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

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BA., BSc.(Hons), MEd.

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

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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.

Michael Fitzgerald (40224643)

2nd of February 2015

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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.

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Paper Nine

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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)

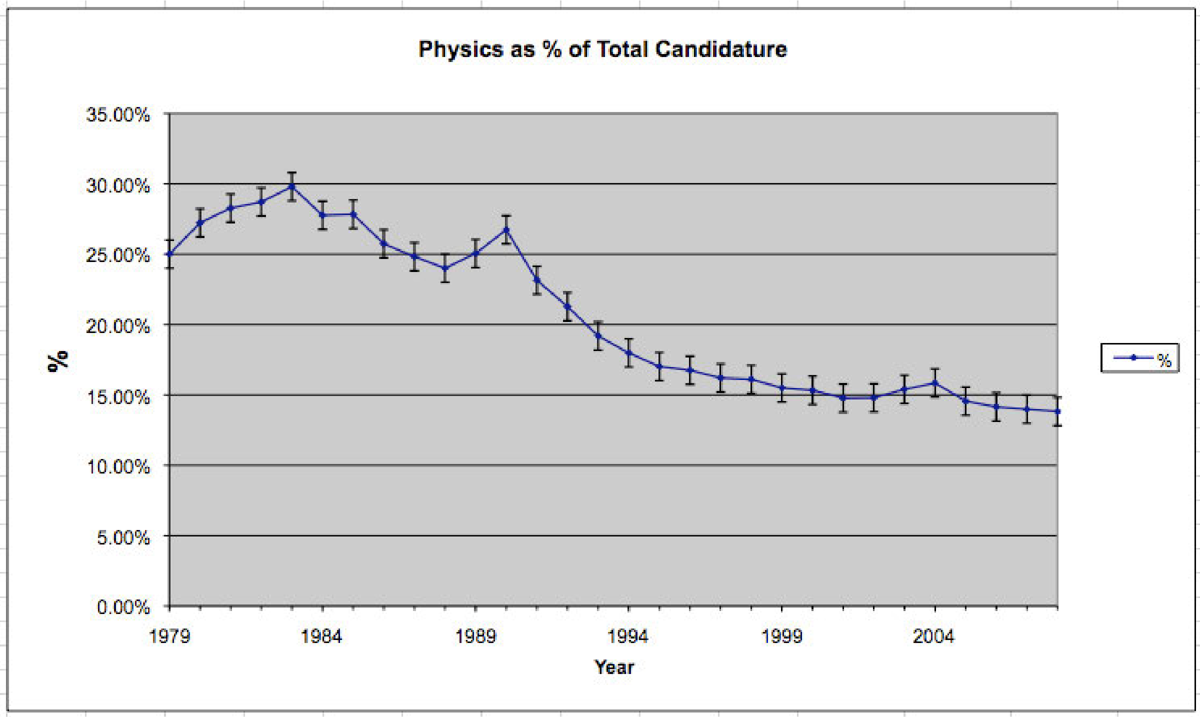

Figure 1. Enrolment in physics in Australian High-schools over time. (Ainley et al. 2008)

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.

Pages 23-76 of this thesis have been removed as they contain published material under copyright. Removed contents published as:

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, 1501–1515. https://doi.org/10.1007/s11165-012-9318-x

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PART B: BLOCKING FACTORS AND PERCEPTIONS

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

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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™.

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.

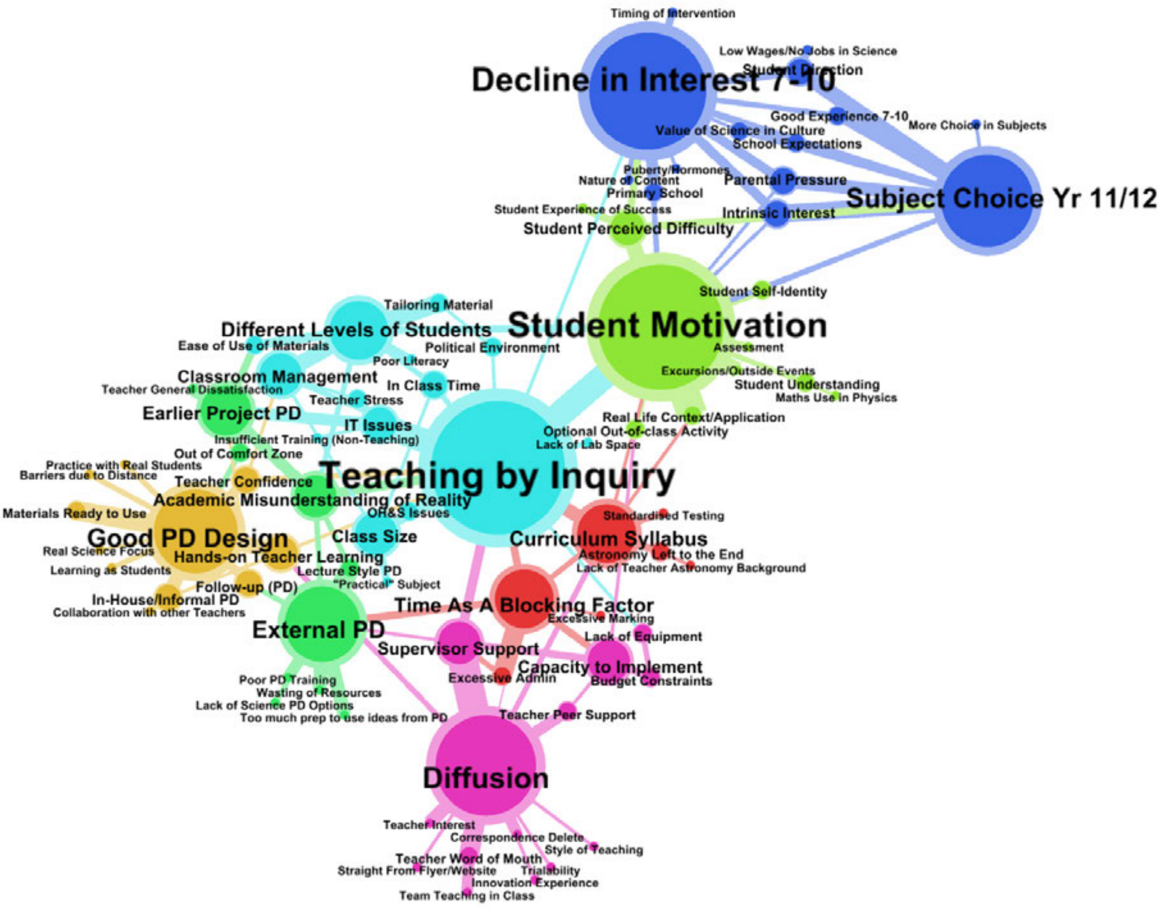

Figure 1: Gephi communities of concepts.

"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.

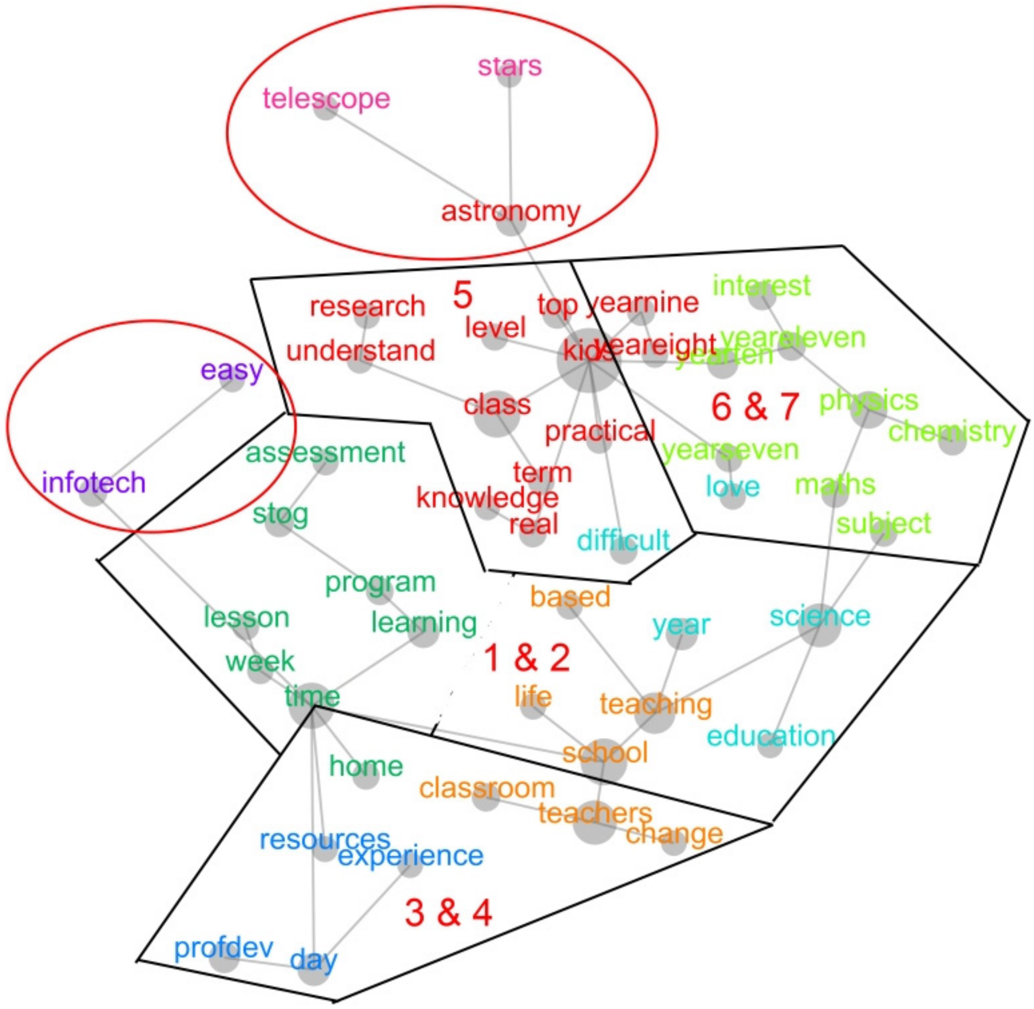

Figure 2: Leximancer VS Gephi representations

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.

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Differences in perception of high school science: Students' and Teachers' views.

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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 Questionaire (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.

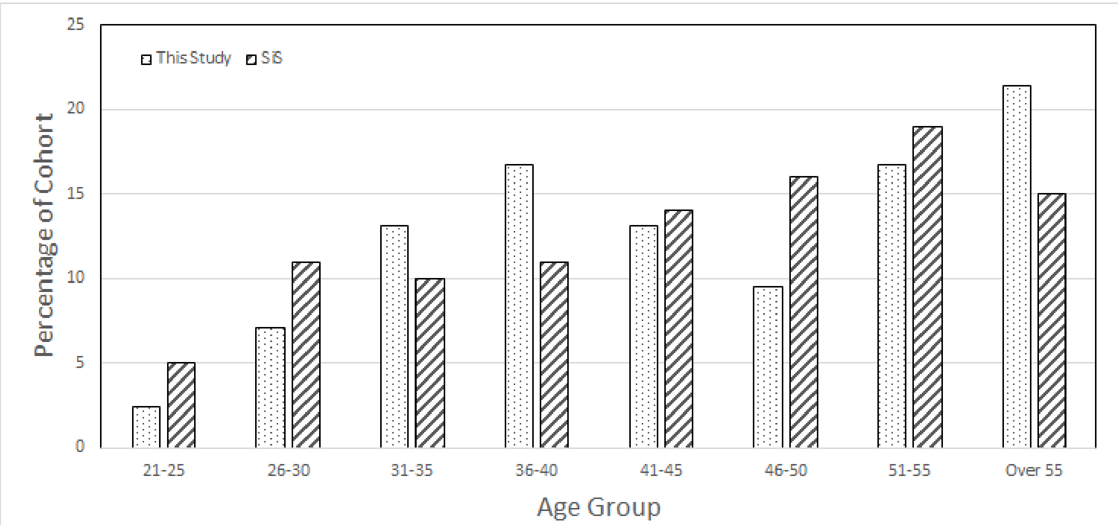

Figure 1: Age distribution of teachers in our sample compared to that in the Staff in Australia's Schools 2007.

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.

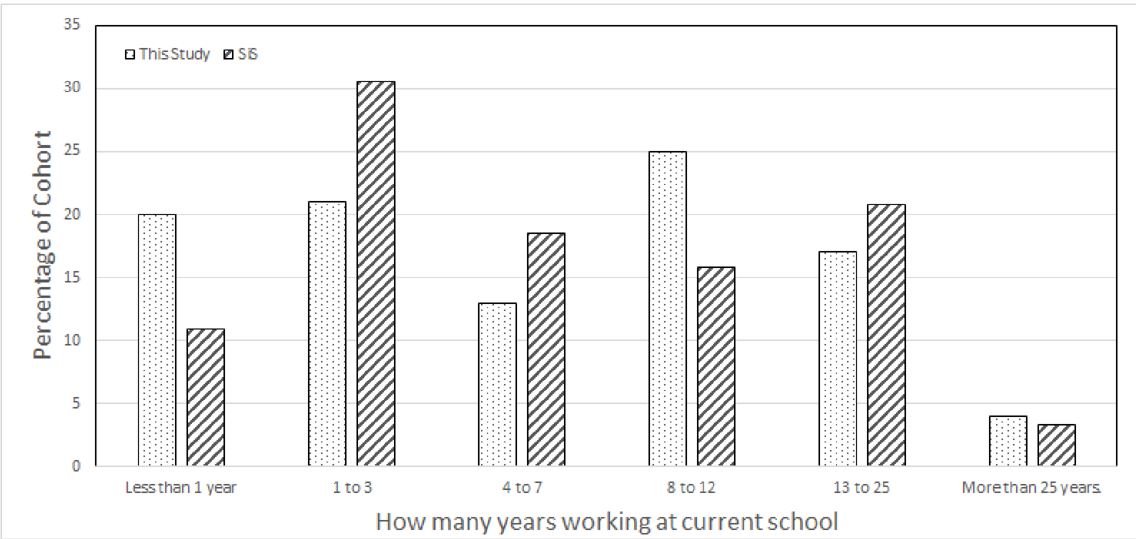

Figure 2: Years spent teaching at current school.

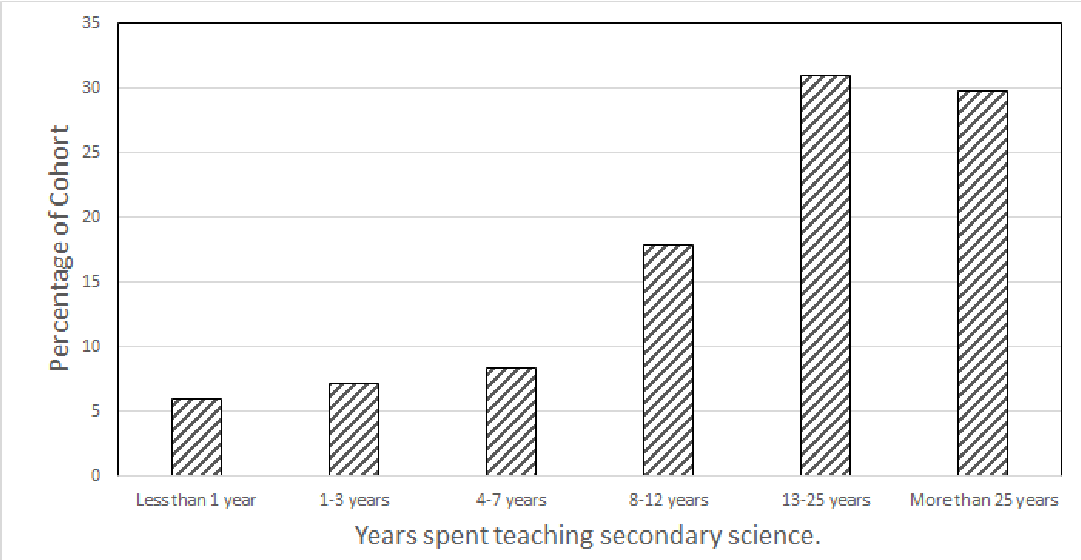

Figure 3: Years spent teaching overall.

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 teacher gives me		Students	2.6	2.7	7.4	21.5	65.7	**5.2E-19**
		Teachers	3.6	7.2	13.3	54.2	21.7	**
2. I work out explanations in science on my own		Students	5.7	8.5	23.4	39.2	23.2	**3.2E-05**
		Teachers	1.2	0.0	16.9	42.2	39.8	*
3. I work out explanations in science with my friends		Students	4.9	5.5	16.1	38.1	35.5	3.4E-02
		Teachers	1.2	0.0	14.5	41.0	43.4	ns
4. I have opportunities to explain my ideas		Students	9.1	10.0	23.0	29.2	28.7	**4.2E-10**
		Teachers	1.2	3.6	4.8	36.1	54.2	**
5. I read a science textbook		Students	20.2	16.5	20.8	22.8	19.6	**6.1E-07**
		Teachers	6.0	10.8	28.9	42.2	12.0	**
6. We have class discussions		Students	5.8	6.0	14.0	27.0	47.1	**2.0E-04**
		Teachers	1.2	0.0	6.0	26.5	66.3	*
7. We do our work in groups		Students	5.5	9.3	28.0	36.6	20.6	**7.3E-10**
		Teachers	1.2	2.4	4.8	56.6	34.9	**
In science, we								
8. Investigate to see if our ideas are right		Students	10.4	12.8	27.2	31.9	17.6	**5.3E-04**
		Teachers	2.4	15.7	42.2	31.3	8.4	*
My science teacher								
9. Lets us choose our own topics to investigate		Students	47.4	25.2	16.9	7.3	3.3	**1.1E-16**
		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*							
			% Response					
Item		Population	*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 do an experiment		Students	7.9	14.4	32.5	29.7	15.5	**1.4E-04**
		Teachers	2.4	7.2	31.3	49.4	9.6	*
11. We do experiments by following instructions		Students	4.2	6.1	19.5	38.5	31.7	**1.8E-05**
		Teachers	2.4	0.0	6.0	59.0	32.5	*
12. We plan and do our own experiments		Students	28.2	25.0	23.3	15.6	7.9	**1.3E-10**
		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*							
			% Response					
Item		Population	*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 science ideas		Students	5.3	14.4	25.5	29.4	25.5	**2.1E-04**
		Teachers	1.2	1.2	24.1	37.3	36.1	*
16. Recognise science in the world around us		Students	6.3	15.2	25.4	26.8	26.3	**5.8E-08**
		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*

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

Item	Population	% Response *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	Students	21.7	34.8	21.0	12.6	9.8	**1.1E-13**
what we do	Teachers	2.4	24.1	38.6	31.3	3.6	**
29. I am curious about the	Students	14.3	26.1	23.4	19.8	16.5	**4.6E-09**
science we do	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	Students	25.6	44.8	14.2	8.1	7.3	**1.1E-08**
the science we do	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		Students	27.5	35.9	20.1	10.0	6.5	**9.2E-10**
concerned about		Teachers	2.4	37.3	39.8	16.9	3.6	**
38. Helps me make decisions		Students	27.4	33.7	20.3	12.0	6.7	**3.8E-06**
about my health		Teachers	6.0	38.6	32.5	19.3	3.6	**
39. Helps me understand		Students	12.0	26.3	27.8	21.6	12.3	**4.4E-04**
environmental issues		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.

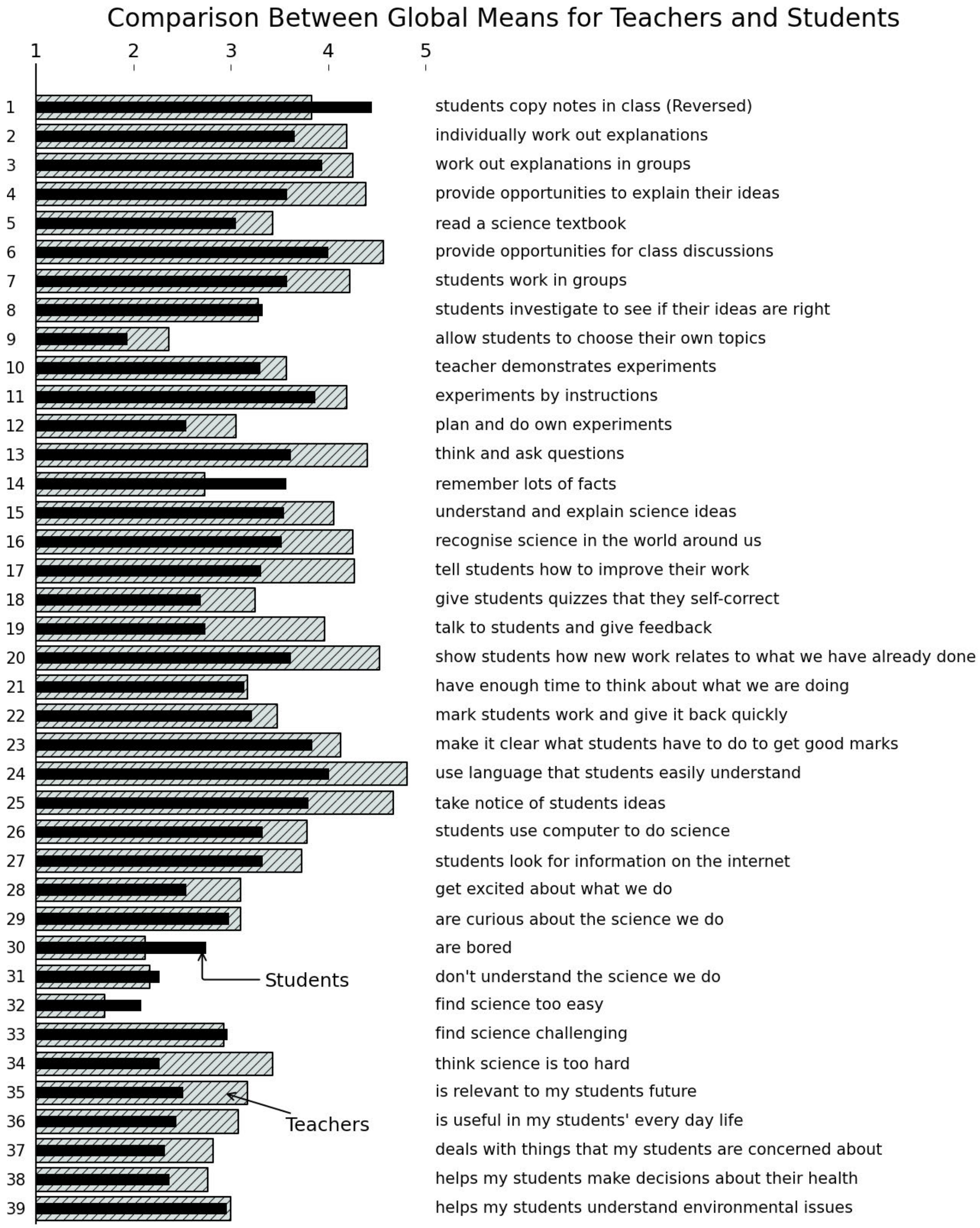

Figure 4: Comparison of teacher and student means.

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.

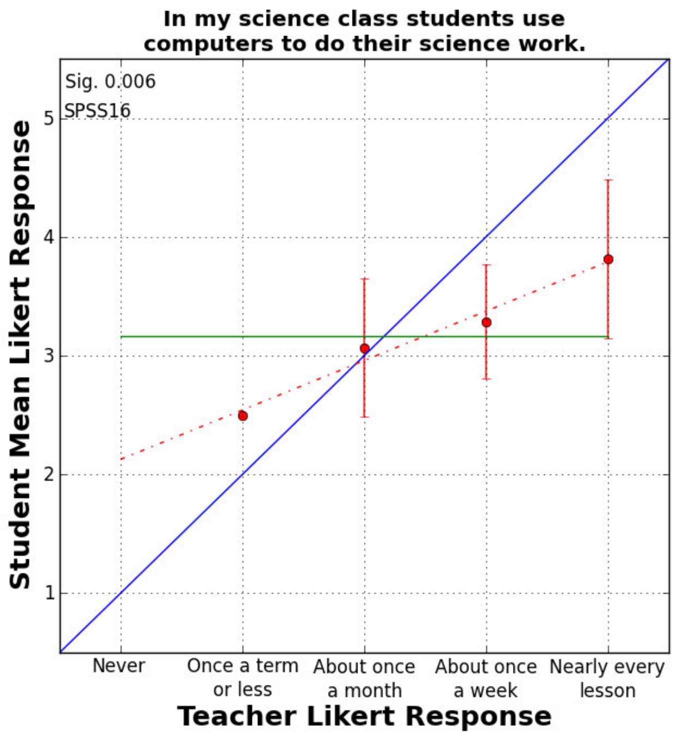

Figure 5: Closeup of Example Figure

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.

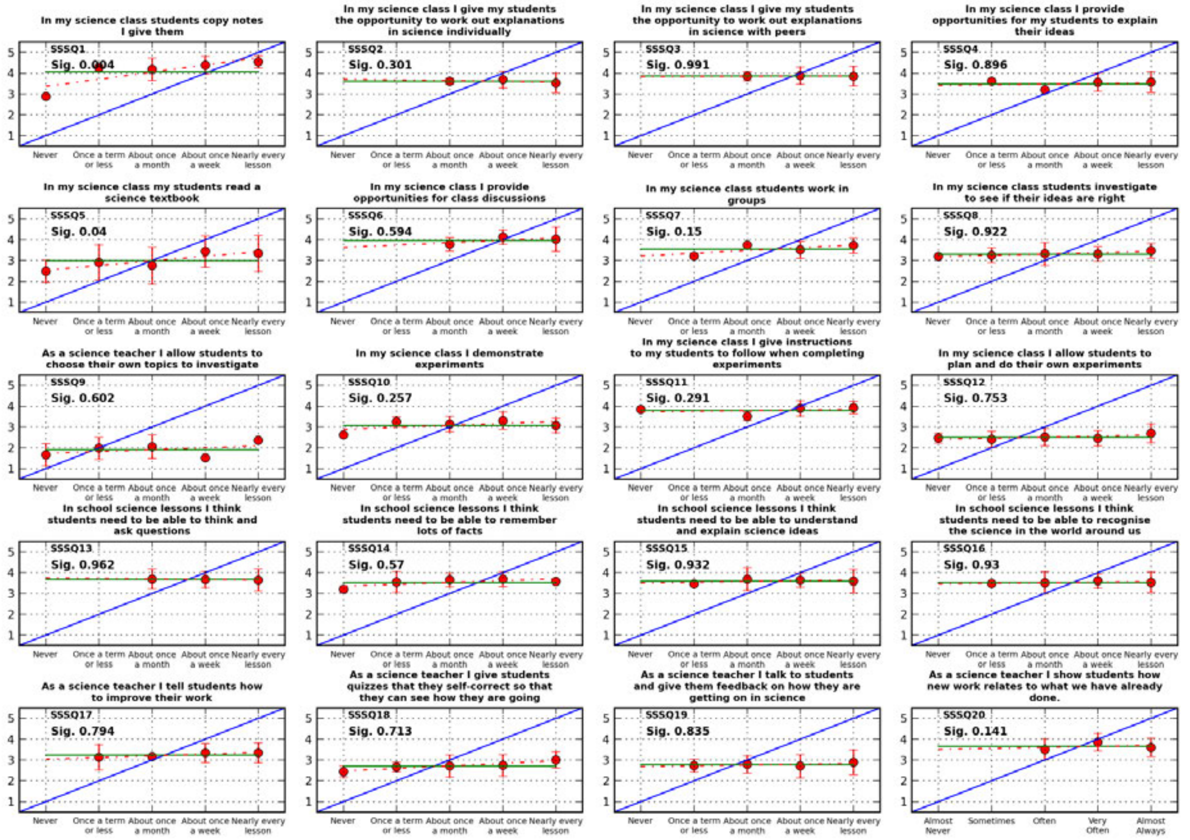

Figure 6: Comparison of teachers perceptions to students' perceptions

for first 20 items on the SSSQ.

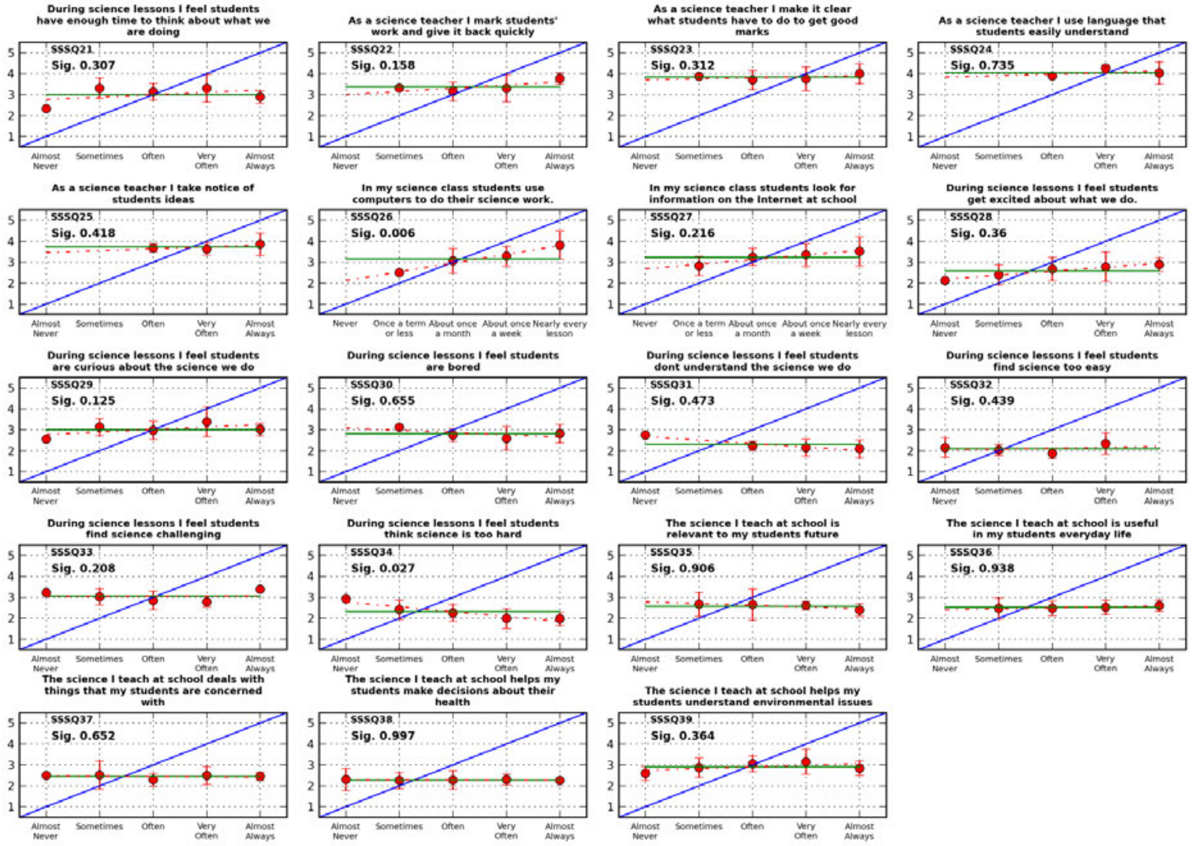

Figure 7: Comparison of teachers perceptions to students' perceptions for second 19 items on the SSSQ.

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.

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PART C: EDUCATIONAL DESIGN AND EMERGENT STUDENT ACHIEVEMENT

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

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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.

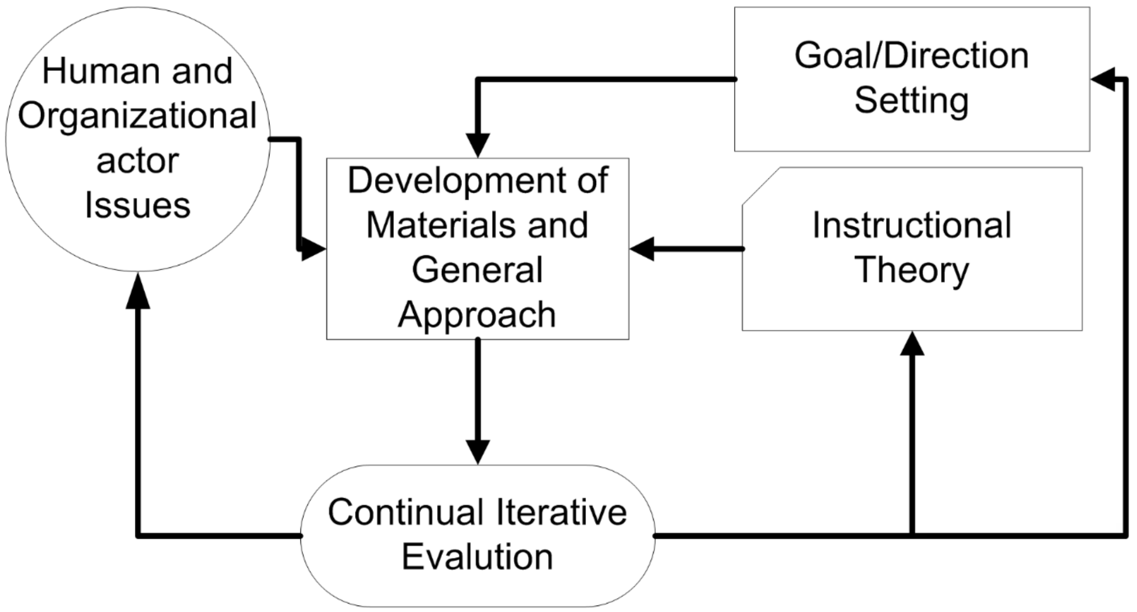

Figure 1: Outline of general educational iterative design model.

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).

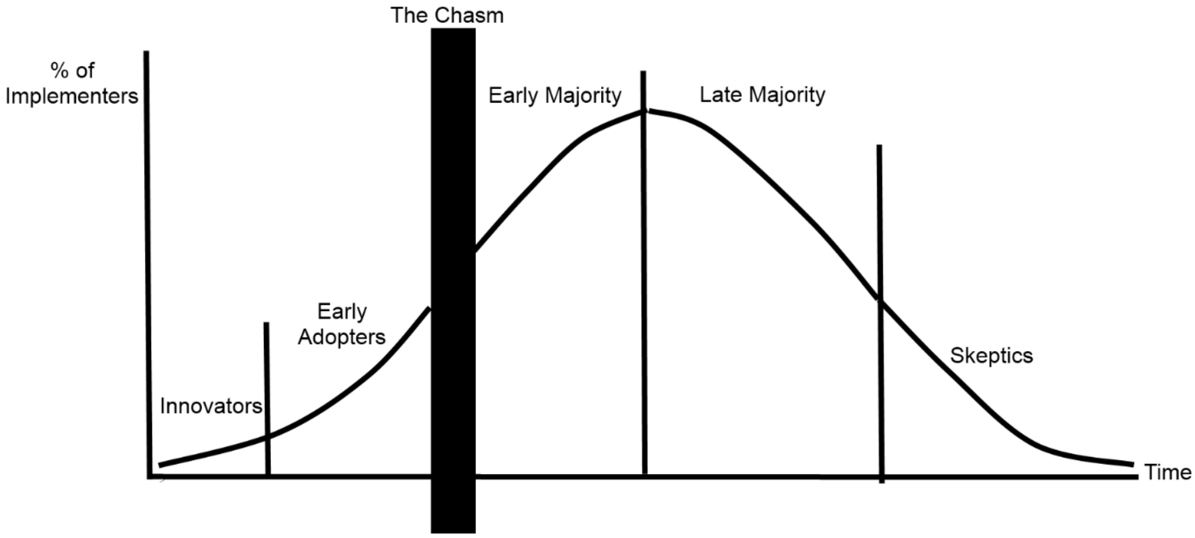

Figure 2: Implementation Adoption curve based on Rogers et al. (2003)

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.

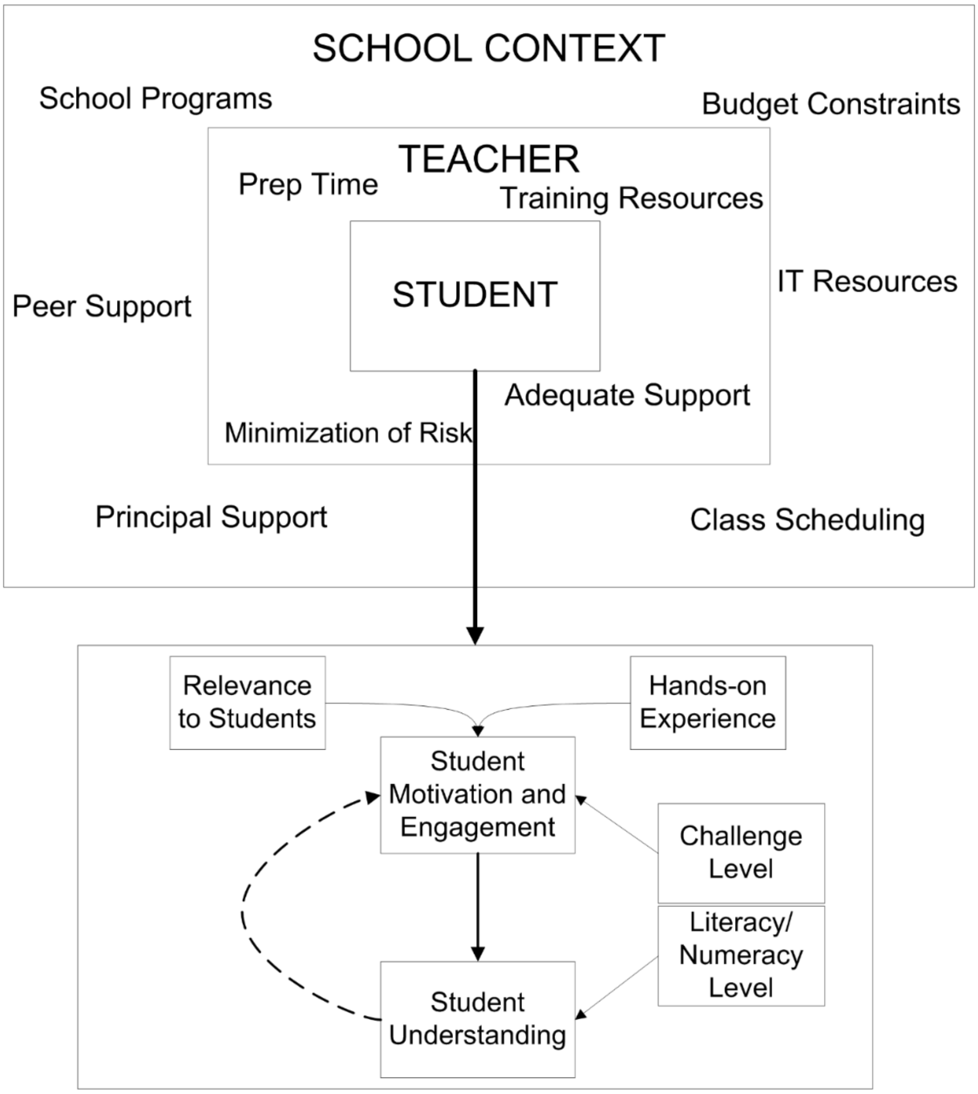

Figure 3: Outline of the various issues to be considered in the educational design.

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.

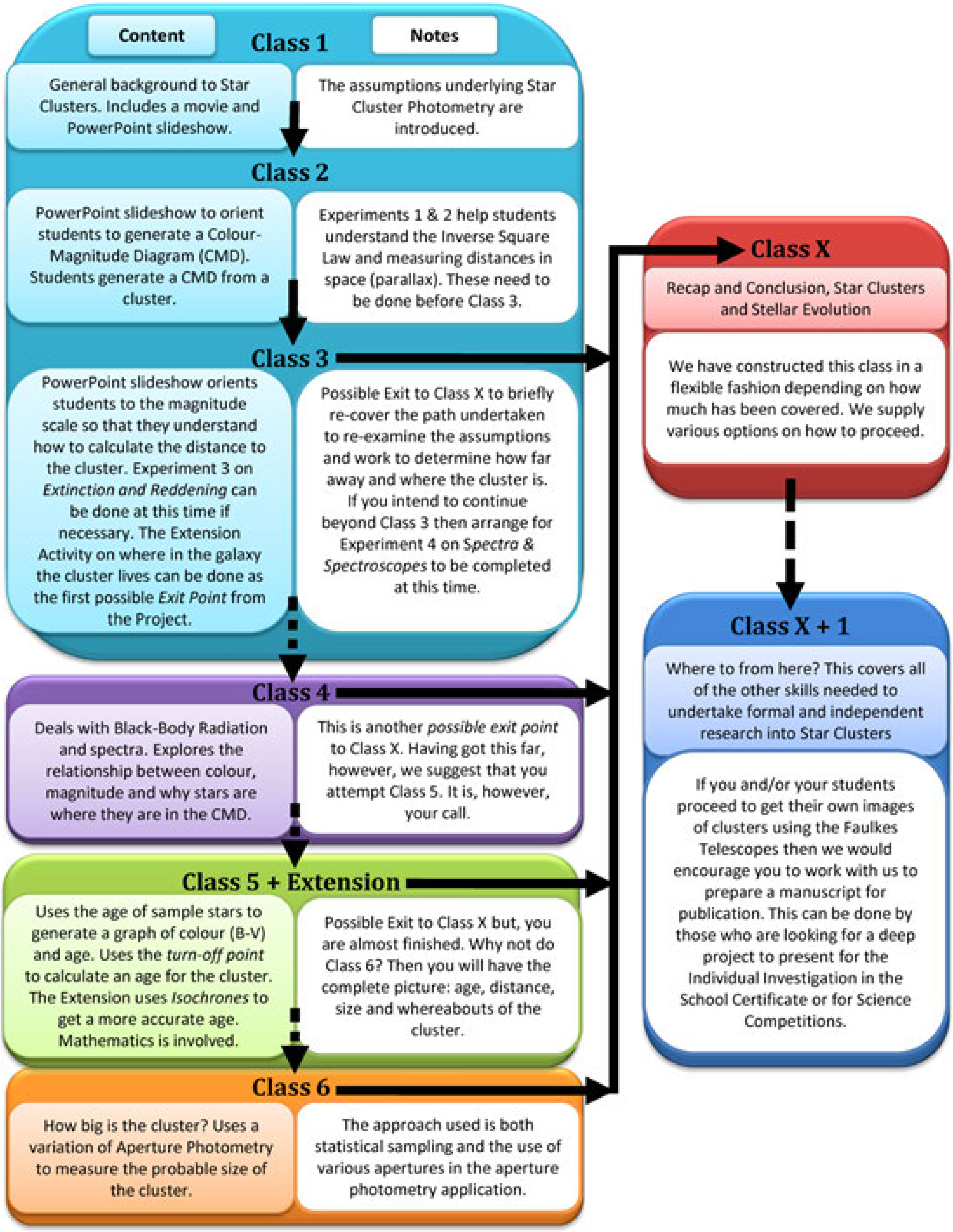

Figure 4: General pathways through the curriculum materials.

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.

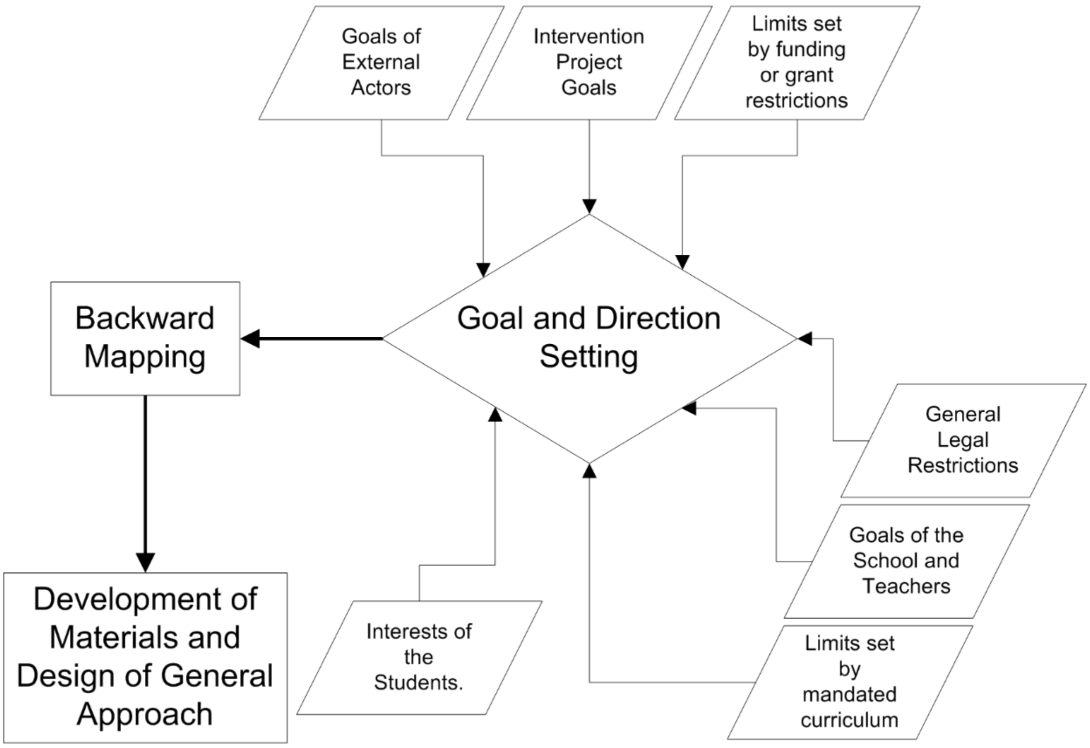

Figure 5: Schematic showing major inputs into the goal and direction setting process.

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.

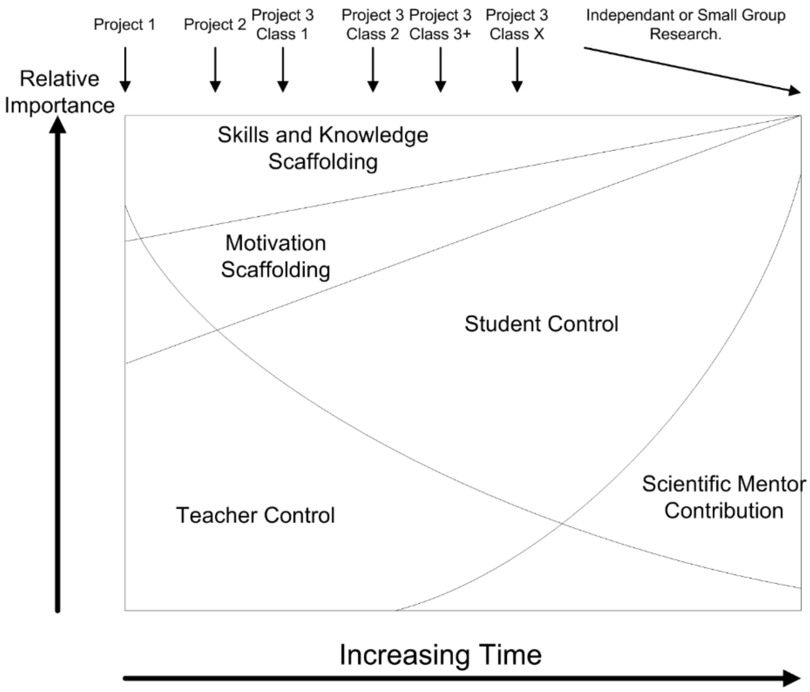

Figure 6: Varieties of importance of control and scaffolding

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.

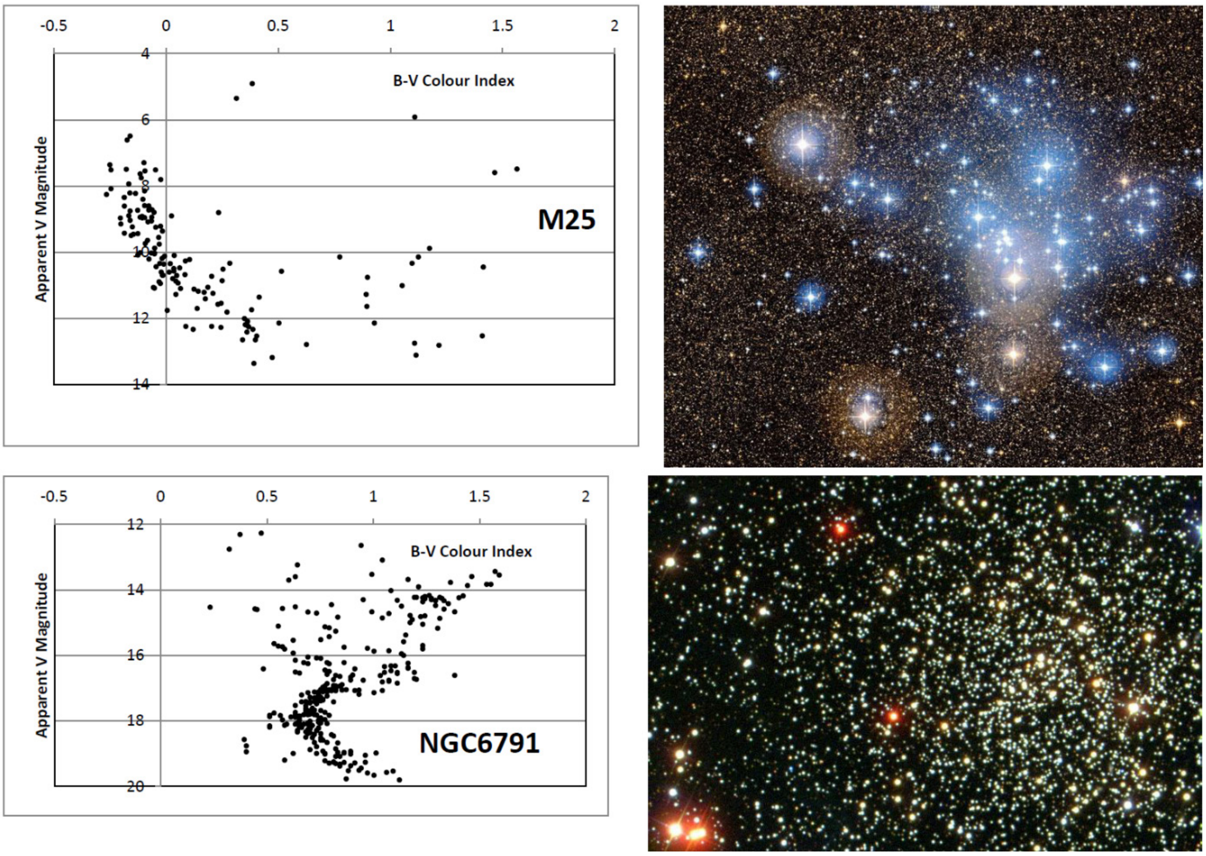

Figure 9: Sample Colour Magnitude diagram and image comparisons of two clusters, a young cluster, M25 (Image from APOD - http://apod.nasa.gov/apod/ap090831.html) and NGC6791 (Image from SDSS image of the week http://www.sdss.org/iotw/). Both sets of data are sourced from Webda (http://www.univie.ac.at/webda/)

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.

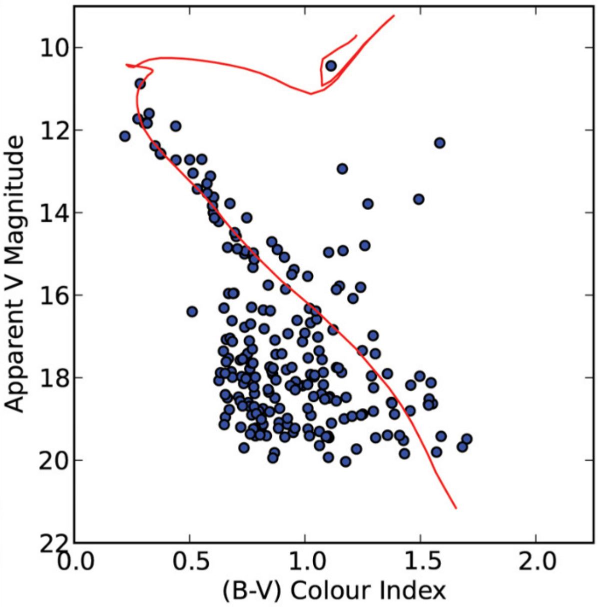

Figure 10: Colour Image of NGC2215 CMD and Colour Magnitude Diagram.

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.

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A large scale inquiry based astronomy intervention project: Impact on high school students' performance and perceptions in science.

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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.

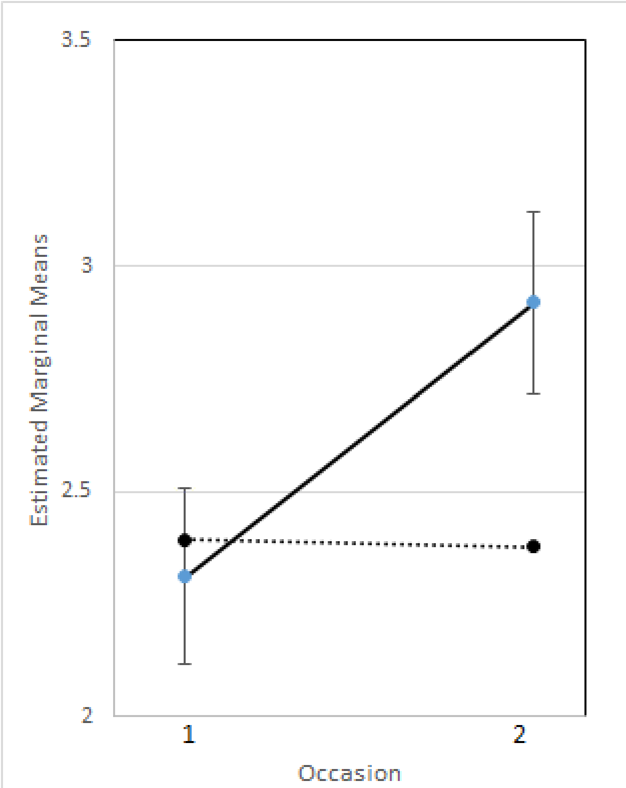

Figure 1: AKQ Gain from global sample of students. Equivalent Dependent Variables are solid lines. Non-Equivalent Dependent Variables are dotted lines.

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).

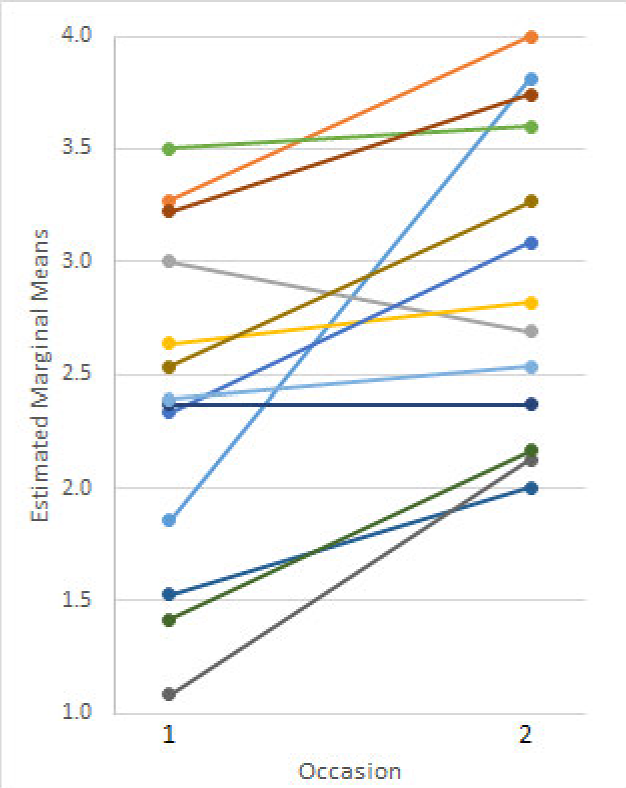

Figure 2: Comparison between pre and post results for all teachers from the equivalent Dependent Variables of the AKQ.

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).

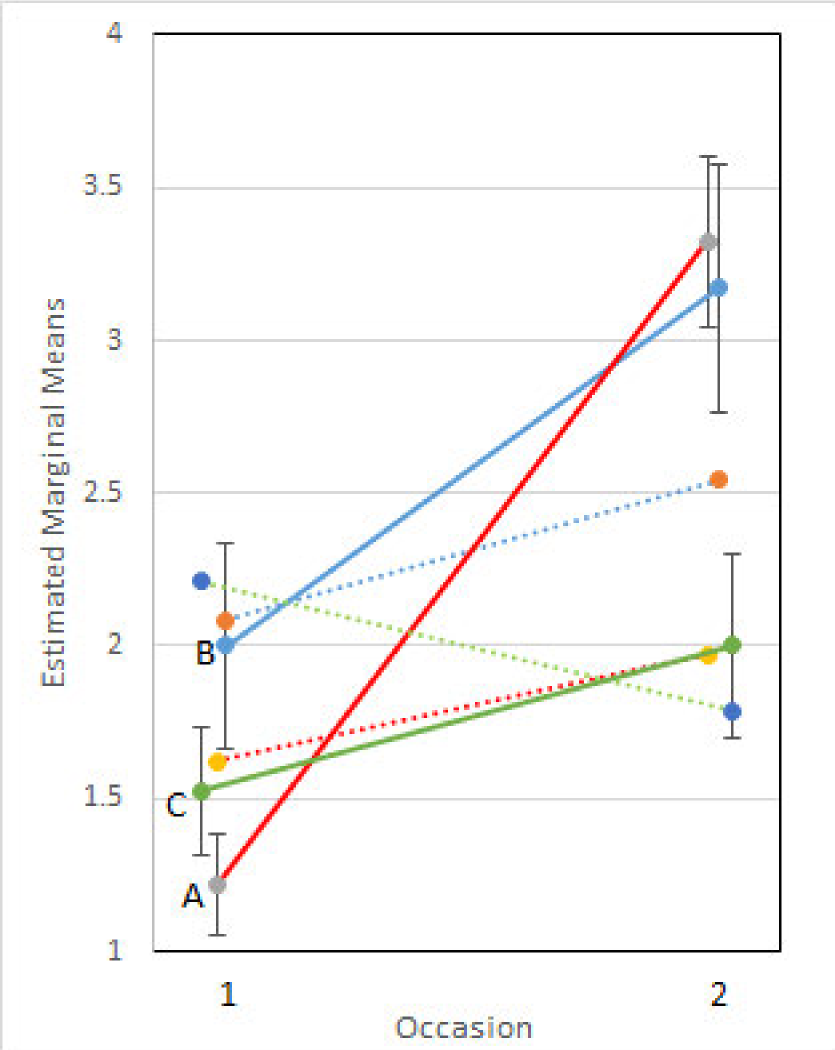

Figure 3: Pre/Post results for 3 teachers at same school. Non-equivalent Dependent Variables (dotted), Equivalent Dependent Variables (solid).

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.

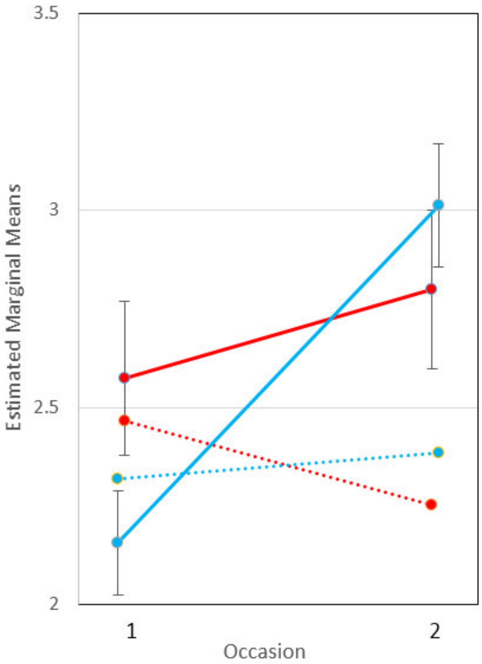

Figure 4: Results comparing those teachers who taught only the first two scaffolding projects (Red) compared to those teachers who taught a full implementation involving all three projects (Blue). Solid lines are equivalent dependant variables. Dotted lines are non-equivalent Dependant variables.

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.

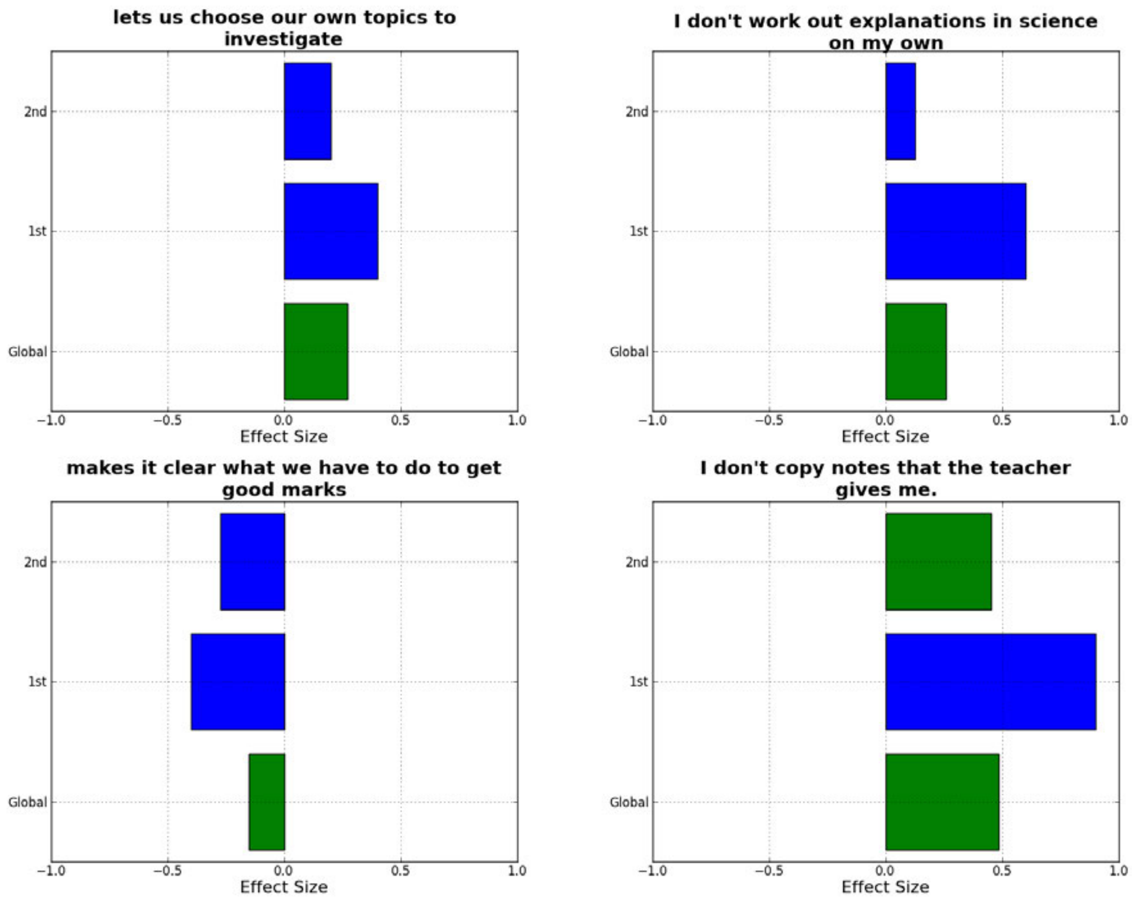

Figure 5: Global changes.

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.

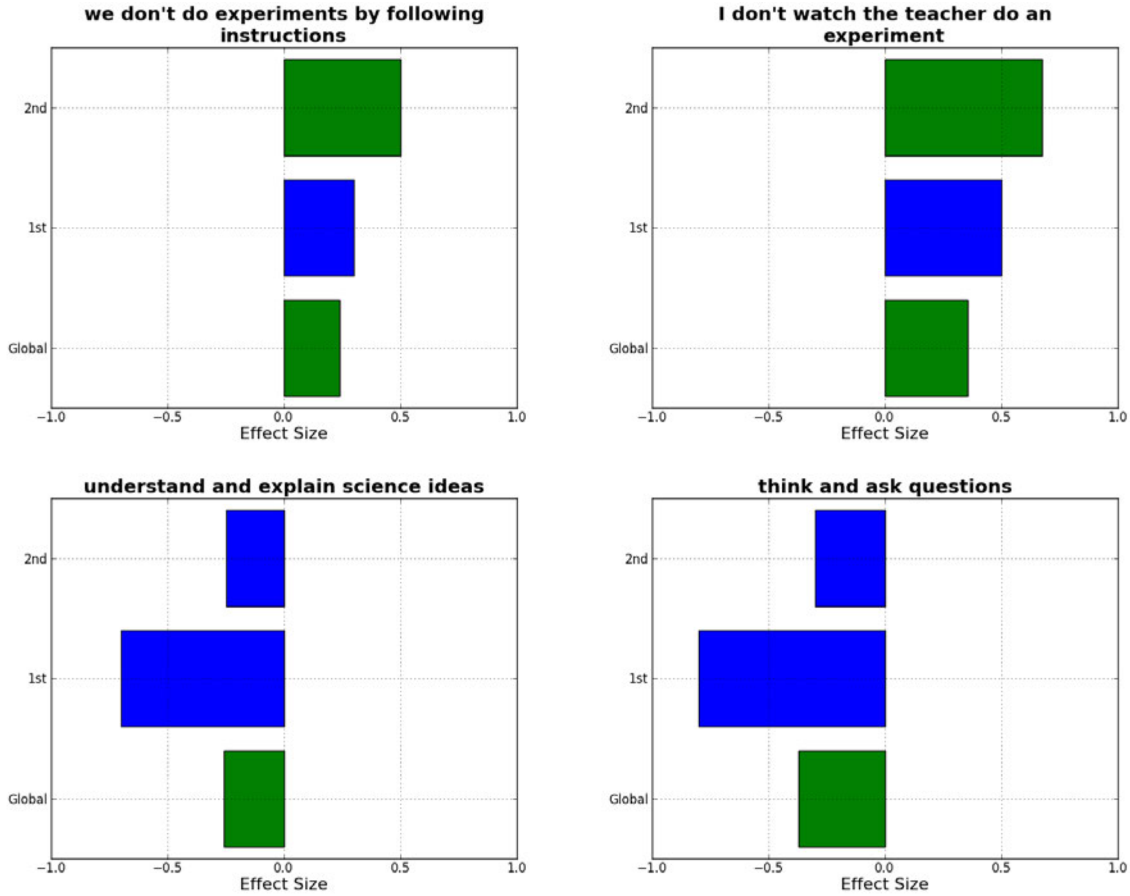

Figure 6: Global changes

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.

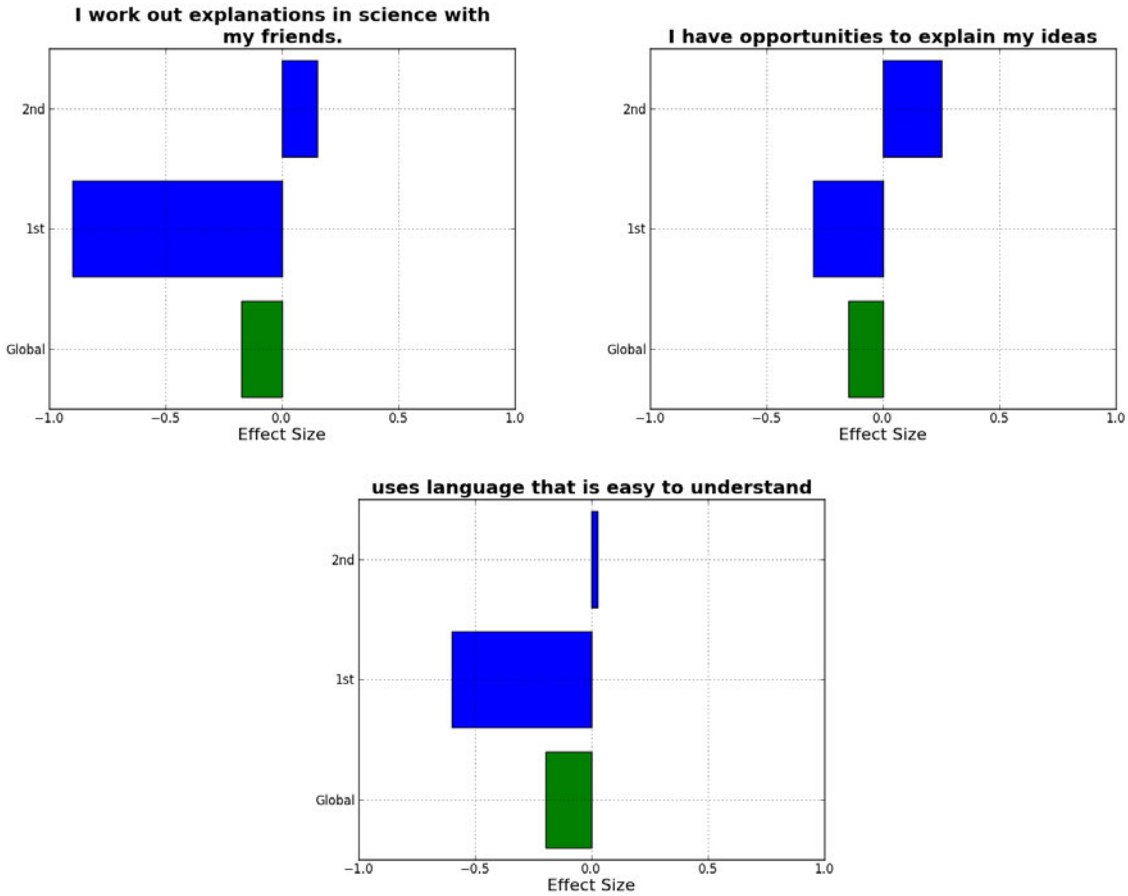

Figure 7 : Changes second time around.

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.

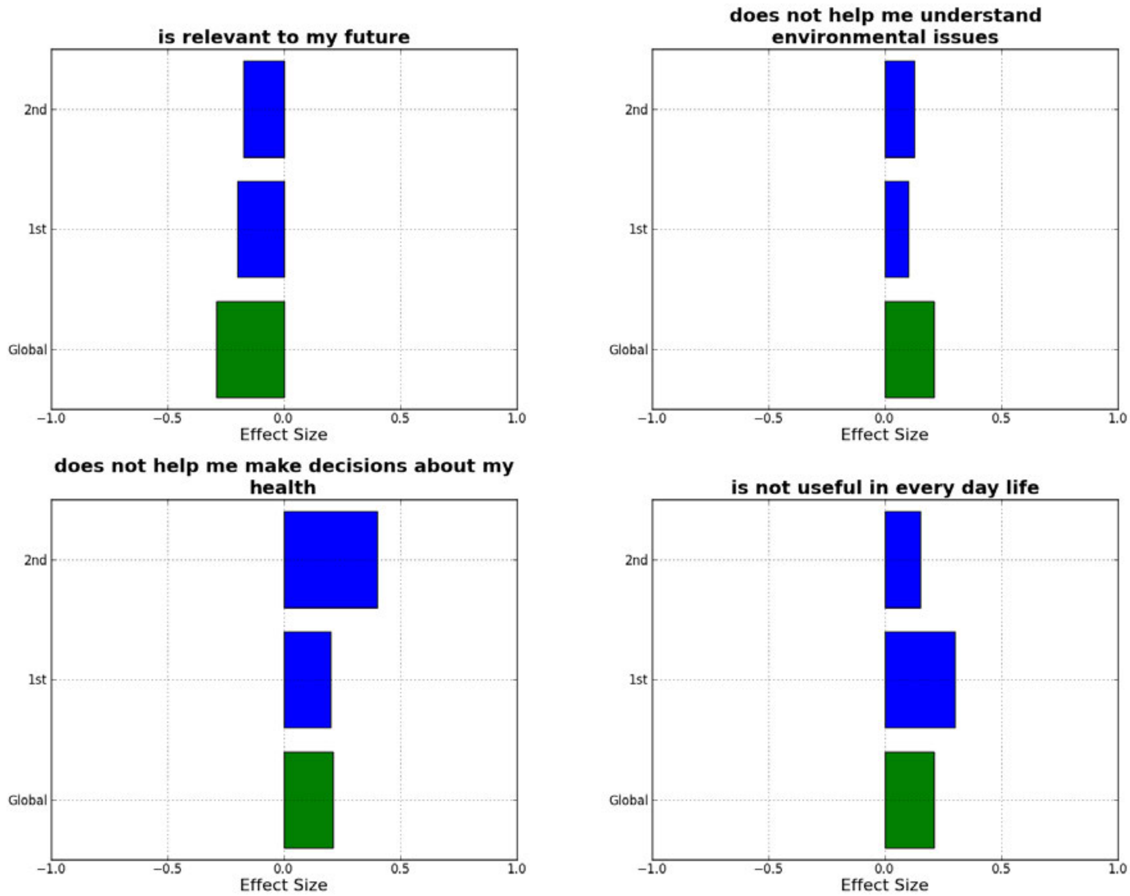

Figure 8: Relevance of Science to everyday life

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.

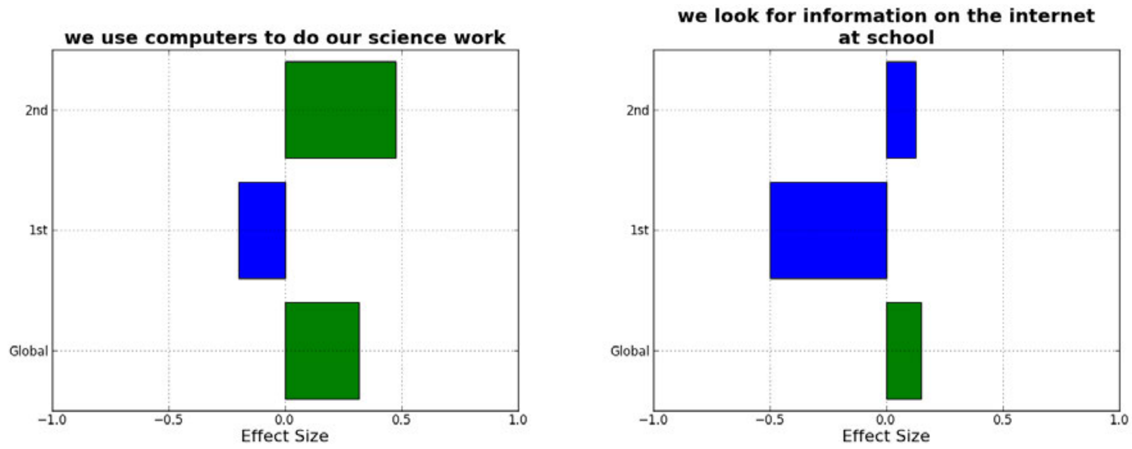

Figure 9: Computer work.

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.

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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.

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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.

Version 2 PRE

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
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Cc: