 2000). Often, there is disconnect between what is taught in the classroom and what real scientists actually do in practice (Herrington, Luxford & Yezierski, 2012). In response to these and other issues with modern school science in Australia which was deemed to be in a 'state of crisis', Tytler (2007) called for an entire 'reimagining of school science'.

Several reforms and recommendations promote the adoption of inquiry-based approaches in the teaching and learning of school science in a reformative attempt to engage more students and impact positively on their conceptual understanding (e.g., European Commission 2007; Goodrum et al. 2001; Goodrum, Druhan & Abbs 2012; Osborne & Dillon 2008). There have been a number of studies that have examined the impact of inquiry-based instruction and which report positive changes in students' achievement in science (e.g. Alfieri et al. 2011; Schroeder et al., 2007, Schneider et al., 2002).

Despite small pockets of success, large-scale uptake of inquiry-based approaches resulting in improved interest and retention rates as well as content knowledge gains is not commonly seen (Anderson 2002, Author et al. 2014d, Author et al. 2013, Goodrum, Druhan & Abbs 2012). Some also have more fundamental criticisms of these approaches being ineffective due to their being too open and providing little guidance hence placing too much load on the learners' cognitive processing (Kirschner et al., 2006; Mayer, 2004). At the very least, inquiry-based approaches need to be sufficiently structured and scaffolded initially (Etkina et al. 2003; Trundle et al., 2009).

In Australia in particular, there has been no real widespread ‘proven’ inquiry-based ‘instructional reform’ in secondary school science with many teachers holding on to their traditional, transmissive approaches in the teaching of science (Goodrum et al. 2001, Goodrum, Druhan & Abbs 2012). The new Australian National Science Curriculum (http://www.australiancurriculum.edu.au/) that is currently due to be implemented calls for investigative, inquiry-based science.

No one educational approach is successful by itself. There is no guaranteed best objective practice as the method used depends on learning situations, the background of the students and the concepts to be covered. The approaches adopted will depend on the concept being covered, the learning environment and the aptitudes and interests of the student (Bransford, Brown, & Cocking, 2000). Knowing this, curriculum materials and a general approach have been designed and implemented with a number of high school classrooms in NSW, Australia in the context of a large-scale astronomical high school intervention project. In this article, we are interested in finding out what impact this particular approach described has had on students’ knowledge outcomes and their perceptions of science at school.

In the context of astronomy, there have been many attempts at providing a medium to large-scale implementation of astronomy inquiry in the classroom with the new technological capacities available over the past two decades (Author et al., 2014d). Prior to this era, authentic astronomy inquiry and research at the high school level utilizing the scientific instrumentation of astronomy was restricted to those with access to a school observatory or significant funding to support fieldtrips and extracurricular activities. This paper is situated in a similar astronomy intervention project that attempts to link students and authentic astronomical instrumentation in a plausible and educationally effective manner. We outline the broad theoretical underpinning of the curriculum materials, teacher professional development approach and broad project approach in another paper (Fitzgerald et al. 2014a). In this paper, we focus specifically on the academic and affective results from the student population involved to contribute to strengthening the practice-theory connection that has been somewhat absent in astronomy education research in the modern era (Bailey & Slater 2004).

The purpose of this article is fourfold. First, we briefly describe the research context and outline the methods used to collect data in a large scale project involving the astronomy content of the curriculum. Second, we report survey data collected from 314 Grade 9 and 10 students on their knowledge outcomes globally, as well as by level of treatment (depth of material covered) and by individual teacher to investigate differences across classes. Thirdly, we report survey data collected from 470 students on their perceptions of what happened in their science classes both before and during the intervention. Finally, the discussion focuses on the implications for future implementation of interventions involving inquiry-based instruction.

RESEARCH CONTEXT AND AIMS

This research was undertaken in the context of a large astronomy intervention project in NSW, Australia (Danaia et al., 2013). In this project, teachers engaged in workshops that addressed content knowledge development and implementation training employing a variety of pedagogical approaches. Teachers worked through the materials both as a student and as a teacher allowing them to develop two perspectives that informed their practice. Workshops varied between three and five days and these were followed by extensive email support and occasional face to face visits upon request provided by the project team as well as by a growing number of teachers who had experience with implementing the project materials. The underlying purpose behind the workshops was to enable teachers and their students to make good use of two 2 metre-class research telescopes located in Hawaii, Faulkes Telescope North (FTN) and in Australia, Faulkes Telescope South (FTS) to pursue investigative inquiry-based science more in line with the ‘ideal’ picture of school science as described by Goodrum et al. (2001) and consistent with recommendations made in several national and international reports (e.g. Lawrence and Palmer 2003; Lyons and Quinn 2010; Drury and Allen 2002; Millar and Osborne 1998).

The materials and approach, designed independently of the intervention project, are more completely described in a broader educational design paper (Fitzgerald et al. 2014a). Here, we provide a brief summary of these materials. The design of the materials is broken into three main separate but interlinked projects: Discovering Telescopes and Deep Sky Objects; Understanding the Universe through Colour; and, Uncovering the Nature and Lives of Stars. In the first project, after a short introductory video, students undertake the pre-intervention versions of the two main quantitative surveys used in this project the outcomes of which are reported in this paper. Then students are introduced to what telescopes are and how they function followed by an exploration, in a jigsaw fashion, of the variety of objects that can be found in the night sky. From this list of objects, the class chooses five objects that can be imaged at the current time by the telescopes.

In the second project, and while images of these objects are being acquired, the class learns about astronomical images taken through special filters and how to reconstitute these black and white images into true-colour representations of an object in readiness for them receiving their images from the telescopes and to use them to create a colour image. Since the colour images are also aesthetically pleasing and made from images that they requested, this project serves to generate some motivation as well as pride of ownership to the students. Thus, in dealing with the manipulation and nature of astronomical images as well as the nature of colour and filters used in astronomy, these first two projects introduce much of the scaffolding necessary for the third project.

In the third project, students explore the nature of stars through a realistic and authentic creation, analysis and interpretation of Colour Magnitude Diagrams (CMDs) of star clusters. This project can be heavily customized by the teacher from a set of four to six classes up to a semester or year-long project where students can become involved in publishable scientific research. At the core of this project is the analysis of images of a cluster taken through standard colour filters leading to the construction and interpretation of their own colour magnitude diagram. The images can be obtained from archived sources or requested from the telescopes for new open clusters. In going through this process, students have a much deeper appreciation of the meaning of these diagrams and interpretation and a deeper understanding of the life cycle of stars. At the end of this project, students are then requested to undertake the post-versions of the two quantitative surveys.

SURVEY DESCRIPTIONS

The core of the quantitative evaluation of impact on the students is through the use of two surveys. The first survey is the Secondary School Science Questionnaire (SSSQ) closely based on the work of Goodrum et al. (2001) which probes students' perceptions of their school science classrooms. The survey is largely unchanged from the original. While the original research was cross-sectional, we use the survey in a longitudinal fashion to probe students' perceptions and experiences in the normal operation of their science classes compared with those they experience during the project.

The second survey is the Astronomy Knowledge Questionnaire (AKQ) comprising 19 multiple choice items constructed from four sources: the Astronomy Diagnostic Test (CAER, 1999) suitably modified for southern hemisphere application, The Test Of Astronomy STandards (TOAST, in Slater, Slater & Bailey, 2010), the Star Concepts Inventory (Bailey et al. 2011), and three items adapted from Dunlop (2000) on how children observe the universe. It was necessary to adapt the Dunlop items because the original items were open-ended questions intended for a relatively small-scale study. These multiple choice items were constructed using the results from a 2004 Federal Government supported study reported by Danaia (2006) in her doctoral thesis where a list of potential responses for each item were based on the most common answers provided by 2016 students all but one of which are alternative scientific conceptions. The reason for the restricted number of 19 items on the survey is to allow them to be completed within the timeframe of a single class period.

The choice of items on the AKQ survey was driven both by the relevant content areas of the curriculum and by the issue of being able to find comparative groups with which to compare the performance of the intervention groups. There are two main problems related to this latter issue. The first problem is that it is difficult to find a separate teacher at the same school who will undertake teaching the same curriculum content in the traditional manner and who would give up two school periods of their class schedule to complete the surveys simultaneously with the implementation class. The second problem is that even if this was possible, the intervention and control groups are not random samples. Rather, they are opportunity samples. Often, the students in a high school science class tend to be picked, or streamed, on the ability level of students.

There are further issues with differing teacher competencies as well as the scheduling of the time of day or day of the week or week during the year when the classes run. To deal with these issues, a quasi-experimental repeated-measures design is employed and based on the use of Equivalent and Non-Equivalent dependent variables. With this approach, some items in the survey are theorized to be affected by the intervention (equivalent Dependent Variables or eDVs) whereas others are not (non-equivalent Dependent Variables or non-eDVs). The eDVs in the AKQ are those items whose content can be mapped to the project materials used and to the content of the science curriculum. In Grades 9 and 10, these mainly surround concepts related to stars. The non-eDVs are those whose content should already have been covered in the lower grades of high school (Grades 7 and 8) and which are hypothesized not to be affected by the traditional approach or the intervention. These cover such things as day and night, phases of the Moon, eclipses, the seasons and movement in the night sky. The sets of equivalent and nonequivalent dependent items are listed in Table 1.

Table 1: Concepts and Sources of Items on the Astronomy Knowledge Questionnaire

non-Equivalent DVs			Equivalent DVs		
#	Concept	Source	#	Concept	Source
1	Causes of the Day/Night	Dunlop 5	4	Star colour and brightness	Bailey 16
2	Phases of the Moon	Dunlop 3a	7	Relative Distances of Objects	TOAST 10
3	Cause of the Seasons	Dunlop 4a	9	Star mass and lifetime	Bailey 5
5	Movement of Stars and Sun	ADT 10	11	Star birth	Bailey 14
6	Big Bang Definition	TOAST 9	12	Star death	TOAST 17
8	Relative Sizes of Objectes	TOAST 11	13	Planet Formation	TOAST 19
10	Big Bang Conceptual	TOAST 15	14	Colour and Temperature	Bailey 20
15	Energy from atoms	TOAST 22	17	Source of higher atoms	TOAST 24
16	Wavelength, energy and spee	TOAST 23	18	Temperature and peak wavelength	TOAST 27
			19	Source of sun's energy	ADT 8

METHOD

The participating schools were identified by the respective science consultants of their particular educational jurisdiction. Thirty-seven schools in three educational jurisdictions were involved with various numbers of science teachers (1-3) in each school being identified by the head of department as potential participants. In some cases, the head of the science department participated. The first round of professional learning (PL) involved teachers from 12 schools (15 teachers) and progressed over a five-day cycle. Days 1-3 involved teachers acting both as students, where they learned the content under direction of one of us, and as teachers where, at times determined by the project team members, collaborative discussions were held to reflect on what they had been learning and how they would implement the material with *their* class. On Day 4, the teachers went to a non-participating school where, in pairs, they collaboratively taught the materials to groups of 12-15 Grade 9 students. Day 5 involved the teachers in considering the extent to which the remaining content, not covered in Days 1-3, took them to the level of open inquiry. In addition, discussions involving pedagogy, investigation and implementation from a more holistic perspective were held.

The second round of PL involved additional teachers some of whom came from the 12 schools involved in the first round. In this second round of PL, only three days were planned with the Day 4 teaching experience removed and the Day 5 components collapsed into the afternoon of Day

3. On implementation with their class, teachers were asked to ensure that their students completed the online questionnaires. This proved to be an obstacle because internet bandwidth was not always available to ensure completion of the two instruments. In these cases, teachers printed the questionnaires that were later coded and entered into the Statistical Package for the Social Sciences (SPSS) ready for analysis.

The Secondary School Science Questionnaire (SSSQ) yielded 39 items that could be compared prior to, and after, implementation. In this case, a cross-tabulation of the students' responses compared their responses before implementation with their responses after the intervention. A Wilcoxon Signed-Ranked statistic was computed to investigate the changes (either positive or negative) in students' responses from the pre to the post occasion. The p-value adopted was a modified Bonferroni Adjustment using the average inter-item correlation of 0.229 for the 45 items on the pre-occasion and 0.272 on the post-occasion. The mean correlation of 0.2505 was used to compute the Modified Bonferroni Adjustment (Sidak's adjustment at http://www.quantitativeskills.com/sisa/calculations/bonfer.htm). The modified p-value is $p < 0.0033$. That is to say, if any particular comparison of the pre-intervention response pattern with the post-intervention pattern yields a p-value less than 0.0033 then the statistic can be accepted as significant and can lead to the rejection of the null hypothesis that the pre- and post-intervention response patterns are not independent of each other.

A total of 470 students who had experienced the intervention supplied SSSQ data on both the pre- and post-intervention occasions. These students were members of 26 classes whose teacher had attended the professional learning days and one teacher who had agreed to participate in the data collection but who had taught the materials in the normal transmissive way. There were 18 students in this non-intervention class.

Teachers were asked to record what elements of the project materials they had completed with their classes and to forward this information to the project team. The amount of material covered depended on the judgment of the science teacher and their knowledge of the class. In some cases, teachers implemented Projects 1 and 2 covering telescopes and the contents of the universe, and scientific color imaging in astronomy with their class. Others chose to cover these elements plus elements from Project 3 that led students to understand how astronomers can infer both the distance to a cluster and the life cycle of different mass stars.

A total of 314 students supplied AKQ data on both the pre- and post-intervention occasions. These students were members of 13 classes whose teacher had attended the professional learning days and one teacher who had agreed to participate in the data collection but who had taught the materials in the normal transmissive way using a text book.

RESULTS

In terms of the global effect of the project on student learning, we can see in Figure 1 that overall there is a statistically significant ($p < 0.0001$) and moderate effect size (0.368) gain in student learning when considering only the equivalent dependent variables. When considering the non-equivalent dependent variables we see a little or no change as predicted by our theory. This represents the overall mean results of all students from all teachers.

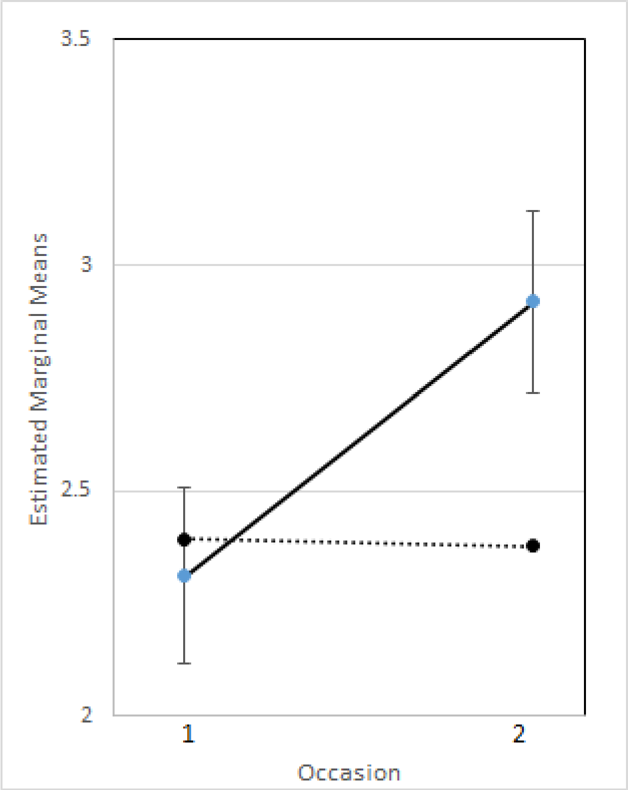


Figure 1: AKQ Gain from global sample of students. Equivalent Dependent Variables are solid lines. Non-Equivalent Dependent Variables are dotted lines.

While this is heartening, this description hides much of the detail. Once the data is analysed by teacher, we can see quite dramatically that not only do different teachers start with students that begin at highly variable starting positions, there are also differences between knowledge gains. This is shown in Figure 2. While most teachers seem to achieve content knowledge gains that are in line with the general global mean, some teachers vastly outperform the general population (the largest being Cohen's d=1.15) while there are a few teachers who have minimal or even negative effects (the most negative being Cohen's d=-0.15).

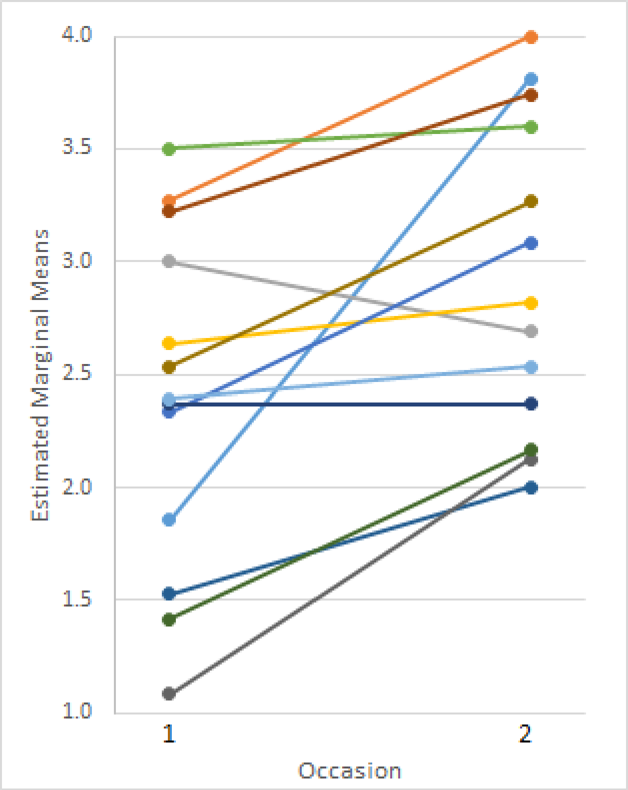


Figure 2: Comparison between pre and post results for all teachers from the equivalent Dependent Variables of the AKQ.

Our quantitative data even with complete matching demographic data from teacher surveys is not sufficient to yet extract all of the variables that might cause these differences amongst most teachers. However, there is a small subset of teachers who have taught at the same school and at the same time where the extraneous factors that might limit validity are held at the lowest possible point. We explore a situation where three teachers at the same school simultaneously taught grade 9 classes to examine their change in content knowledge.

One of these teachers was implementing for the second time, having previously implemented the project in the year before. Another teacher was implementing the project for the first time. The third teacher agreed to survey their students while not undertaking the project materials but implementing the normal curriculum related astronomy unit. These results are presented in Figure 3. The red line (A) is the teacher who was teaching the material for the second time, the blue line (B) is for the teacher teaching for the first time, the green line (C) is for the teacher who taught the subject matter traditionally (i.e. out of a textbook).

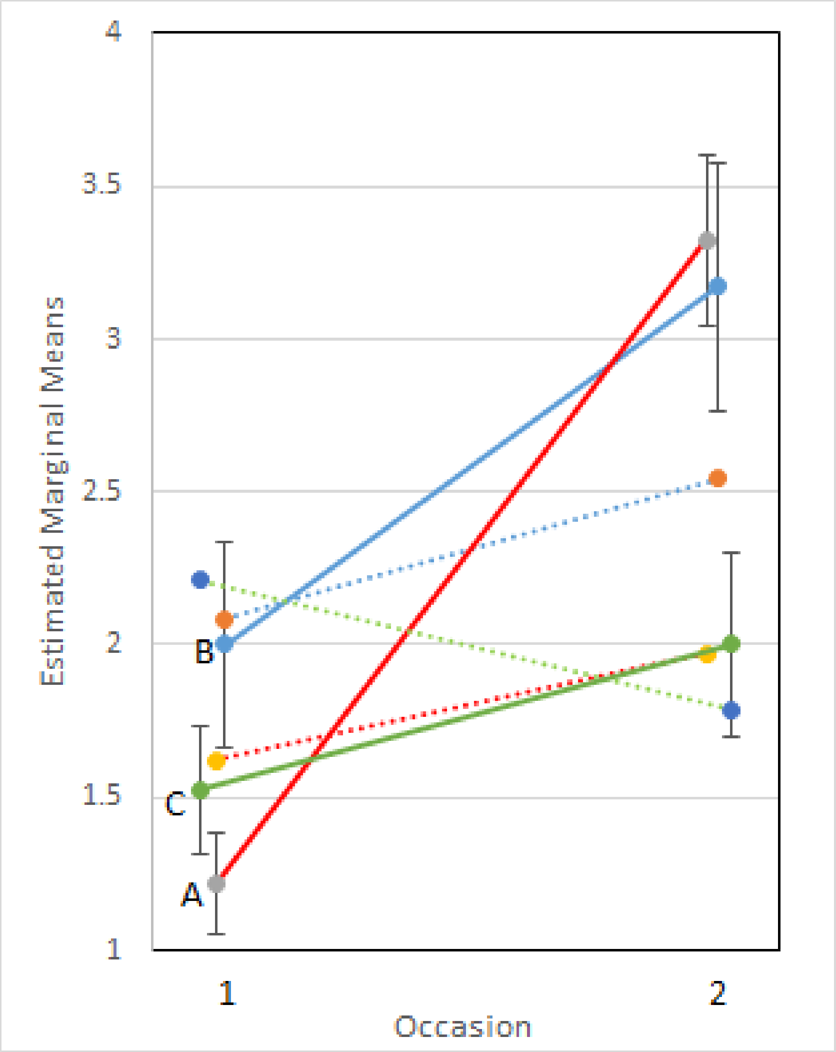


Figure 3: Pre/Post results for 3 teachers at same school. Non-equivalent Dependent Variables (dotted), Equivalent Dependent Variables (solid).

We also examine the data from the aspect of the teachers' treatment level in terms of whether teachers undertake only the first two 'scaffolding' projects or the complete set of three projects including the deeper exploration of stellar astronomy. Figure 4 shows that there is a larger gain when the longer version of the project has been utilised.

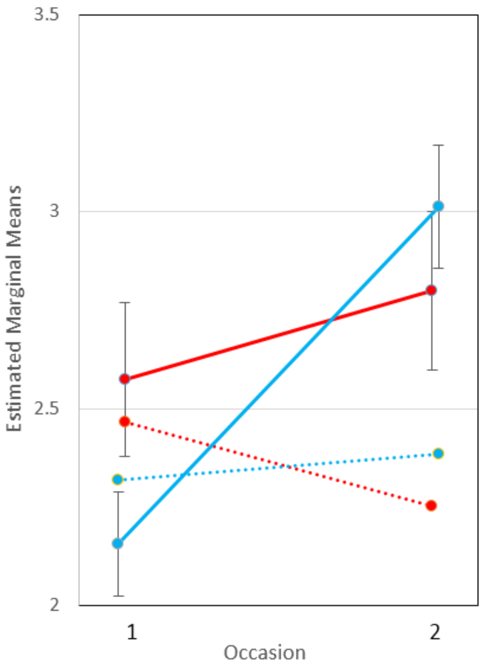


Figure 4: Results comparing those teachers who taught only the first two scaffolding projects (Red) compared to those teachers who taught a full implementation involving all three projects (Blue). Solid lines are equivalent dependant variables. Dotted lines are non-equivalent Dependant variables.

STUDENTS' PERCEPTIONS OF SCHOOL SCIENCE

Examining the SSSQ pre/post results, we find a variety of different changes. In the following figures, we present the effect size of the pre/post change in individual items on the SSSQ for the global sample (Global) and two sets of results for the teachers who had implemented the material once and those who were implementing the second time around. Green bars represent statistically significant differences, whereas blue bars are not statistically significant.

The first most dramatic changes are 8 global differences when comparing the students' perceptions of the project to their normal classroom, which are displayed in Figures 5 and 6. Students perceive dramatically less note copying in their classrooms in the project than outside. This is to be expected as in the design, not only is note copying forbidden, there is actually no provided notes to copy or set readings. The only large-scale text provided is instructions to the teacher which is not relevant to the students.

Students also feel that they have more capacity to choose their own topics to investigate. Early in the project students research an astronomical object of their own choice and are able to request images of such objects. Students perceive that there is less focus on what is necessary to get good marks in the project classes, even though it is directly covering the curriculum content. Related to this is a lesser focus on generating explanations individually as most of the activities provided are focussed around group work and discussion.

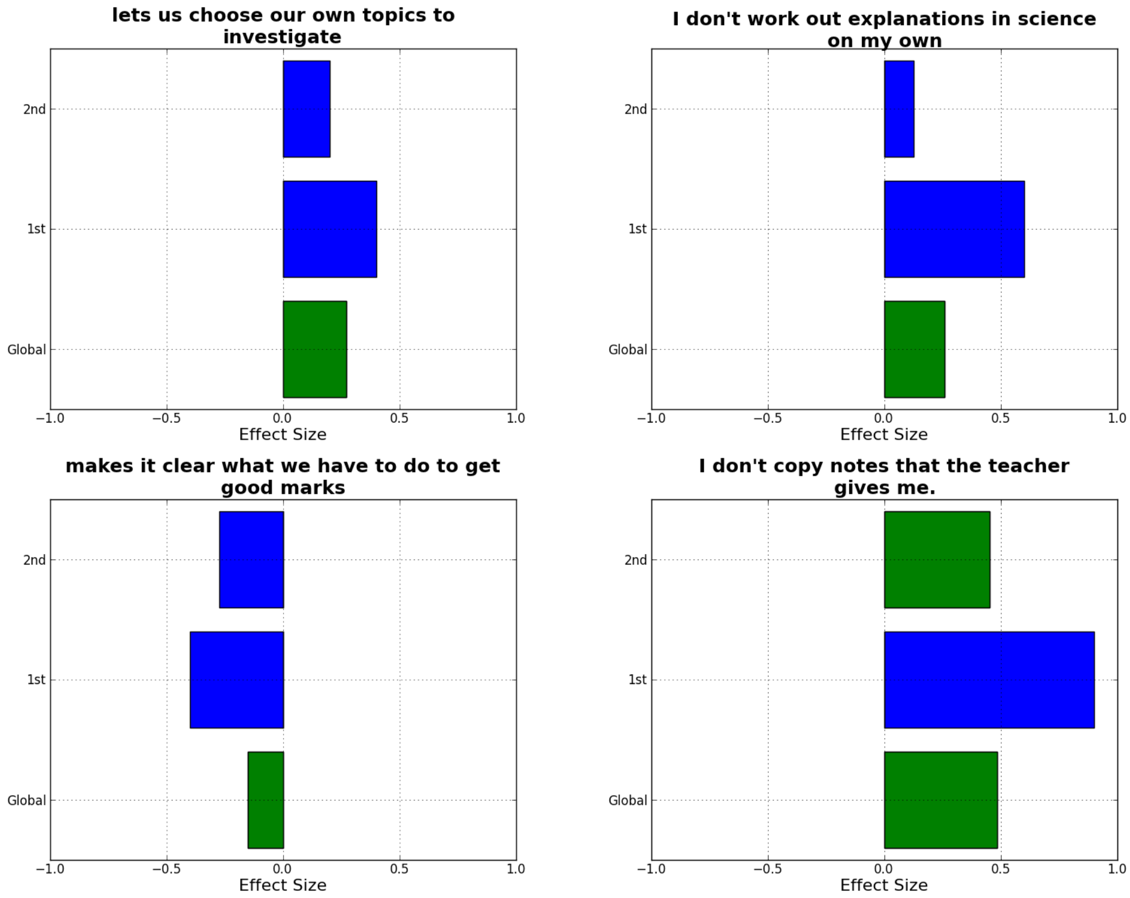


Figure 5: Global changes.

The students’ perception of experimental work also dramatically changed. They perceived there to be much less simple front-of-the-class demonstrations of experiments by the teacher. There was also much less simple cookbook instruction type experiments than the usual class as the project provides more guided or open-ended inquiry based exploration style practical experiences. Students also thought that school science was less about thinking and asking questions or understanding and explaining science ideas. This could be seen as ambiguous as to whether it is a positive or negative, although it also potentially indicates that the nature of the classroom is much more on active learning through direct interaction with phenomena rather than the more abstract “bookwork” that they perceive in their normal classroom.

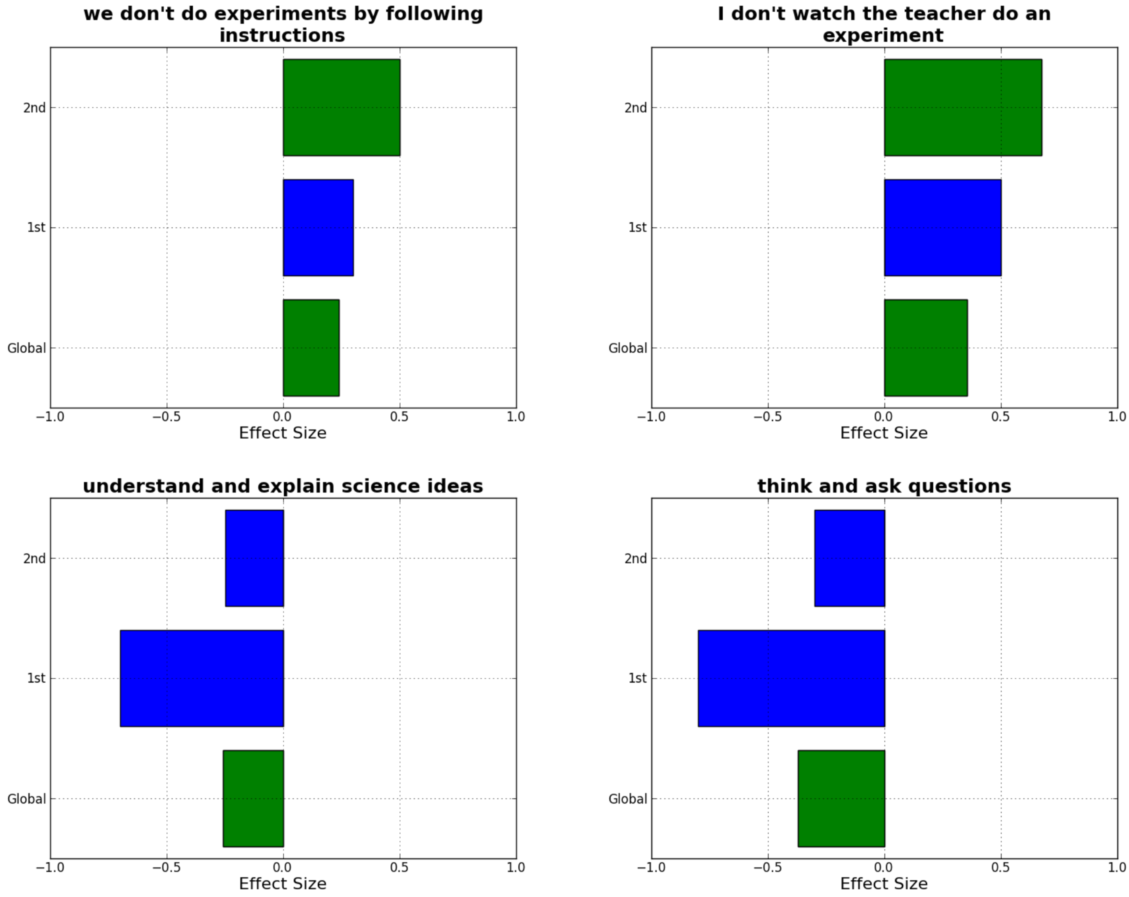


Figure 6: Global changes

There were also some interesting results when comparing teachers’ first time implementing with their second time implementing, shown in Figure 7. In the first implementation, there were perceived to be much fewer opportunities to explain their ideas or to work out explanations with friends as well as a perception of more difficult language on the part of the teacher than in their ordinary classes. By the second implementation these aspects had been largely remediated. Globally, the effect is slightly negative as in the population there would be many more teachers undertaking the project for the first time than for the second time.

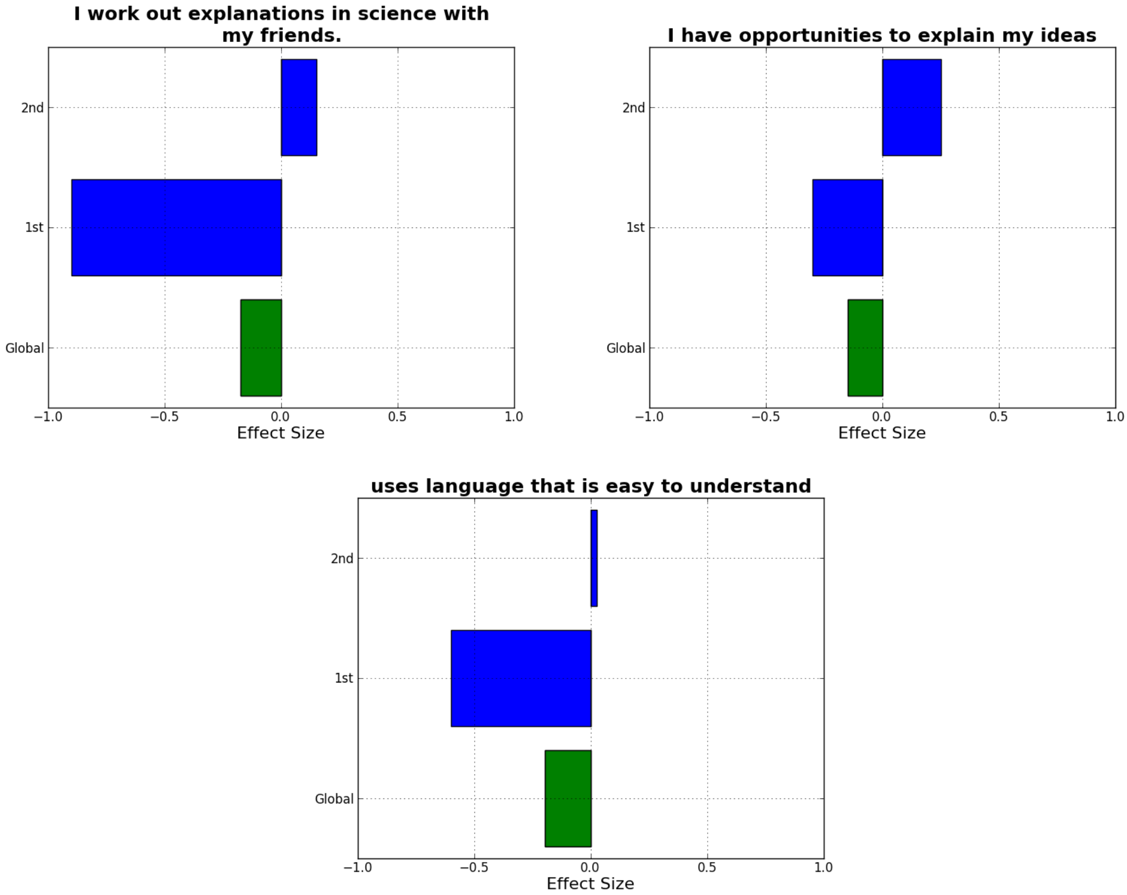


Figure 7 : Changes second time around.

Relatively negative impact was seen in items related to everyday life as shown in Figure 5. Students largely perceived the material covered as not being relevant to their future, not useful to their everyday life, did not help them understand environmental issues or make better decisions about their health. There was also no change in whether they felt that it more adequately dealt with things they were concerned about. This is not a surprising result given the content area. These questions were designed to tap into students’ perceptions of their entire classrooms. In the context of this project, the science examined was not only largely outside of the Earth, but outside the entire solar system. It has no relevance to health decisions and only very small links to environmental issues through the nature of the Sun as a star. The relevance to the students’ future item taps largely into their occupation intentions and hence it can be hard for students to see how it is relevant on a purely economic level. It is also true that in everyday life you need not know that the sun is going to become a red dwarf in 5 billion years.

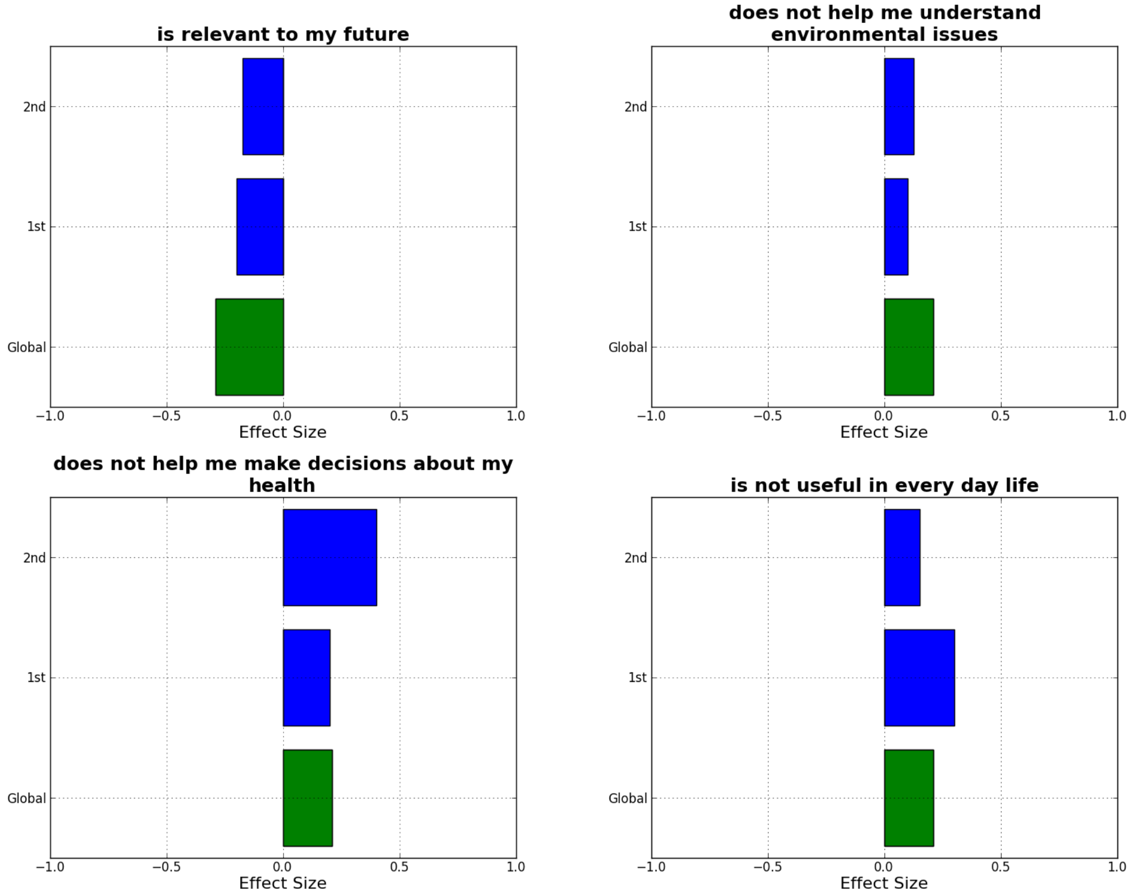


Figure 8: Relevance of Science to everyday life

In terms of computers, there was a lot more use of computers to do their science work as shown in Figure 9. This is largely as astronomy is very much now a computational science and interacting with the raw data is always done on a computer. There are no hands on stars. Students also spent more time looking for information on the internet during the intervention period.

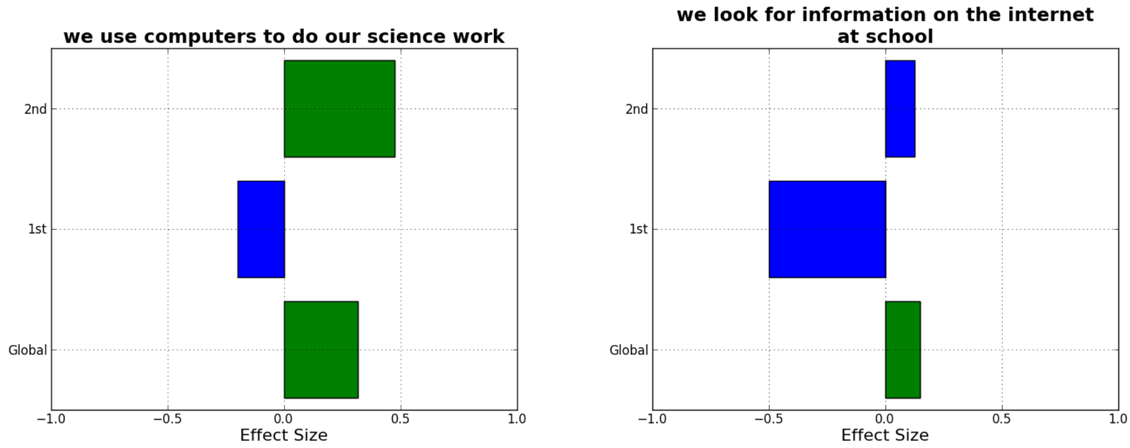


Figure 9: Computer work.

There were 22 items upon which change was largely not seen which can be divided into three broad groupings, those relating to the teacher, those relating to the in-class practice and those related to student affective opinions of science and school science.

There was little change on most items concerning the activities largely focused around the teacher. Students say little change in how often the teacher tells them how to improve their work, gives them quizzes to see they were going, talks to them about how they were getting on in science, taking notice of their ideas and showing them how new work relates to what they had already done.

The aspects of in-class practice that saw little change were the rates of reading a science textbook, planning and doing their own experiments, having class discussions, learning about scientists and what they do, doing their work in groups, investigating to see if their ideas are right and having enough time to think about what we are doing.

Students' opinions of science and school science were little changed. There were statistically significant, but minimal effect size changes, in their boredom levels (slightly higher), understanding of the science they did (slightly less), feeling that the science was too easy (marginally more) and enjoying science in general (marginally less). There was little change in the students getting excited about what they did or in their curiosity levels about the science they do. They did not find the project different in challenge level or difficulty and there was also little change in their enjoyment of the science they did at this school or in their class/project.

SUMMARY AND DISCUSSION

In this paper, we have explored the impact of a large-scale high school astronomy intervention project following an inquiry-based educational approach on students' content knowledge and perceptions of school science. We have found that globally, students' content knowledge gains as measured by a pre/post-test showed a moderate effect size (ES 0.368, $p < 0.0001$) gain. When the data was analysed with respect to individual teachers it was very apparent that while most teachers achieved similar moderate gains, some teachers vastly outperformed others while some showed negative gains. It was also apparent that the more often the teacher has implemented the materials, the more success is seen. Also, it was shown the further that the teacher moved through the provided materials, the larger the effect size gain.

In terms of student perception of their school science experience, we have found significant change in some respects and none in others. In particular, the students' perception of the way both experimental and ordinary work is done in the classroom is significantly different with much less teacher-led experiments and simple 'bookwork' with more use of computers and the internet. Students also saw the class as being less about abstract questioning and explaining ideas potentially indicating the class was more focused on active learning.

Students did overall think that the project was less relevant to their everyday life and concerns than their usual class. This is not unsurprising given the extraterrestrial content of the material. Student perceptions were unchanged on various other items as well. Their excitement, curiosity, challenge/difficulty levels of school science were unchanged. More disturbingly, their enjoyment of school science or science in general was not shifted or shifted slightly negatively.

Aspects of student perceptions that seemed to have more relation to the teacher's general demeanor were also little changed.

The positive results from this study are quite heartening in terms of changed practices in the classroom along the lines of the 'ideal' picture of school science as well as the clear content knowledge gains on behalf of the students. However, it is clear that the project has not shifted students' appreciation of school science or science in general. This may be that the project does not adequately address these issues in its design. This aspect will be further investigated in a qualitative manner and potentially lead to improvements if implemented. It may also be the case that a single intervention project on the order of a few class periods per week over the course of a limited amount of time during one school year may not have much large-scale impact when it might be considered a unique event in an otherwise commonly unexciting traditional school science classroom (Goodrum et al., 2001, 2007, 2012, Danaia et al. 2013). In combination with a variety of similar approaches for other content areas sustained over a relatively large period of time (for instance, a school term) that the changed classroom environment may have a chance to impact students' perceptions/attitudes.

In terms of the 'ideal' picture as portrayed by Goodrum et al. (2001) and when compared to the vision of a re-imagining of school science as portrayed by Tytler (2007), this model presents a step in the right direction. However, the actual implementation of this project in actual schools relied on a tightly focused attention towards eliminating particular blocking factors preventing large-scale roll-out (Fitzgerald et al. 2014c). While partially successful in this project, it cannot be understated that the capacity of implementing such an innovation into the ordinary school classroom in an ordinary school context within the ordinary school curriculum is highly problematic. The results from this study show that there is likely to be an improvement in content knowledge gains and in some areas of the students' experience of school science. Making this happen on a large-scale as mandated by the new Australian Curriculum will be a daunting, and unlikely, prospect without large-scale investment in sustained professional learning for teachers. Even more importantly, the students' perceptions as this is occurring must be monitored to make sure that such investments are actually having their desired effects.

REFERENCES

Ainley, J., Kos. J., Nicholas, M., (2008), "Participation in Science, Mathematics and Technology in Australian Education", Australian Center for Educational Research Research Monograph No. 63

Alfieri, L., Brooks, P.J., Aldrich, N.J., Tenenbaum, H.R., (2011), "Does Discovery-Based Instruction Enhance Learning?", Journal of Educational Psychology, 103:1, 1

Bailey, J., Johnson, B., Prather, E., Slater, T., (2011), "Development and Validation of the Star Properties Concept Inventory", International Journal of Science Education, 34, 14, 2257

Collaboration for Astronomy Education Research (CAER) (1999). Astronomy diagnostic test. Retrieved 20th May, 2009, from http://solar.physics.montana.edu.aae.adt/ modified for Southern Hemisphere 2002 by the University of Sydney, further modified 2004 by Charles Sturt University.

Danaia, L., (2006), "Student experiences, perceptions and performance in junior secondary school science: An intervention study involving astronomy and a robotic telescope", PhD Thesis, Charles Sturt University

Danaia, L., Fitzgerald, M., McKinnon, D., (2013), "Students' Perceptions of High School Science: What has Changed Over the Last Decade?", Research in Science Education, 43(4), 1501

Drury, C., & Allen, A. (2002). Task force on the physical sciences: report and recommendations. Departmentof Education and Science, Ireland.

Dunlop, J., (2000), "How Children Observe the Universe", Publications of the Astronomy Society of Australia, 17, 294

Etkina, E., Matilsky, T., Lawrence, M., (2003), "What can we learn from pushing to the edge? Rutgers Astrophysics Institute motivates talented high school students.", Journal of Research in Science Teaching, 40:10, 958

European Commission. 2007, Science Education Now: A Renewed Pedagogy for the Future of Europe, Brussels, Belgium: European Commission, Directorate General for Research.

Fitzgerald, M., Criss, J., Lukaszewicz, T., Frew, D.J., Catelan, M., Woodward, S., Danaia, L., McKinnon, D.H., (2012), “RR Lyrae Stars in the Globular Cluster NGC 6101”, Publications of the Astronomical Society of Australia.

Fitzgerald, M., Danaia, L., McKinnon, D., (2014a), “Inquiry-based educational design for large-scale high school astronomy projects using real telescopes.”, Journal of Science Education and Technology, Submitted

Fitzgerald, M.T., Inwood, L., McKinnon, D.H., Dias, W.S., Sacchi, M., Scott, B., Zolinski, M., Danaia, L., Edwards, R., (2014b), “Photometric and Proper Motion Study of Neglected Open Cluster NGC 2215”, Astronomical Journal, in review

Fitzgerald, M., Danaia, L., McKinnon, D., (2014c), “Blocking Factors Inhibiting Inquiry-based Science Teaching and Potential Solutions: Perceptions of Positively-inclined Early Adopter Science Teachers.”., International Journal of Science Education, Submitted

Goodrum, D., Hackling, M., Rennie, L., (2001), “The Status and Quality of Teaching and Learning Science in Australian Schools”, Department of Education, Traing and Youth Affairs. Canberra.

Goodrum, D., Druhan, A., Abbs, J., (2012), “The Status and Quality of Year 11 and 12 Science in Australian Schools”, Australian Academy of Science: Canberra

Herrington, D.G., Luxford, K., & Yezierski, E.J. (2012). Target inquiry: Helping teachers use a research experience to transform their teaching practices. Journal of Chemical Education, 89(4), 442-448.

Kirschner, P., Sweller, J., & Clark, R. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experimental and inquiry-based teaching. *Educational Psychologist, 40,* 75-86.

Lawrance, G. A., & Palmer, D. H. (2003). Clever teachers, clever sciences: preparing teachers for the challenge of teaching science, mathematics and technology in 21st century Australia. Canberra: Department of Education, Science and Training.

Lyons, T., & Quinn, F. (2010). Choosing science: understanding the declines in senior high school science enrolments. Research report to the Australian Science Teachers Association (ASTA). University of New England, Australia: National Centre of Science, ICT and Mathematics Education for Rural and Regional Australia (SiMERR Australia).

Millar, R., & Osborne, J. (1998). Beyond 2000: science education for the future (The report of a seminar series funded by the Nuffield Foundation). London: King's College London, School of Education.

Mayer, R. (2004). Should there be a three-strike rule against pure discovery learning? The case for guided methods of instruction. American Psychologist, 59, 14-19.

Osborne, J. and Dillon, J. 2008, Science Education in Europe: Critical Reflections, London: Nuffield Foundation.

Schroeder, C.M., Scott, T.P., Tolson, H., Huang, T-Y, Lee, Y-H, (2007), "A Meta-Analysis of National Research: Effects of Teaching Strategies on Student Achievement in Science in the United States", Journal of Research in Science Teaching, 44:10, 1436

Slater, S.J., Slater, T.F., & Bailey, J.M. (2010). *Discipline-Based Education Research: A Scientist's Guide.* New York: W.H. Freeman & Co.

Trundle, K.C., Atwood, R.K., Christopher, J.E. & Sackes, M. (2009). The effect of guided inquiry-based instruction on middle school students' understanding of lunar concepts. Research in Science Education, 40(3), 451-478.

Tytler, R., (2007), "Re-imagining science education: Engaging students in science for Australia's future." Camberwell, Victoria: Australian Council for Educational Research

CSIRO PUBLISHING

Publications of the Astronomical Society of Australia, 2012, **29**, 72–77
http://dx.doi.org/10.1071/AS11046

RR Lyrae Stars in the Globular Cluster NGC 6101

M. T. Fitzgerald[A,B,F], *J. Criss*[C], *T. Lukaszewicz*[C], *D. J. Frew*[A,B], *M. Catelan*[D], *S. Woodward*[C], *L. Danaia*[E], *and D. H. McKinnon*[E]

[A]Department of Physics & Astronomy, Macquarie University, NSW 2109, Australia
[B]Macquarie University Research Centre in Astronomy, Astrophysics & Astrophotonics, Macquarie University, NSW 2109, Australia
[C]Oakhill College, Castle Hill, NSW 2154, Australia
[D]Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica de Chile, Chile
[E]Charles Sturt University, Bathurst, NSW 2795, Australia
[F]Corresponding author. Email: mfitzasp@gmail.com

Abstract: V- and I-band observations were taken over 9 months to study the RR Lyrae population in the metal-poor diffuse globular cluster NGC 6101. We identify one new variable, which is either a potential long-period red giant variable or eclipsing binary, and recover all previously identified RR Lyraes. One previously studied RR Lyrae is reclassified as an RRc type, while two period estimations have been significantly refined. We confirm that NGC 6101 is Oosterhoff type II with a high ratio of $n(c)/n(ab+c) = 0.833$ with a very long mean RRab period of 0.86 d. By using theoretical RR Lyrae period-luminosity-metallicity relations, we use our V- and I-band RR Lyrae data to gain an independent estimate of the reddening towards this cluster of $E(B-V) = 0.15 \pm 0.04$ and derive a distance of 12.8 ± 0.8 kpc. The majority of the work in this study was undertaken by upper secondary school students involved in the Space to Grow astronomy education project in Australia.

Keywords: globular clusters: individual (NGC 6101) — RR Lyrae variable

Received 2011 September 12, accepted 2011 December 14, published online 2012 February 24

1 Introduction

RR Lyraes variable stars are important tools in determining the distances to globular clusters in our galaxy, as well as providing useful bounds on metallicity estimates. However, our knowledge of the RR Lyrae populations of quite a number of globular clusters is lacking (Clement 2001; Catelan et al. 2006). To add to this store of knowledge, the RR Lyraes within globular cluster NGC 6101 were chosen as our object of study in mid-2010. NGC 6101 is a metal-poor ([Fe/H] $= -1.98$; Harris 1996 (2010 Edition)) southern low central concentration globular cluster located at $\alpha = 16\,\mathrm{h}\,25\,\mathrm{m}\,48\,\mathrm{s}$ $\delta = -72°12'07''$. Prior to this latest metallicity estimate, values for [Fe/H] ≈ 1.8 were more typical (Sarajedini et al. 1991, Geisler et al. 1995, Harris 1996, Rutledge et al. 1997, Rosenberg et al. 2000, Sarajedini et al. 2007, Dotter et al. 2010), while there is also a study that suggests that [Fe/H] may be ≈ 2.1 (Kraft & Ivans 2003). This cluster had previously only been studied via photographic plates (Alcaino 1974; Liller 1981), where 10 RR Lyraes were identified, but their periods were not determined, and their mean magnitudes could only be roughly estimated.

During the course of our observations, however, another CCD study of the RR Lyrae population in NGC 6101 was published by Cohen (Cohen et al. 2011). In this paper we build on Cohen's study by adding a newly identified potential small-amplitude red variable (SARV) or eclipsing binary as well as updating the periods and reclassifying two RR Lyrae variables. We also provide a longer timebase (≈ 9 months, vs. 5 days) and more staggered light-curve data as well as providing additional I-band observations to provide an independent estimate of the reddening and extinction towards this cluster together with a new estimate of the distance. As our study follows fairly closely after the Cohen et al. (2011) study and there have been no intervening publications on this cluster, we wish to avoid needless repetition. Consequently, we refer the reader to Cohen et al. (2011) for a more detailed literature review on this cluster. The majority of the work within this study was undertaken by Year 11 high school students in Sydney, New South Wales, Australia as part of a large-scale astronomy education initiative, Space to Grow, which is also briefly described.

2 Observations

V- and I-band observations of cluster NGC 6101 were taken over 31 nights between June 2010 and April 2011 using the Merope CCD camera attached to the robotically controlled 2-metre Faulkes Telescope South at Siding Spring Observatory, NSW, Australia. The pixel scale of the camera was $0.2785''$/pixel in 2×2 binning mode with a 4.7×4.7 arcminute square field of view. As the cluster

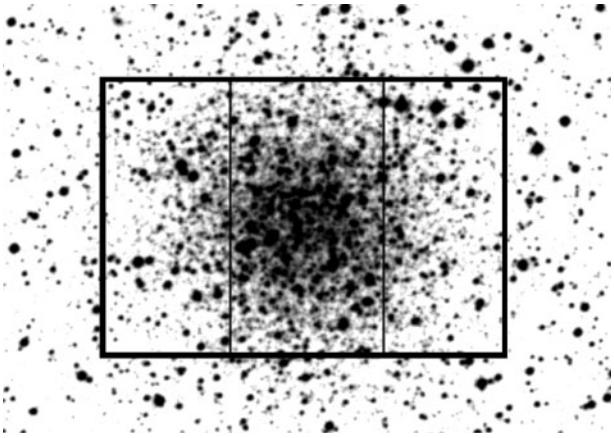


Figure 1 Image of NGC 6101 area from DSS (Red) with overlay showing typical observation field of view (6.75 × 4.7 arcminutes). NE is at top left.

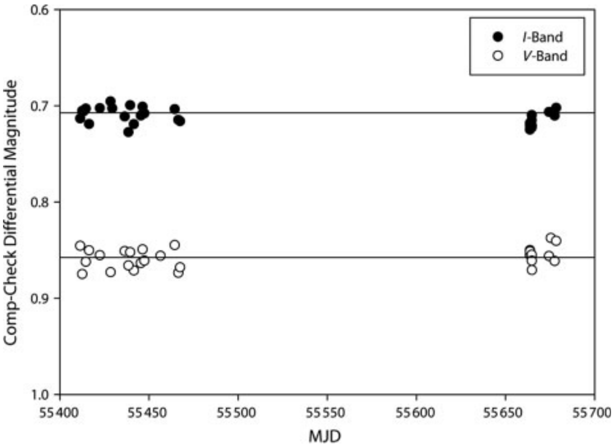


Figure 2 Comparison versus check-star magnitudes showing stability (RMS ≈ 0.01 mags) between observations.

itself is larger than this field of view, twso images per observation per filter were taken with a significant central overlap to also help eliminate a column defect in the camera (see Figure 1). The typical seeing in these images was ≈1.5 arcseconds. Bias and flat-field frames were taken and the science frames reduced at the telescope automatically prior to delivery to the observer. Observations of Landolt standard stars Mark A 1, 2, 3 and SR109-71 (Landolt 1992) were used to calibrate the images to the standard Johnson–Cousins system, for which a photometric solution with an RMS of 0.01 mag was achieved.

3 Discussion

3.1 *Aperture Photometry*

Observations of NGC 6101 were taken in the V and I bands by the Faulkes Telescope South over two main seasons: one over August and September 2010 and a further season to help refine the periods in April 2011. Aperture photometry using a 2.8 arcsecond–radius aperture was performed through Makali'i software for all measured stars, with the sky estimated from representative patches of dark sky from the largely star-free edges of the images. While point spread function (PSF) photometry would have been preferred, we were limited to our choice of methodology due to reasons outlined in Section 4. However, due to the quite diffuse nature of this globular cluster, aperture photometry performed well. The stability of the comparison star over all observations was found by comparison to a check star, which was found to be ≈0.01 mags RMS in both bands (shown in Figure 2). The comparison star used was found to have an apparent magnitude of $V = 14.65 \pm 0.01$ and $I = 13.34 \pm 0.01$ from the photometric solution. V- and I-band magnitudes measured for each RR Lyrae are provided as online supplementary material.

Other variables in the field of view were found by using the Find Variables function within Muniwin, a simple Windows-based automated aperture photometry variable star package. The 10 original RR Lyraes from Liller (1981) and one RR Lyrae later discovered by Cohen et al. (2011) were independently recovered using this method as well as one new variable. The new variable is probably a small-amplitude long-period variable or eclipsing binary (V23: RA 16:26:01.62, Dec –72:12:29.78) (see Section 3.4). We have continued using the naming convention set by Liller (1981) and continued by Cohen et al. (2011). A finder chart for those stars available in our field of view is given in Figure 3. Differential aperture photometry with respect to the comparison star was used to determine the apparent magnitudes for each variable star in both I and V. An ANOVA period-finding method within the Peranso software was used to find the most likely periods of each of the RR Lyraes.

3.2 *RR Lyrae Properties*

Our measured RR Lyrae properties are provided in Table 1, while their light curves are presented in Figure 5. We compare our RR Lyrae properties with those of Cohen et al. (2011). The amplitudes of the RR Lyrae light curves in this study are slightly, but insignificantly (0.02 ± 0.08 mags) larger than in Cohen et al. (2011). Most periods are comparable to 0.005 of a day or less, apart from two notable exceptions: V5 (this paper: 0.4259 d; Cohen: 0.7420 d) and V6 (0.3462 d; 0.5230 d). The data for V5 and V6 folded on the Cohen (2011) period estimates do not provide a believable light curve from our data, while our own period estimates in both cases provide very tight light curves. It is also the case that from visual inspection of Figure 4 from the Cohen et al. (2011) paper that these two stars, especially V5, are the 'worst' fitting of all their RR Lyrae templates and are also flagged as the RRab/c classification as being 'uncertain'. Running the same ANOVA period-finding method using observational RR Lyrae data from Cohen et al. (2011) finds the likely periods to be less than 0.003 d different from our findings. It is probable that our longer time baseline (≈9 months) and more staggered and random phase coverage provides a better dataset to determine periods accurately, without

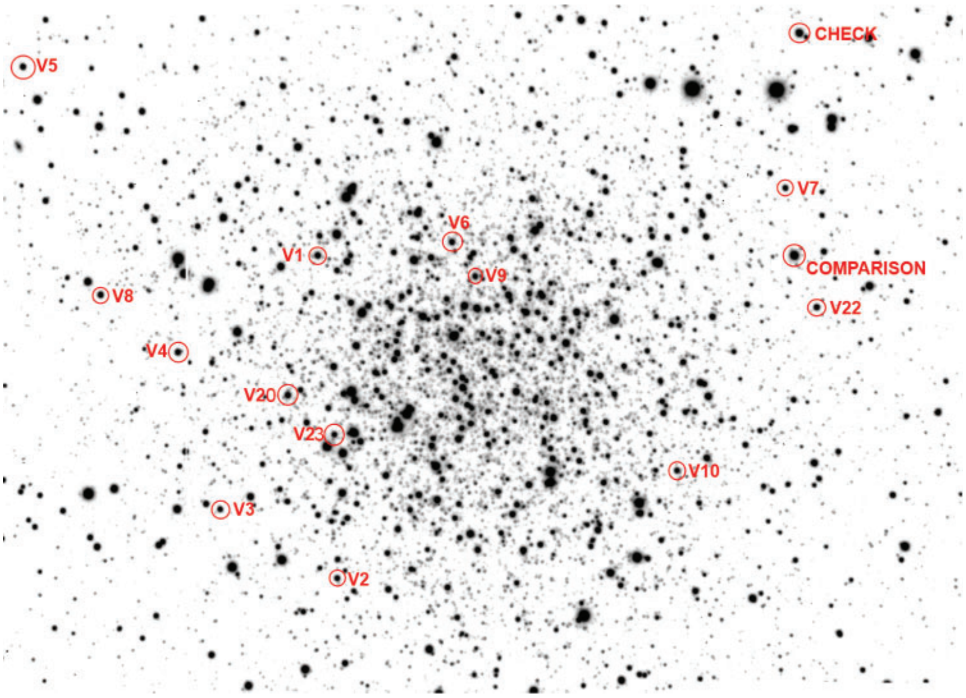


Figure 3 Finder chart constructed from V-band images used in this study. NE is at top left.

Table 1. RR Lyrae properties

ID	Period (days)	m_v^{a} (mag)	$(V-I)^{\text{b}}$ (mag)	Type$^{\text{c}}$ (mag)	A_v
V1	0.4583	16.26	0.58	RRc/1	0.44
V2	0.4116	16.44	0.38	RRc/1	0.62
V3	0.7545	16.51	0.56	RRab/0	0.82
V4	0.3490	16.49	0.32	RRc/1	0.52
V5	0.4259	16.54	0.59	RRc/1	0.44
V6	0.3462	16.35	0.54	RRc/1	0.44
V7	0.4101	16.46	0.57	RRc/1	0.48
V8	0.4152	16.51	0.44	RRc/1	0.56
V9	0.3402	16.16	0.55	RRc/1	0.38
V10	0.3486	16.36	0.38	RRc/1	0.52
V20	0.9144	16.22	0.56	RRab/0	0.40
V22	0.3191	16.42	0.45	RRc/1	0.12

[a] $m_v = (m_{\text{min}} + m_{\text{max}})/2$.
[b] $m_v - m_i$ where m_i is defined similarly to m_v.
[c] Classification schema of Bailey (1902)/more recent classification defined by Alcock et al. (2000).

assumption, than the short time baseline (≈ 5 days) of Cohen et al. (2011), despite the lower precision of our photometry. There is no question that the profile-fitting method in Cohen et al. (2011) would be the superior method, but only if the data has relatively complete coverage over phase. It is also noted that V1 has a unusually high period for an RRc type RR Lyrae of 0.4583 d. From visual inspection as well as multiple numerical period finding methods using data from this paper and Cohen et al. (2011), both datasets separately present an equally likely period at 0.3141 d. However, by combining both available sets of data, after correcting for differences in mean magnitude, the period of 0.4583 d is by far the most likely from both visual and numerical methods.

Our mean V magnitudes are on average 0.056 mags brighter than those of Cohen et al. (2011), which may plausibly be due to leakage of light from other stars into our measurements due to the aperture photometry method used compared to their point-spread function method. We were limited to using aperture photometry due to the nature of this study, which is outlined in more detail in Section 4. This is, however, a relatively small systematic deviation and could also be just as easily explained by a combination of other factors such as differences in standard star calibrations or sky background estimates between the two studies, among other issues, as the RR Lyraes in this relatively diffuse globular cluster, apart from V9, are significantly separated from other surrounding stars.

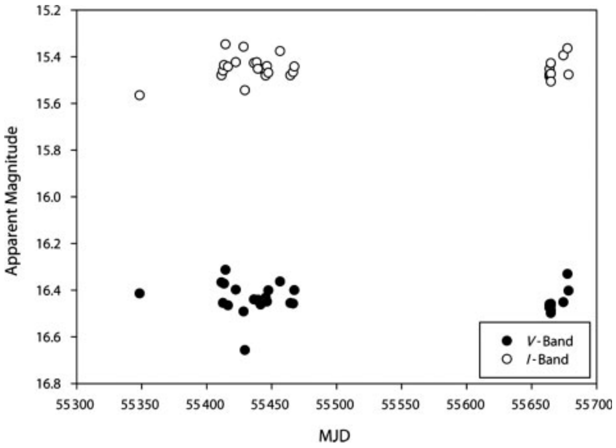


Figure 4 *V*- and *I*-band apparent magnitude of V23 over entire observing season. The points on the graph are approximately the size of the standard deviation of the comp-check magnitudes.

On the basis of the difference in period and also the obvious sinusoidal shape of the light curve, we reclassify V5 as an RRc type, while V6 retains its original RRc classification, although its period is now more aligned with the RRc average in this cluster. Combining our updated and new data with the previous Cohen et al. (2011) data, we confirm that the *P*ab stars have unusually long periods, in this case, $\langle P\text{ab}\rangle = 0.86$ d, while $\langle P\text{c}\rangle = 0.383$, as well as confirming the classification of Oosterhoff type II with a high ratio of $n(c)/n(ab+c) = 0.833$.

3.3 Interstellar Reddening, Extinction and Distance

Apart from V9, which was determined to have significant light contamination from nearby stars, all the other variables were acceptably free from contamination. Theoretical RR Lyrae period-luminosity-metallicity relations (Catelan et al. 2004) were fitted to the *V* and *I* band data by introducing a constant representing the apparent magnitude, *m*, using a manual least squares minimization method.

$$M_v = 1.455 + 0.277\ \log Z$$
$$M_i = 0.4711 - 1.1318\ \log P + 0.2053\ \log Z$$

Z was derived from the [Fe/H] = −1.98 from Harris (1996 (2010 edition)). From these fits, $(m-M)_v = 15.997 \pm 0.032$ and $(m-M)_i = 15.808 \pm 0.044$ were determined, where the errors were determined from the rms standard error of the fit. This provides a colour excess of $E(V-I) = 0.189$, implying an $E(B-V) = 0.15 \pm 0.04$, and an A_v of 0.47 ± 0.13 mags assuming a standard reddening law with $R = 3.1$. This compares well with the most recent estimates of $E(B-V) = 0.11 \pm 0.02$ (Schelgel et al. 1998), $E(B-V) = 0.09 \pm 0.01$ (Cohen et al. 2011) and the less certain $E(B-V) = 0.06 \pm 0.02$ (Sarajendi & De Costa 1991) and $E(B-V) = 0.1$ (Marconi et al. 2001). This leads to a distance estimate to NGC 6101 of $(m-M)_v = 16.00 \pm 0.03$, $(m-M-A_v) = 15.53 \pm 0.14$ or 12.8 ± 0.8 kpc which compares reasonably with the Cohen et al. (2011) estimation of $(m-M) = 16.00 \pm 0.03$, as well as $(m-M) = 16.07 \pm 0.1$ from Harris (1996).

3.4 New Variable, V23

The other new variable identified, V23, is of inconclusive type. Both ANOVA and phase-dispersion minimization methods did not find any plausible periodicity. Its variability, rms of 0.07 mags in *V*, as shown in Figure 4, is significantly higher than the comp-check rms stability of 0.01 mags. Its mean de-reddened $(V-I)$ colour of 0.95 and similar magnitude of 16.48 to the RR Lyraes, places it quite firmly on the RGB implying that it might be a long-period, small-amplitude red variable, although it is not positioned at its expected location near the tip of the RGB, or potentially an eclipsing binary considering the inability to find any periodicity over our 9-month time base.

4 Educational Aspects

This research was carried out within the scope of the educational Space to Grow project, an Australian Research Council Linkage Grant funded over three years. The project is supported by four industry partners. These include the Catholic Schools Offices of Bathurst and Parramatta (27 schools), the NSW Department of Education Western Region (11 schools) and the Las Cumbres Observatory Global Telescope network. A major aim of this project is to use astronomy as a vehicle to engage students in real science at school. In particular, students and teachers are provided with the opportunity to obtain and use real scientific data from the two 2-metre Faulkes Telescopes run by LCOGT.net. It is intended that the science that is done in class becomes publishable in the mainstream astronomical literature, which is evidenced by our previous publication involving high-school students on a little-studied planetary nebula (Frew et al. 2011) The Space to Grow Project also encompasses an educational research and development component designed to investigate the impact of the approaches adopted on students and teachers. Preliminary results obtained from the educational research reveal that students are engaged and excited by this approach to open inquiry in astronomy research.

Most of the measurement and interpretation work on NGC 6101 was carried out by two Year 11 students (JC and TL) as an independent research project for assessment led by MF and supervised by their teacher SW. The only parts of this paper that were not significantly undertaken by the students were the initial acquisition and reduction of data from the telescopes, the determination of RRa/bc Lyrae types, the Oosterhoff classification, the discussion of V23 and the final writing of the paper. The initial first draft of this paper was also constructed by the students. The draft was later condensed and moulded into the more formal scientific structure required.

The high school context was also the source of the limitation of only using aperture photometry on the cluster. There is no adequate free solution to perform optimal/PSF photometry within a Windows or Mac environment. While this approach worked well for this relatively diffuse globular cluster, we intend to get future students to work on other denser globular clusters. This will require the development of a free cross-platform optimal/PSF photometry package capable of being run on computers normally found in schools and which suffer from being ‘tightly tied down’ by IT administrators. These issues are currently being worked on.

5 Conclusion

In this paper we have observed the globular cluster NGC 6101 over a period of ≈9 months to adequately survey the RR Lyrae population in this cluster. Our data

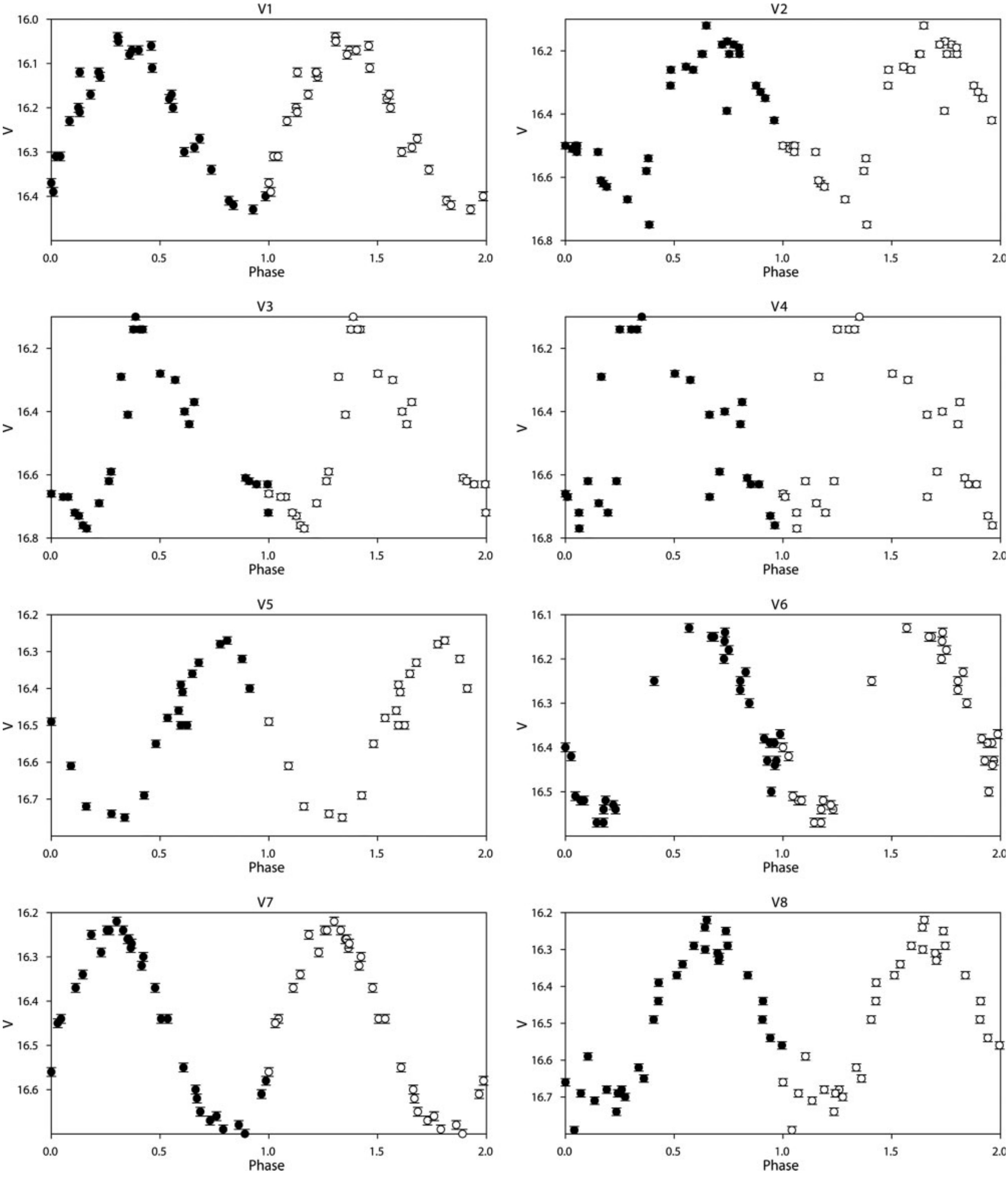


Figure 5 Light curves of observed RR Lyraes phase-plotted over two cycles on most likely period.

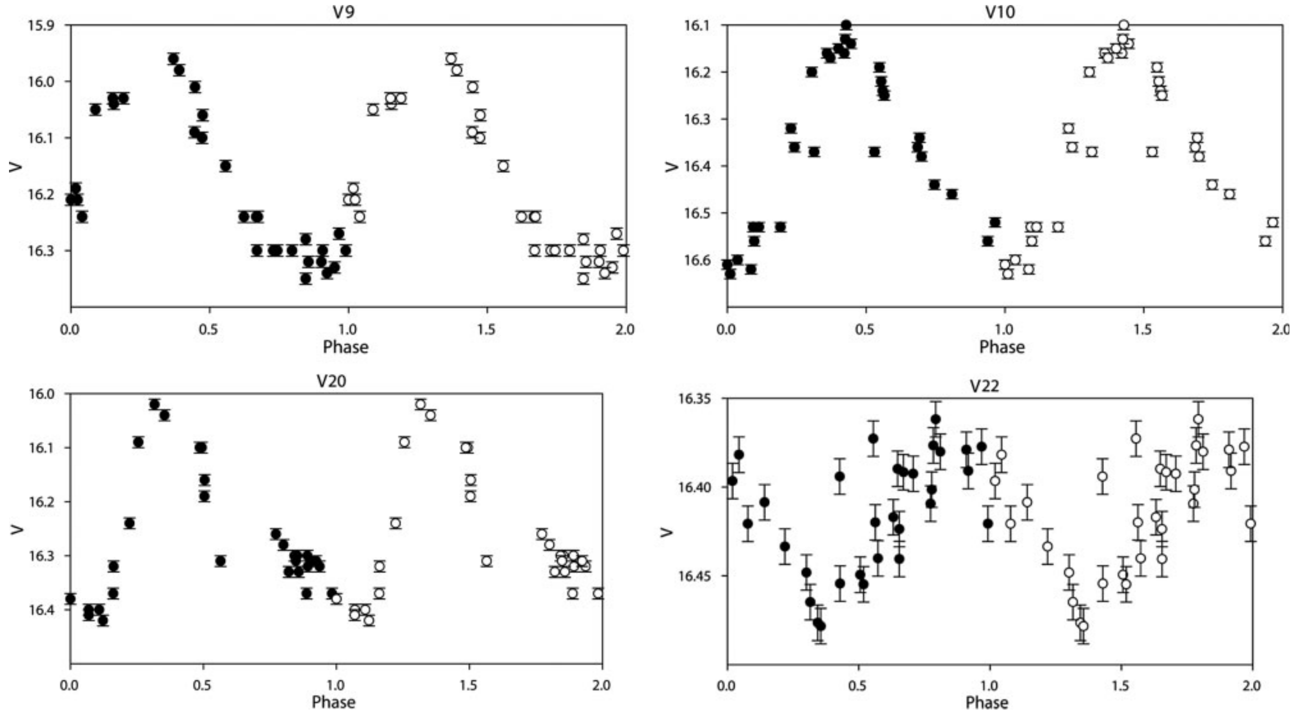


Figure 5 (*Continued*)

compliments and updates the study of Cohen et al. (2011), reclassifying one RR Lyrae and updating the periods of two RR Lyraes. We have also identified one new variable, potentially a small-amplitude semi-regular or irregular variable or eclipsing binary. As well as this we have arrived at an independent estimate of the reddening, $E(B-V)=0.15\pm0.04$, and distance, $(m-M)_v=16\pm0.03$, $(m-M-A_v)=15.53\pm0.14$ or 12.8 ± 0.8 kpc. The majority of the work in this project was undertaken by upper secondary school students involved in the Space to Grow astronomy education project in Australia.

Acknowledgments

MF acknowledges receipt of MQRES PhD scholarship from Macquarie University. Appreciation is given to the freely available software used in this project: Subaru Image Processor Makali'i (`http://makalii.mtk.nao.ac.jp/`) and Munwin (`http://c-munipack.sourceforge.net/`) as well as the non-free Peranso period-finding software (`http://www.peranso.com/`).

References

Alcaino, G., 1974, A&AS, 18, 9
Alcock, C., et al., 2000, AJ, 542, 257
Bailey, S. I., 1902, AnHar, 38, 1
Catelan, M., Pritzl, B. J. & Smith, H. A., 2004, ApJS, 154, 633
Catelan, M., et al., 2006, MmSAI, 77, 202
Clement, C. M., et al., 2001, AJ, 122, 2587
Cohen, R. E., Sarajedini, A., Kinemuchi, K. & Leiton, R., 2011, AJ, 727, 1
Dotter, A., et al., 2010, AJ, 708, 698
Frew, D. J., et al., 2011, PASA, 28, 83
Geisler, D., Piatti, A. E., Claria, J. J. & Minniti, D., 1995, AJ, 109, 605
Harris, W. E., 1996, AJ, 112, 1487
Kraft, R. P. & Ivans, I. I., 2003, PASP, 115, 143
Landolt, A. U., 1992, AJ, 104, 340
Liller, M. H., 1981, AJ, 86, 1204
Rosenberg, A., Piotto, G., Saviane, I. & Aparicio, A., 2000, A&AS, 144, 5
Rutledge, G. A., Hesser, J. E., Stetson, P. B., Mateo, M., Simard, L., Bolte, M., Friel, E. D. & Copin, Y., 1997, PASP, 109, 883
Sarajedini, A. & Da Costa, G. S., 1991, AJ, 102, 628
Sarajedini, A., et al., 2007, AJ, 133, 1658

The Astronomical Journal
Preprint typeset using LaTeX style emulateapj v. 11/10/09
S

PHOTOMETRIC AND PROPER MOTION STUDY OF NEGLECTED OPEN CLUSTER NGC 2215

M.T. Fitzgerald[1,2], L. Inwood [3], D.H. McKinnon[2], W. S. Dias[5,6], M. Sacchi[4],
B. Scott[7],M. Zolinski[7], L. Danaia[4], R. Edwards[7]
The Astronomical Journal

ABSTRACT

Optical UBVRI photometric measurements using the Faulkes Telescope North were taken in early 2011 and combined with 2MASS JHK$_s$ and WISE infrared photometry as well as UCAC4 proper motion data in order to estimate the main parameters of the galactic open cluster NGC 2215 of which large uncertainty exists in the current literature. Fitting a King model we estimate a core radius of $1.12'\pm0.04'$ (0.24±0.01pc) and a limiting radius of $4.3'\pm0.5'$ (0.94±0.11pc) for the cluster. The results of isochrone fits indicates an age of $log(t) = 8.85 \pm 0.10$ with a distance of $d = 790 \pm 90$pc, a metallicity of $[Fe/H] = -0.40 \pm 0.10$ dex and a reddening of $E(B-V) = 0.26 \pm 0.04$. A proportion of the work in this study was undertaken by Australian and Canadian upper secondary school students involved in the Space to Grow astronomy education project, and is the first scientific publication to have utilized our star cluster photometry curriculum materials.

Subject headings: Methods: observational — open clusters and associations : general — open clusters and associations : individual (NGC 2215) — Techniques: photometric

1. INTRODUCTION

Open clusters have been used both for studies of stellar evolution and for dynamics and evolution of the Galactic disk. Compilations of fundamental parameters of these objects can be found in the catalogues of Dias et al. (2002a) and WEBDA (Mermilliod 1988). However, of the 2174 open clusters cataloged only ≈400 clusters have been investigated with modern high quality CCD observations (Netopil et al. 2010), thus indicating the need in many cases to make further observations and analyses that allow a deeper, more precise and complete picture of stellar clusters within the Galaxy. This is especially true for NGC 2215, which is located in the third quadrant, a region that needs the largest number of results to improve the characterization of the Galaxy.

The open cluster NGC 2215 has a variety of diverging estimates for its distance, age, reddening and diameter over the last five decades with no previous metallicity estimates. These are outlined in Table 1. The first known study of open cluster NGC 2215 (Right Ascension $06^h20^m54^s$, Declination $-07^\circ17'\ 42''$,J2000.0 and galactic latitude 216.01417°, galactic longitude -10.0896°) was published by Becker (1960) using data collected from photographic plates to produce the first color-magnitude diagram (CMD) containing 33 stars down to $V \approx$15.5 with d = 995pc, $E(B-V)$ = 0.10 and 2.9pc (10′) in diameter.

TABLE 1
Previously Estimated Parameters for NGC 2215.
If later estimates appear to be quoted from earlier studies, these estimates have been left blank.

Reference	D (pc)	$E(B-V)$ mag	Age log(t)	Diam (′)
Becker (1960)	995	0.1		
Becker & Feinhart (1971)	1932	0.33		18.8
Maitzen et al. (1981)		0.244	7.6	
Pandey et al. (1989)			8.55	
Frandsen & Arentoft (1998)	980	0.31	8.8	
Kharchenko et al. (2005)	1298	0.3	8.43	33.6
Loktin et al. (2001)	1293	0.300	8.369	7
Bukowiecki et al. (2011)	1265	0.37	8.45	8.8

Few photometric follow up studies to the original conducted by Becker (1960) are reported. One is indicated in Becker & Fenkart (1971) as a personal communication although no actual paper has been able to be found. Their parameters were d = 1225pc, $E(B-V)$ = 0.33 and a size of 3.6pc (10.1′). Maitzen et al. (1981) report the Becker (1960) distance but report $E(B-V)$ = 0.244 using more sensitive Strömgren (1966) photometry. They also estimate $log(t)$ = 7.6 from the (B-V) turnoff attributed to Cannon (1970) who cites Becker (1960) as the original source.

Later papers report discordant ages, distances and reddening. Pandey et al. (1989) reports $log(t)$ = 8.55. Perez (1991) lists in his Table 1 data attributed to Becker & Fenkart (1971) d = 1225pc and $E(B-V)$ = 0.33. Becker & Fenkart (1971), however, report the distance as 1932pc and a diameter of 10pc (17.8′). Frandsen & Arentoft (1998) report $log(t)$ = 8.8, d = 980pc and an $E(B-V)$ = 0.31.

The Catalogue of Open Cluster Data (Kharchenko 2005) lists the data derived from ASCC-2.5 (Kharchenko et al. 2001) to this cluster as: ($E(B-V)$ = 0.30, $(m-M)$ = 10.55 (1293pc), $log(t)$ = 8.43 and diameter of the cluster of 6pc (16.8′), from only a small number (12) of brighter stars. Similarly, the data recorded in the

---

[1] Department of Physics & Astronomy, Macquarie University, Sydney, Australia
[2] Edith Cowan University, Joondalup, WA, Australia
[3] Denison College, Bathurst Campus, Australia
[4] Charles Sturt University, Bathurst, Australia
[5] UNIFEI, Instituto de Física e Qímica, Universidade Federal de Itajubá, MG, Brazil
[6] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Cidade Universitária,
[7] West Kildonan Collegiate, Winnipeg, Manitoba, Canada

FIG. 1.— BVR Color Image made from images used in this study. North is up, East is left. The field is roughly $9' \times 9'$.

Dias et al. (2002a) catalogue of open clusters reports similar parameters, taken from Loktin et al. (2001) but with a visual estimate of the angular diameter of ($7'$), initially from Lynga (1987). A recent 2MASS IR study (Bukowiecki et al. 2011) estimates $d = 1265pc$, $E(B-V) = 0.37$, $log(t) = 8.45$ and a diameter of $8.8'$. These parameters appear to be inconsistent with those referred above. Thus, this paper attempts to clarify the disparate parameters attributed to this cluster.

2. OBSERVATIONS

UBVRI observations of open cluster NGC 2215 were taken on January 27th 2011 using the Merope CCD Camera attached to the robotically controlled 2-metre Faulkes Telescope North at Haleakala, Hawaii. The pixel scale of the camera was $0.2785''/pixel$ in 2×2 binning mode with a $4.7' \times 4.7'$ field of view. As the cluster itself was assumed to be larger than this field of view, five separate overlapping fields were taken with 3-5 short exposures per filter (U=200s, B=60s,V=40s,R=25s and I=15s) and 3 additional longer exposures (B=400s, V=300s, I=75s) of the central $4.7' \times 4.7'$. Bias and flat-field frames were taken and the science frames reduced at the telescope automatically prior to delivery to the observer. These images then had cosmic rays and bad pixels detected and removed using STARLINK (Disney & Wallace 1982) internal routines as well as the L.A.Cosmic algorithm (Dokkum 2001). An accurate WCS in the ICRS for each image was obtained using astrometry.net software (Lang et al. 2010). A BVR mosaic of the full field of view is shown in Figure 1. The typical seeing in all of these images was $\approx 1.2''$.

Multiple observations of the SA98, RU149 and PG0918 Landolt standard fields (Landolt 1992, 2009, Clem & Landolt 2013) surrounding the main observations were used to calibrate the images to the standard Johnson system using an ordinary linear squares regression fit. The calibration equations used are of the form:

TABLE 2
COEFFICIENTS OF THE CALIBRATION EQUATIONS.

Zeropoint	Extinction	Color Term	*rms*
$u_1 = 22.119(43)$	$u_2 = -0.429(39)$	$u_3 = -0.006(03)$	0.011
$b_1 = 23.565(32)$	$b_2 = -0.190(29)$	$b_3 = +0.046(03)$	0.013
$v_1 = 23.490(25)$	$v_2 = -0.114(22)$	$v_3 = -0.084(02)$	0.010
$r_1 = 23.391(42)$	$r_2 = -0.051(37)$	$r_3 = -0.063(02)$	0.013
$i_1 = 23.370(54)$	$i_2 = -0.023(47)$	$i_3 = +0.064(01)$	0.018

$$U = u + u_1 + u_2 X + u_3(U - B) \quad (1)$$

$$B = b + b_1 + b_2 X + b_3(B - V) \quad (2)$$

$$V = v + v_1 + v_2 X + v_3(B - V) \quad (3)$$

$$R = r + r_1 + r_2 X + r_3(V - R) \quad (4)$$

$$I = i + i_1 + i_2 X + i_3(V - I) \quad (5)$$

where upper case letters represent the magnitudes and colors in the standard system and lower case letters were adopted for the instrumental magnitudes and X is the airmass. Observations made were only kept if there was a corresponding observation in a filter that facilitated a color correction. The range of airmass was quite short (≈1.0 to ≈1.2) and the range of colors spanned from (B-V)≈0 to ≈2.0. The multiple observations of the cluster itself are in the range of airmass 1.13 to 1.17.

The coefficient values are reported in Table 2, where the numbers in brackets refer to the error in the last figures of the provided coefficient. Figure 2 shows the differences between our observed photometry and the Clem & Landolt (2013) catalogue values for, on average, 48 observations per filter. A photometric solution with *rms* of ≈0.01 mags in UBVR and ≈0.02 in I were achieved. It is particularly notable that the U band has an uncommonly low color term. From four other observing nights using the same observational setup, the mean U band color term has been estimated to be -0.033 ± 0.012 and the BVRI color terms are also similarly comparable to those obtained on this night.

3. OBSERVATIONAL PARAMETERS, MEASUREMENTS AND RESULTS

All astrometric and photometric measurements made in this study as well as proper motion data obtained from UCAC4 (Zacharias et al. 2013) and photometric data from 2MASS (Skrutskie et al. 2006) and WISE (Wright et al. 2010) are given in an online data file, with the format as shown in Table 3 contained within the Appendix.

3.1. *Photometry*

Photometry of our images was undertaken via aperture photometry using Aperture Photometry Tool (APT) (Laher et al. (2012)). Aperture photometry using a 4 pixel radius (r≈FWHM) aperture was performed using APT with aperture corrections for all measured stars. The sky was estimated for each star using the mode value per pixel for the local area of the image.

As there were multiple images taken of multiple overlapping fields, the number of measurements per star per filter range from 1 to 13 depending on their position in

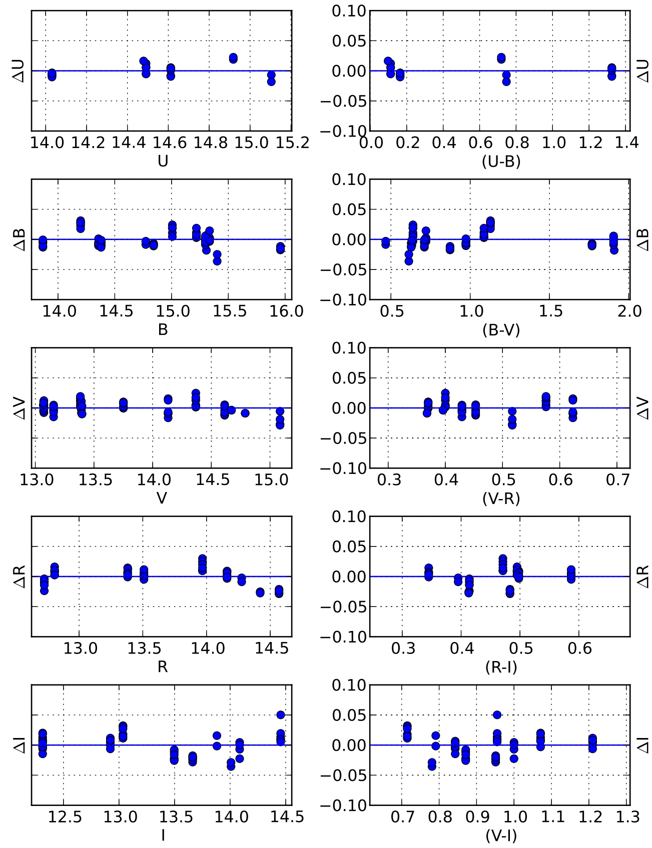


FIG. 2.— Residuals of the fit to the standard stars for the night. The *rms* residuals of the transformations to the standard system are: ΔU = 0.011; ΔB = 0.013; ΔV = 0.010; ΔR = 0.013; ΔI = 0.018.

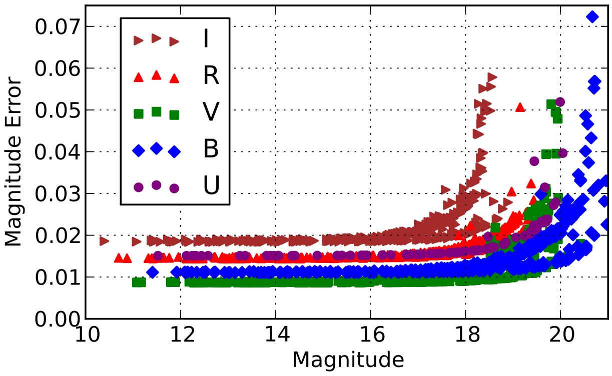


FIG. 3.— Estimated photometric errors in the standard system in aperture photometry.

the field. These measurements were corrected for airmass and zeropoint then averaged together using the inverse of their estimated photometric error as weights to accommodate the different possible exposure times. This weighted mean magnitude corrected for airmass and zeropoint terms was then corrected for the color term.

Our instrumental photometric errors were combined with the errors propagated from the coefficients in the standard solution. The final errors are presented in Figure 3.

3.2. *Comparison to Previous Photometry*

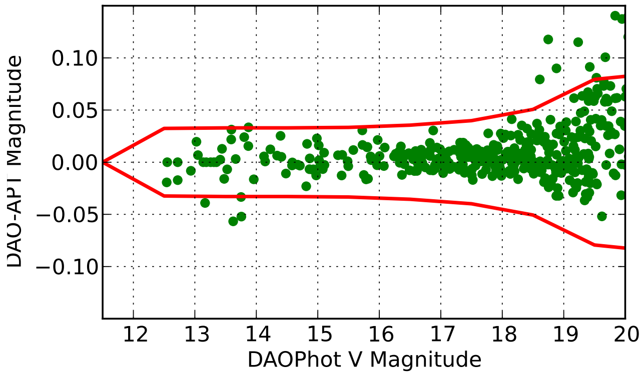


FIG. 4.— Comparison between results from DAOPhot PSF and APT aperture photometry (APT). Dots are data points, line represents the 3σ combined estimated total photometric error.

As this is the first scientific use of APT to such depth that we are aware of, we compare our calibrated APT aperture photometry to calibrated PSF photometry using the latest version of DAOPhot (Stetson 1987) via the automated ALLPHOT (available from github.com/sfabbro/allphot) scripts. We find that very acceptable convergence between DAOPhot and APT. We present these results in Figure 4.

We have compared our aperture photometry magnitudes to those available in roughly similar wavebands from all-sky surveys. We compare our B and V magnitudes to those available in the eighth data release of APASS (Henden et al. 2009). Our V magnitudes (ΔV =0.012±0.033) and our B magnitudes (ΔB =0.024±0.019) agree well with APASS magnitudes. Comparing our data to DENIS I (Epchtein et al. 1994, Deul et al. 1995) photometry, our results are not significantly (0.03±0.08) different.

A further night of observations were collected using the same telescope and methodology as within this paper in March 2013 but only of the central $4.7' \times 4.7'$ of the field of view with only two science images per filter. The night was only borderline photometric with poorer (≈2”) seeing, but had a larger airmass coverage (≈1.0 to ≈1.5) and similarly high quality color coverage. Comparing the observations on the two nights shows that the 2011 observations used in this paper agreed with the later 2013 comparison images. The mean differences in each filter are: $\Delta U = -0.049 \pm 0.034, \Delta B = -0.012 \pm 0.051, \Delta V = -0.012 \pm 0.084, \Delta R = -0.034 \pm 0.040, \Delta I = -0.030 \pm 0.033$.

3.3. *Size of Cluster*

To estimate the central co-ordinates and the size of the cluster, a King model (King 1962) was fitted to a Radial Density Profile (RDP) using both a traditional starcount method as well as a photometry based method. In the photometric method we essentially performed the radial count directly on the DSS image. For the starcount method we used the USNO-B1, 2MASS and WISE catalogues. For the photometric method we used three (blue, red and IR) DSS images.

We would have preferred to use our own CCD images and star counts as the source data, but as the cluster itself is on the order of the same angular size as the image, there was insufficient background to fit a King model. We initially fit a King model by varying the core radius and

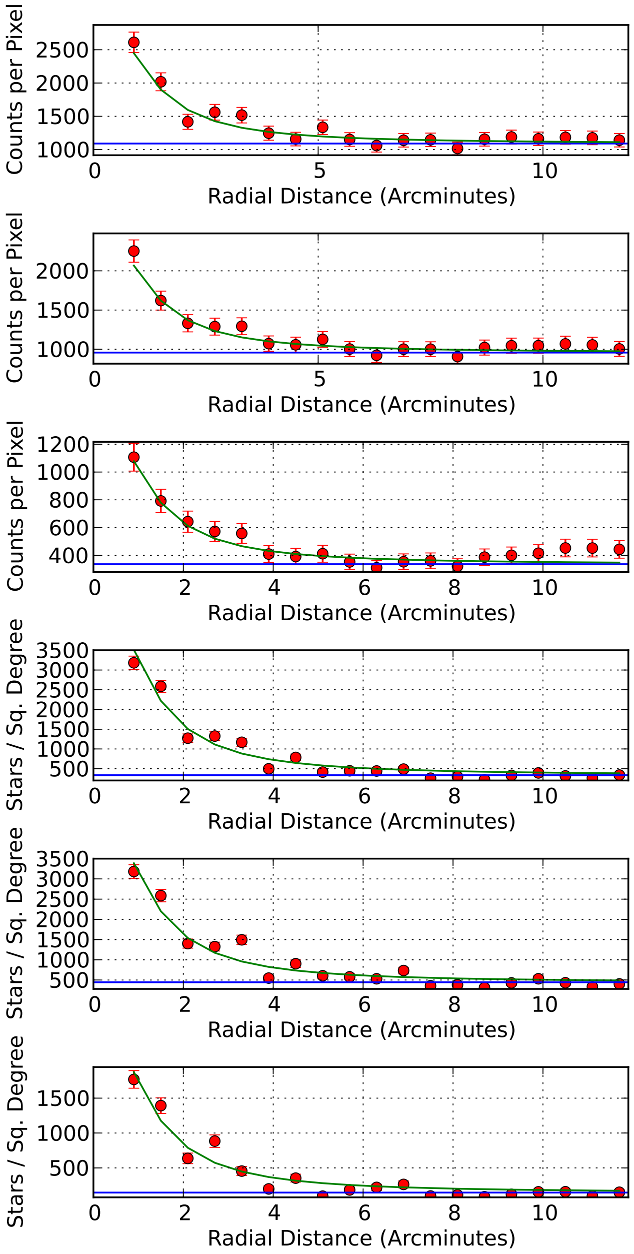


FIG. 5.— The six radial density plots used to estimate the core and limiting radius of the cluster. From the top, the data sources are DSS Blue, DSS Red, DSS IR, WISE, 2MASS and USNO-B1

peak density roughly by eye, then used least squares to find the best fit to the data. The specific King-like model used was that outlined by Maciejewski and Niedzielski (2007) defined using $\rho(r) = f_{bg} + \frac{f_0}{1+(\frac{r}{r_{core}})^2}$ and $r_{lim} = r_{core}\sqrt{\frac{f_0}{3\sigma_{bg}} - 1}$, where σ_{bg} is the background density, f_0 the central density of stars, and r_{core} the core radius.

Using the method outlined in Maciejewski and Niedzielski (2007), the central co-ordinates of the cluster were estimated to be Right Ascension $06^h20^m54^s$, Declination -07°17′42″. Individual King model fits to each RDP were made and are shown in Figure 5. From the mean values from these model fits, the core radius, $R_c = 1.12' \pm 0.04'$ and the limiting radius, $R_{lim} = 4.3' \pm 0.5'$ were determined leading to a concentration value, $c = R_c/R_{lim}$, of 0.26. The implied $8.6' \pm 1.0'$ diameter is similar to those estimated qualitatively by Dias et al. (2002a) and Becker & Fenkart (1971).

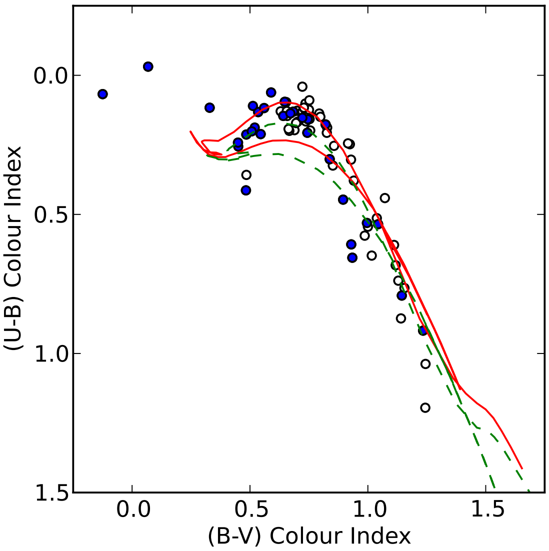


FIG. 6.— Color-Color Diagram used for initial $E(B-V)$ and metalicity estimation. Dotted lines is the original solar metallicity isochrone, solid lines are corrected isochrones showing the metallicity estimation ($[Fe/H] = -0.4$ dex) via isochrone correction via the principle of the $(U-B)_{0.6}$ excess. White dots indicate the star has a low proper motion membership probability.

3.4. *Metallicity, Reddening and Extinction*

(U-B) *vs* (B-V) Color-Color diagrams were plotted initially against solar near-ZAMs ($log(t) = 6.6$) isochrones (Girardi et al. 2002). The (U-B) *vs* (B-V) diagram is well known to be very useful in estimating reddening but a less commonly utilised property of this diagram, is that it can also be used to estimate the metallicity of the cluster. We used the $\delta(U-B)_{0.6}$ ultraviolet excess method initially outlined by Sandage (1969) and further refined by Cameron (1985) and Karatas & Schuster (2006) by effectively exploiting the same principle by fitting the data using a grid of isochrones that vary in metallicity rather than focussing on a single deviation at a particular (B-V=0.6) color.

We initially vary the E(B-V) using a solar metallicity isochrone to roughly fit our UBV data assuming a value for R_v of 3.1 (Winkler 1997) for which we obtained $E(B-V) \approx 0.26$. At this stage we can increase the age of the isochrone to a rough lower age limit (log(t)≈ 8.8) due to the lack of OB and early A type main sequence stars which results in a shortened isochrone with a slightly different shape. This is shown as the dotted line isochrone in Figure 6. We can then shift the metallicity to correct for the $\delta(U-B)_{0.6}$ ultraviolet excess, and in so doing be confident that we are finding a good estimate of the metallicity, as shown by the solid line in Figure 6. In this case, the best visual isochrone fit is Z=0.004, which translates into $[Fe/H] = -0.4 \pm 0.1$ dex. Comparing the $\delta(U-B)_{0.6}$ of ≈ 0.1 mag from this isochrone fit to the calibration of Karatas & Schuster (2006), we find an $[Fe/H]$

of ≈ -0.38 dex, confirming our isochrone method is, essentially, very similar to the ultraviolet excess method. However, there is a subtle difference, in that the shape of the isochrone does subtly change at all colors with age, presumably leading to a variation in the ultraviolet excess and while this is a fairly small change, it would be non-zero.

Our overall reddening $E(B-V) = 0.26 \pm 0.04$ is quite heavily constrained using this diagram. The error estimate is from visual inspection as the most extreme reddening that could be visually plausible for that particular metallicity. Most of the prior estimates of reddening from shallower broadband photometric data as shown in Table 1 are around $E(B-V) \approx 0.3$, and Schlegel et al. (1998) dust maps imply an $E(B-V)$ of 0.372, although this close to the Galactic plane this value can only be approximate at best and represents total extragalactic extinction rather than a typical within-Galaxy extinction. However the more reddening-sensitive Strömgren photometry from Maitzen et al. (1981) is very close at $E(B-V) = 0.244$, which gives confidence in our lower broadband reddening estimations. Also, this reddening seems quite typical, and in fact is roughly the mean value, for stellar clusters at these galactic co-ordinates (Vázquez et al. 2008).

3.5. *Mean Cluster Proper Motion, Membership Probability and Field Star Rejection*

Astrometric reduction of our images were made using the astrometry.net software (Lang et al. 2010) while the positions were estimated from the pixel centroid outputs from APT. From these positions, the UCAC4 proper motions and 2MASS and WISE photometries were extracted via Vizier (Ochsenbein et al. 2000).

The optimum sampling radius of $4.5'$ was determined using UCAC4 data following the recipe of Sanchéz et al. (2010). This agrees satisfactorily with the limiting radius of the cluster presented previously. Following the method outlined in Dias et al. (2006) we applied the Zhao & He (1990) statistical method to UCAC4 stars in the area using the central coordinates and optimum sampling radius previously mentioned.

Briefly, the method consisted in fitting the observed distribution of proper motions with two overlapping normal bivariate frequency functions, an elliptical one for the field stars and a circular one for the cluster stars, weighting the stellar proper motions with different errors. With the frequency function parameters we could determine the individual probability of the membership of each star in the cluster, as suggested by Zhao & He (1990).

We obtained the mean proper motion for the cluster of $\mu_\alpha cos\delta = +1.2 \pm 0.4$ mas/yr and $\mu_\delta = -5.3 \pm 0.4$ mas/yr, the field proper motion of $\mu_\alpha cos\delta = -1.8 \pm 2.9$ mas/yr and $\mu_\delta = -5.9 \pm 2.2$ mas/yr. These results compare well with previous estimates by Dias et al. (2002b) from Tycho2 data of $\mu_\alpha cos\delta = +2.61 \pm 0.58$ mas/yr and $\mu_\delta = -5.60 \pm 0.58$ mas/yr.

Figure 7 presents the vector proper motion diagram of the 105 UCAC4 stars in the cluster's region while also showing the field and cluster mean proper motions and standard deviations. In this work, we consider as kinematic members 51 stars with $P \geq 61\%$. There are seven higher proper motion stars within our field of view and measured photometrically that are outside the plotting bounds of Figure 7. A CMD showing the kinematic members is presented in Figure 8. Although there is still contamination of field stars due to limitation of the method and data, one can clearly see the signature of the cluster when considering only the kinematic member stars. This kinematic membership was used primarily to remove obvious non-members in order to achieve a more accurate visual fit.

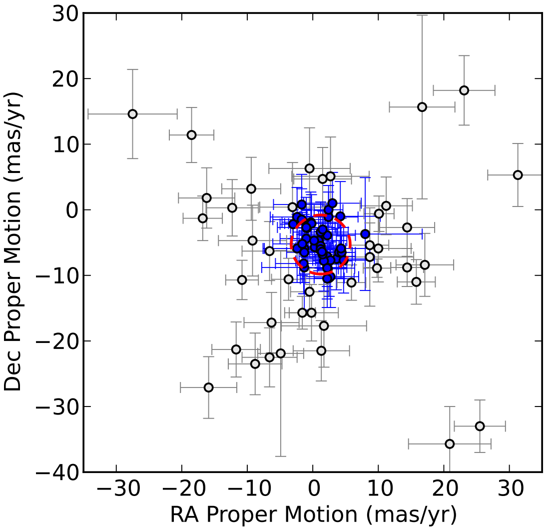


Fig. 7.— Proper Motion Diagram of stars measured in UCAC4 catalogue within the region of radius of $4.5'$ from the central coordinates of NGC2215. Filled circles have cluster probabilities above 0.61, empty circles have cluster probabilities below 0.61, the dashed circle represents the mean cluster proper motion 3σ range.

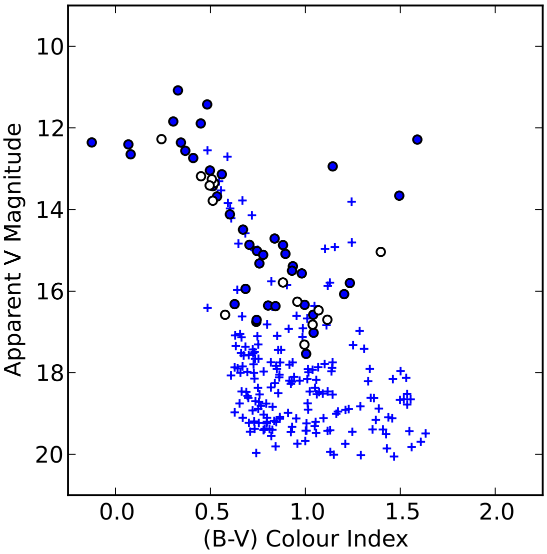


Fig. 8.— Color Magnitude Diagram of all stars measured with photometric errors less than 0.1 mag and radial distance from the center of the cluster less than 4 arcminutes. Circular symbols represent stars rejected as non-members from the cluster, plus symbols represent stars with no proper motion data available, filled circles have cluster probabilities above 0.61.

4. COMBINATION OF OPTICAL PHOTOMETRY WITH 2MASS AND WISE

In an endeavour to provide further constraints to our parameter estimates, we combined our optical photometry with near-IR data available from 2MASS and WISE all-sky surveys. After crossmatching the optical data with the infrared data, multiple CMDs across the entire optical/near-IR/mid-IR spectrum were used to visually fit isochrones using custom-designed software. It was found that comparing the optical CMDs to the infrared CMDs very heavily constrained the plausible values for stellar population parameters as even slight adjustments away from the optimal parameters led to large differences in quality of fit at opposite ends of the spectral range.

The visual fit was performed simultaneously in the optical and IR considering as initial the pre-estimated values of E(B-V) and metallicity via the color-color diagram. To determine the fundamental parameters we adopted the extinction ratios provided by Cardelli et al. (1989), considering as usual $R_V = 3.1$. We used isochrones of (Girardi et al. 2002) obtained from Padova database of stellar evolutionary tracks and isochrones.

The CMDs with the final isochrone fits to the data are presented in Figure 9. The stellar population of the cluster is very heavily constrained as the bright end of the main sequence can be easily distinguished, with final parameters estimated to be $d = 790 \pm 90$pc, $E(B-V) = 0.26 \pm 0.04$, $log(t) = 8.85 \pm 0.10$ and $Fe/H = -0.4 \pm 0.1$ dex. The uncertainties were estimated to accommodate the values derived from the extreme visual fittings on simultaneous CMDs. A possible background population is apparent at ($log(t) \approx 9.65$, $d \approx 4$kpc, $E(B-V) \approx 0.36$ and $Fe/H \approx -0.8$) which could be the population of the Perseus spiral arm.

5. CONCLUSION

In this paper we have undertaken a UBVRI, 2MASS JHK$_s$ and WISE W_1/W_2 photometric data and UCAC4 proper motion to study the relatively neglected Galactic open cluster, NGC 2215. We have shown that the combination of optical and infrared data can be incredibly constraining in fitting stellar isochrones to observational data. While the distance parameter is relatively trivial, changes in metallicity, age or reddening parameters away from the optimal solution have fairly dramatic impacts on the quality of fit across the optical to infrared spectrum, heavily constraining the fit in a much stronger manner than using optical or infrared data alone. In a simultaneous visual fit we estimated the final parameters to be $d = 790 \pm 90$pc, $E(B-V) = 0.26 \pm 0.04$, $log(t) = 8.85 \pm 0.10$ and $[Fe/H] = -0.4 \pm 0.1$ dex. This is the first estimate of the $[Fe/H]$ for the open cluster NGC 2215. Using the UCAC4 data the mean proper motion of NGC 2215 was estimated to be $\mu_\alpha cos\delta = +1.2 \pm 0.4$ mas/yr, $\mu_\delta = -5.3 \pm 0.4$ mas/yr.

Applying the King model fit in the radial density profiles of multiple sources of data we estimate a core radius of $1.12' \pm 0.04'$ (0.24 ± 0.01pc) and a limiting radius of $4.3' \pm 1.5'$ (0.94 ± 0.11pc) for the cluster. A large part of the initial scientific work within this project was undertaken by upper secondary school students involved in the Space to Grow astronomy education project (Danaia et al. (2012)) in Australia and Canada.

We acknowledge the support of LCOGT.net whose provision of time on the Faulkes Telescopes has enabled this and other education/science crossover projects to take place. W. S. Dias acknowledges the São Paulo State agency FAPESP (fellowship 2013/01115-6). This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France. This research has made use of Aladin. In addition, this research has made use of the WEBDA database, operated at the Institute for Astronomy of the University of Vienna. This publication also makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Finally, this research made use of the cross-match service provided by CDS, Strasbourg.

Facilities: Faulkes Telescope North.

REFERENCES

Becker, W., 1960, Zeitschr.Astrophys., 49, 168
Becker, W., Fenkart, R., 1971, A&AS, 4, 241
Becker, W., Svolopoulos, S.N., Fang, C. 1976, Astron.Inst.Univ.Basel
Bukowiecki, L., et al 2011, AcA, 61, 231
Buser, R. 1978, A&A, 62, 425
Cannon, R.D. 1970, MNRAS, 150, 111
Cameron, L.M., 1985, A&A, 146, 59
Cardelli, J.A., Clayton, G.C., Mathis, J.S., 1989, AJ, 345, 245
Clem, J.L., Landolt, A.U., 2013, AJ, 146:4, 88
Danaia, L., et al., 2012, AEdRv, 11a0106D
Deul, E.R., et al. 1995, MmSAI, 66, 549
Dias, W.S., et al. 2002 A&A 389, 871
Dias, W.S., Lepine, J.R.D., Alessi, B.S. 2002 A&A, 388, 168
Dias, W.S., Assafin, M., Florio, V., Alessi, B.S., Libero, V., 2006 A&A, 446, 949
Dokkum, P.G., 2001 PASP, 113, 1420
Disney, M.J., Wallace, P.T. 1982, Q. Jl. R. Astr. Soc., 23, 485
Epchtein., N. et al 1993, AASS, 217, 3
Frandsen, S., Arentoft, T 1998, TJAD, 4, 1
Girardi, L., et al. 2002, A&A, 391, 195
Henden, A., et al., 2009, AAS, 21440702H
Kharchenko, N.V. 2001, KFNT, 17, 409
Kharchenko, N.V. 2005, A&A 438, 1163
Karatas, Y., Schuster, W.J., 2006, MNRAS, 371, 1793
King, I. 1962, AJ, 67, 471
Laher, R., 2010, PASP, 124, 737
Landolt, A. 1992, AJ, 104, 340
Landolt, A. 2009, AJ, 137, 4186
Lang, D., et al. 2010, AJ, 139, 1782L
Loktin, A.V., Gerasimenko, T.P., Malysheva, L.K. 2001, A&AT, 20:4, 607
Lynga, G. 1987, Computer Based Catalogue of Open Cluster Data, 5th ed. (Strasbourg: CDS)
Loktin, A. V., Gerasimenko, T. P., Malysheva, L. K., 2001, Astron. Astrophys. Trans. 20, 607
Maitzen, H.M., Seggewiss, W., Tueg, H. 1981, A&A, 96, 174
Maciejewski, G., Niedzielski, A. 2007, A&A, 467, 1065
Mermilliod, J.C. 1988, Bull. Inform. CDS 35, 77
Netopil, M., Paunzen, E., Stütz, C. 2010, Star Clusters in the Era of Large Surveys, A& SS Proceedings 2012, pp 53-61
Ochsenbein, F., Bauer, P., Marcout, J. 2000, A&ASS 143, 23
Pandey, A. et al. 1989, MNRAS, 236, 263
Paunzen, E. et al. 2010, A& A, 517, A32
Perez 1991, RexMAA, 22, 99
Sanchez, N., Vicente, B., Alfaro, E.J. 2010 A&A, 510, A78

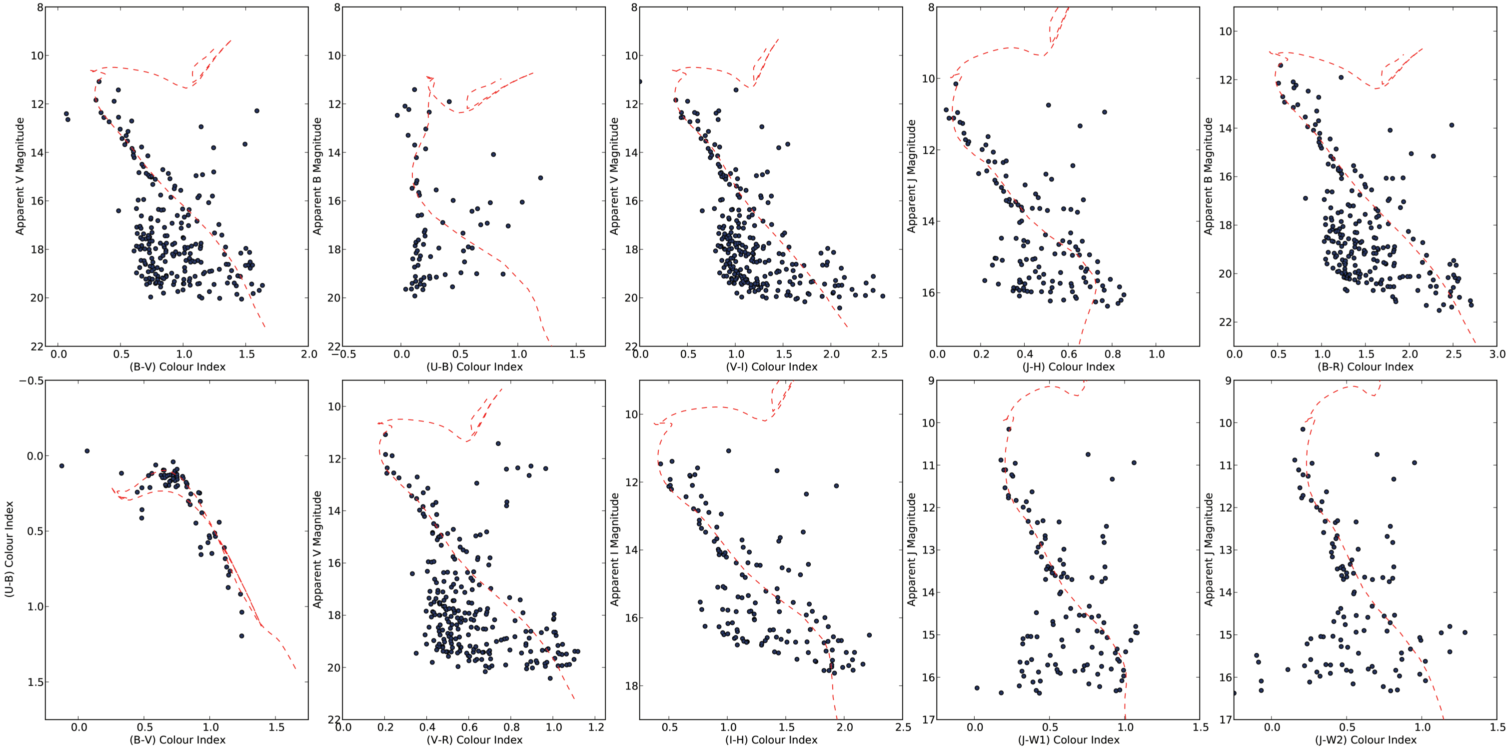


Fig. 9.— Color Magnitude Diagrams of the NGC 2215. The UBVRI photometric measurements refes to our data, JHK_s are data from 2MASS and W1 and W2 are data from WISE. Overplotted are best fit isochrones from Padova models (Girardi et al. 2002) for distances 776pc, age of $log(t) = 8.8$, the $E(B - V) = 0.26$ and $[Fe/H] = -0.4$ dex.

Sandage, A. 1969 AJ, 158, 1115
Schlegel, D.J., et al. 1998, AJ, 500, 525
Skrutskie, M.F., et al. 2006, AJ, 131, 1163
Stetson, P., 1987, PASP, 99, 191
Strömgren, B., 1966, ARA&A, 4, 433
Winkler, H. 1997, MNRAS, 287, 481
Wright, E., et al. 2010, AJ, 140, 1868
Vazquez, R.A., et al. 2008, AJ, 672, 930
Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ 145, 44
Zhao, J.L., He, Y.P., 1990, A&A, 237, 54

APPENDIX

EXAMPLE OF SAMPLE DATA

TABLE 3
EXCERPT SAMPLE OF ONLINE DATA

ID	RA	Dec	U	err_U	B	err_B	V	err_V	R	err_R	I	err_I
81	95.17041184	-7.287	17.015	0.020	16.681	0.015	15.773	0.012	15.259	0.012	14.792	0.025
82	95.17075504	-7.266	nan	nan	19.610	0.016	18.955	0.012	18.533	0.015	18.115	0.025
83	95.17084992	-7.295	nan	nan	21.371	0.031	19.802	0.014	18.883	0.017	18.060	0.025
84	95.17111166	-7.320	nan	nan	18.775	0.017	17.915	0.014	17.376	0.014	16.910	0.026
85	95.17118048	-7.291	19.433	0.025	19.164	0.016	18.194	0.012	17.653	0.013	17.154	0.025
86	95.17119417	-7.318	nan	nan	19.177	0.018	18.165	0.014	17.543	0.014	16.983	0.026
87	95.17122750	-7.329	nan	nan	13.560	0.015	13.045	0.012	12.729	0.012	12.430	0.025
88	95.17155497	-7.278	16.765	0.019	16.644	0.015	15.952	0.012	15.527	0.012	15.096	0.025
89	95.17253750	-7.342	nan	nan	14.263	0.015	13.563	0.012	13.155	0.012	12.763	0.025
90	95.17291161	-7.284	17.630	0.019	16.929	0.015	15.780	0.012	15.141	0.012	14.527	0.025

J	err_J	H	err_H	K_s	err_{K_s}	W1	err_{W1}	W2	err_{W2}	μ_α	μ_δ	err_{μ_α}	err_{μ_δ}	Probability
14.095	0.024	13.698	0.020	13.533	0.037	13.563	0.029	13.606	0.037	-0.2	-15.7	4.1	4.3	0.06
16.782	0.128	16.216	0.149	15.491	0.200	16.288	0.080	17.199						
16.088	0.075	15.653	0.111	15.417										
16.368	0.093	15.730	0.108	16.314		16.189	0.077	17.165						
16.057	0.082	15.584	0.111	15.383	0.205									
11.992	0.024	11.785	0.020	11.716	0.019	11.667	0.025	11.691	0.024	-0.9	-2.8	2.5	2.9	0.91
14.474	0.063	14.179	0.046	14.039	0.072									
12.201	0.024	11.856	0.020	11.766	0.021	11.712	0.024	11.739	0.024	14.4	-8.8	2.5	2.9	0
13.668	0.029	13.056	0.020	12.901	0.030	12.796	0.026	12.861	0.029					

From left to right, these values are our 1) ID#, 2) Right Ascension in Degrees, 3) Declination in Degrees, 4 & 5) U magnitude and error, 6 & 7) B magnitude and error, 8 & 9) V magnitude and error, 10 & 11) R magnitude and error, 12 & 13) I magnitude and error, 14 & 15) 2MASS J magnitude and error, 16 & 17) 2MASS H magnitude and error, 18 & 19) 2MASS K magnitude and error, 20 & 21) WISE W1 magnitude and error, 22 & 23) WISE W2 magnitude and error, 24) Proper Motion in Right Ascension (mas/yr), 25) Proper Motion in Declination (mas/yr), 26) RA proper motion error, 27) Dec proper motion error, 28) Proper Motion Membership Probability

PART D: CONCLUSION AND RECOMMENDATIONS

In this doctoral research, the following objectives were addressed.

> Objective 1: What is the context and background within which this project is set?
>
> Objective 2: What are the important blocking factors and perceptions affecting this project?
>
> Objective 3: Can we develop, implement and evaluate an approach to meet the challenges and issues raised?

Broadly, these aims have been achieved. Dissemination of research findings has been through the publications in this thesis, but also through many posters and talks at conferences and universities both nationally and internationally. While this thesis has contributed to the academic discipline of astronomy education research, it also points towards pragmatic considerations that should be taken on board when endeavours such as these are considered.

The background within which an astronomy innovation takes place must be carefully considered. The actual state of what is occurring in the high school classroom from the perspective of the student must be considered. In this thesis we explored whether student's perceptions of relevant aspects of their science classroom had changed over the last decade. For the most part there seemed to be little large-scale change in the population we were considering. This is despite the indicated various state and national level attempts to change the situation. These initiatives seem to have not had significant impact on the general experience of students in science, leading us to suspect that a number of important dimensions in the high school science education picture have not been adequately addressed at a large scale.

While containing this current picture of the state of high school science in mind, it was also important to achieve an understanding of how particular intervention projects similar to our own function and what potential impact they have on changing the poor nature of high school science education. Unfortunately, while there were a large number of projects that strove to address this problem, very little of them presented any form of reliable evaluation of their efficacy. Most projects also were very short-term and tending to shrink to a shoestring budget or totally shut down once their funding ran out, which was generally of the order of 4 years, although some existed somewhat longer. While funding is one of the key problem areas for these projects, it is also the lack of evaluation, beyond simple anecdotes, that hampers considerations of whether these projects actually do have an impact on students and whether this is at all a cost effective endeavour.

Focussing in from this larger perspective, acquiring a better idea of what was occurring on the general teaching/school level coalface was absolutely necessary to help drive the intervention project. Initially in the project, little was occurring and the identification of what was holding the intervention back was absolutely necessary. In long semi-structured interviews with many teachers we probed the many dimensions behind what prevented them from really getting the intended intervention project functioning within their school.

A large number of issues were brought to attention. A very strong blocking factor related to various time issues which impacted upon multiple factors. The most readily apparent issue related to time was the required preparatory time to include new teaching approach in their classrooms as well as the time needed for significant amounts of training (whether formal or informal) to be able to use the materials in class. Once in the classroom, time limitations become problematic in terms of the in-class time they have to use the materials which, due to curriculum and school program requirements, can be very limited depending on the school. A large number of other impacting factors were brought up, including their lack of experience with inquiry teaching, lack of confidence, difficulties with class size and resources.

To address these issues, teachers suggested a variety of solutions. They required strong support for their undertaking, not only from their supervisors but also from their fellow teachers. The professional learning experiences that they tended to experience were rated very poorly. The quality of these experiences needed to be boosted, especially in making sure their professional learning was based around active learning focussed on the same style of undertakings that their students were going to experience in their classroom. Not only this, but the teachers required significant feedback and follow-up on what they had learnt within these sessions.

These perceptions from the teachers provided significant input into designing an effective approach to enable them to undertake inquiry in the classroom, but this was from the perspective of the teacher. We then explored in a more quantitative manner whether these teachers' perceptions of their in-class practices matched those of their students. Using the same instrument as that used in ascertaining whether the students experience of their high school classroom had changed over the last decade, we explored whether the current perception of the classroom was shared between the teachers and the students.

In undertaking the comparison between teacher and students perception of the classroom, we found two major issues. Firstly, the teachers overall had a significantly positively biased view of the quality of science in their classrooms. To add to this, secondly, the teachers and the students' perceptions were not at all correlated. What this indicates is that primarily that not only do teachers think they are teaching better overall than the students do, but that teachers' perceptions of the relative quality of their science classrooms are quite divorced from that of the students' perceptions. This finding suggests that, while their opinions and feedback are useful in the design phase, teachers cannot be trusted to provide an accurate evaluation of the quality of their own classroom teaching in the final analysis.

Taking the findings of the larger context uncovered in the early parts of the thesis and combining them with the research based on our more specific population in the second part of the thesis, we use these to outline our model of educational design used in the intervention as well present its evaluation and results. We link the issues necessary to be addressed that were identified to their solution using an iterative design based model.

In the iterative design based model, we continually develop the curriculum materials and approach in response to the issues and ideas generated from active solicitation of informal feedback from the teachers. As well as this, we set a solid focus with goals and directions from which we backward map as well as incorporate well-known findings from prior educational instructional theory. Both of these aspects are also updated with respect to the constant feedback. As well as the informal feedback from teachers (which must, as noted in earlier research in the thesis, be taken carefully), quantitative assessment of the students perceptions of their classroom and their content knowledge gains must be used as the final arbiter of design success.

We then explore the evaluation of the design in actual classrooms based heavily around these quantitative measures, but also supported by focus group interviews with a smaller subsection of students. In a broad global overview, moderate to strong (?) mean gains in content knowledge have been achieved by the student population as a whole. Focussing in on specific aspects though, we can see a relatively broad dispersion of gain scores when the data are examined teacher by teacher. Most teachers do closely model the moderate global gain, but some far overshoot the positive gain while there are some teachers who have small negative gains. Also emerging from the content knowledge data is that teachers who have previously taught the material prior (i.e. implementing the project for the second or more time) experience much higher gains than their initial attempt.

In terms of students' perceptions of their classroom, as measured by the SSSQ, we see strong global differences between what students experience in their everyday classroom and that seen in the project. In particular, there are strong positive changes on various aspects of the classroom identified by Goodrum et al. (2001) as modelling the 'ideal' form of science education. These include such aspects as a dramatic drop in note copying, an improved capacity to choose own topics for investigation and a significant improvement in experimentation in the classroom. Having noted that, student perceptions of their enjoyment of science and it's relevance to their lives seems largely untouched over the course of this relatively short-term (weeks) intervention. This perhaps indicates what is commonly known, that interest in science in the student population is a long-term project that must be cultivated over multiple years starting in the elementary school levels with an important focus especially at the middle school years. While interventions like these in high school are necessary to scaffold student interest and motivation, they are not sufficient in and of themselves.

Some students, however, when the stars have aligned and piqued their interest will find this intervention project one of the keystones of their interest in science. In the project we have provided the capacity for individual research for those students who do want to push further than the classroom. There have been various research projects, many still in motion, in the high school classroom, but we have presented two examples of final published scientific research from high school students showing that it is possible for authentic scientific research to be undertaken at the high school level. The first is a study of a neglected open cluster, NGC2215, undertaken by a high school student in Bathurst in collaboration with students in Canada and various scientists. The second is a study of RR Lyrae stars in NGC6101, a neglected globular cluster deep in the southern skies.

During this research, we had three objectives to meet.

> Objective 1: What is the context and background within which this project is set?
>
> Objective 2: What are the important blocking factors and perceptions affecting this project?
>
> Objective 3: Can we develop, implement and evaluate an approach to meet the challenges and issues raised?

As can be seen from the publications within, all three objectives have been sufficiently met. We have defined the context and background for the implementation project on both the high school level and project level. We have identified many of the blocking factors and problematic perceptions that subtly (and not so subtly) impact on the quality of implementation. We have also presented a design to rise to these challenges which has been evaluated showing both moderate success and many avenues for improvement (and the design facility to do so) in the future.

Changing the nature of the high school classroom is a very complex affair and it is very unlikely a national, state or even jurisdictional approach will function to remediate this problem totally. The functional unit of change seems to be at the school and teacher level where these schools share communication and also similar blocking factors and types and characteristics of teachers and students. If an intervention is aimed from too high a level, it is possible that the many minutiae preventative details that are apparent on the ground level will not be perceived. By a mixture of quality direct interaction with teachers and schools as well as the capacity for admitting failure and accepting change on the part of the intervention project itself, success at changing the nature of high school science education can be attained.

REFERENCES

Ainley, J., Kos. J., Nicholas, M., (2008), “Participation in Science, Mathematics and Technology in Australian Education”, Australian Center for Educational Research Research Monograph No. 63

American Association for the Advancement of Science (AAAS). (1990). Science for all Americans: project 2061. New York: Oxford University Press.

Bennett, J., (2001),”Science with attitude: the perennial issue of pupils’ responses to science”, School Science Review, 82(300), 59

Committee for the Review of Teaching and Teacher Education (CRTTE). (2003). Australia's teachers: Australia's future advancing innovation, science, technology and mathematics agenda for action. Canberra: Department of Education, Science and Training.

Danaia, L., McKinnon, D., Parker, Q., Fitzgerald, M., Stenning, P., (2012), “Space to Grow: LCOGT.net and Improving Science Engagement in Schools”, AER, 11

Danaia, L., Fitzgerald, M., McKinnon, D., (2013), “Students’ Perception of High School Science: What has Changed Over the Last Decade”, Research in Science Education, 43 (4), 1501

Drury, C., & Allen, A. (2002). Task force on the physical sciences: report and recommendations. Department of Education and Science, Ireland. http://www.sciencetaskforce.ie/.

Fensham, P.J., (2011), “Knowledge to Deal with Challenges to Science Education from Without and Within” in Corrigan, D., Dillon, J., Gunstone, R., (eds) “The Professional Knowledge Base of Science Teaching”, Science Education

Gilbert, J., (2005), “Catching the Knowledge Wave? The Knowledge Society and the Future of Education“ (Wellington: NZCER)

Goodrum, D., Hackling, M., Rennie, L., (2001), “The Status and Quality of Teaching and Learning Science in Australian Schools”, Department of Education, Traing and Youth Affairs. Canberra.

Goodrum, D., Druhan, A., Abbs, J., (2012), “The Status and Quality of Year 11 and 12 Science in Australian Schools”, Australian Academy of Science: Canberra

International Bureau for Education. (2001). Science education for contemporary society: problems, issues and dilemmas. Geneva: International Bureau for Education, UNESCO.

Lyons, T., & Quinn, F. (2010). Choosing science: understanding the declines in senior high school science enrolments. Research report to the Australian Science Teachers Association

(ASTA). University of New England, Australia: National Centre of Science, ICT and Mathematics Education for Rural and Regional Australia (SiMERR Australia).

Millar, R., & Osborne, J. (1998). Beyond 2000: science education for the future (The report of a seminar series funded by the Nuffield Foundation). London: King's College London, School of Education.

Osborne, J., Collins, S., (2000), "Pupils and parents' views of the school science curriculum", School Science Review, 82:298, 23-30

Osborne, J. (2006). Message from the President E-NARST News, 49, 1–2.

Rennie, L., 2012, "Evaluation of the Scientists in Schools Project 2011-2012", Report prepared for CSIRO Education, January 2012

Sjoberg, S., (2005), "How do learners in different cultures relate to science and technology? Results and perspectives from the project ROSE", Asia-Pacific Forum on Science Learning and Teaching, 6:2, 1

Tytler, R., Symington, D., (2006), "Science in school and society", Journal of the Australian Science Teachers Association, 52:3, 10-15

Tytler, R., (2007), "Re-imagining science education: Engaging students in science for Australia's future." Camberwell, Victoria: Australian Council for Educational Research

Tytler, R., Symington, D., Smith, C., Rodrigues, S., (2008), "An innovation framework based on best practice exemplars from the Australian School Innovation in Science, Technology and Mathematics (ASISTM) project", Dept of Education, Employment and Workplace Relations: Canberra.

Charles Sturt
University

OFFICE OF
ACADEMIC GOVERNANCE

Private Mail Bag 29
Panorama Avenue
Bathurst NSW 2795
Australia

Tel: +61 2 6338 4185
Fax: +61 2 6338 4194

9 May 2012

Associate Professor David McKinnon
School of Teacher Education
BATHURST CAMPUS

Dear Associate Professor McKinnon,

The CSU Human Research Ethics Committee (HREC) operates in accordance with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Research Involving Humans.*

The HREC has reviewed your report requesting an extension for your research project ***"Space to Grow: The Faulkes Telescope and improving science engagement in schools"***, protocol number 2009/025 and I am pleased to advise that this request for an extension meets the requirements of the *National Statement*; and an extension for this research is granted for a twelve month period from 9/05/2012.

Please note the following conditions of approval:

- all Consent Forms and Information Sheets are to be printed on Charles Sturt University letterhead. Students should liaise with their Supervisor to arrange to have these documents printed;
- you must notify the Committee immediately in writing should your research differ in any way from that proposed. Forms are available at **http://www.csu.edu.au/__data/assets/word_doc/0010/176833/ehrc_annrep.doc** you must notify the Committee immediately if any serious and or unexpected adverse events or outcomes occur associated with your research, that might affect the participants and therefore ethical acceptability of the project. An Adverse Incident form is available from the website: as above;
- amendments to the research design must be reviewed and approved by the Human Research Ethics Committee before commencement. Forms are available at the website above;
- if an extension of the approval period is required, a request must be submitted to the Human Research Ethics Committee. Forms are available at the website above;
- you are required to complete a Progress Report form, which can be downloaded as above, by 9/05/2013 if your research has not been completed by that date;
- you are required to submit a final report, the form is available from the website above.

You are reminded that an approval letter from the CSU HREC constitutes **ethical approval only.**

If your research involves the use of radiation, biological materials or chemicals separate approval is required from the appropriate University Committee.

Please don't hesitate to contact the Executive Officer: telephone (02) 6338 4628 or email ethics@csu.edu.au if you have any enquiries about this matter.

Yours sincerely,

Julie Hicks
Executive Officer
Human Research Ethics Committee
Direct Telephone: (02) 6338 4628
Email: ethics@csu.ed.au

Cc: