International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

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To cite this article: T. G. K. Bryce & E. J. Blown (2012) The Novice-Expert Continuum in Astronomy Knowledge, International Journal of Science Education, 34:4, 545-587, DOI: 10.1080/09500693.2011.642325

To link to this article: https://doi.org/10.1080/09500693.2011.642325

Published online: 04 Jan 2012.

International Journal of Science Education
Vol. 34, No. 4, March 2012, pp. 545–587

The Novice-Expert Continuum in Astronomy Knowledge

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The nature of expertise in astronomy was investigated across a broad spectrum of ages and experience in China and New Zealand. Five hypotheses (capable of quantification and statistical analysis) were used to probe types of expertise identified by previous researchers: (a) domain-specific knowledge-skill in the use of scientific vocabulary and language and recognising relationships between concepts in linguistic and schematic forms; (b) higher-order theory in terms of conceptual structure and enriched scientific knowledge and reasoning; with an expectation of cultural similarity. There were 993 participants in all, age 3–80 years, including 68 junior school pupils; 68 pre-school pupils; 112 middle-school students; 109 high-school students; 79 physics undergraduates; 60 parents; 136 pre-service primary teachers; 131 pre-service secondary teachers; 72 primary teachers; 78 secondary teachers; 50 amateur astronomers and astronomy educators; and 30 astronomers and physicists; with approximately equal numbers of each group in both cultures; and of boys and girls in the case of children. For them, the methodology utilised Piagetian interviews with three media (verbal language, drawing, play-dough modelling), and for adults a questionnaire inviting responses in writing and drawing was used. The data from each group were categorised into ordinal scales and then analysed by means of Kolmogorov–Smirnov two-sample tests. The findings supported the hypotheses with evidence of all forms of expertise increasing with experience in both cultures (α level 0.05). The relative gains, overlaps and deficits in expertise across the novice-expert continuum are explored in detail.

Keywords: *Survey; Cross-cultural; Physics education; Astronomy knowledge; Novice-expert continuum; Knowledge-skill*

Introduction

Research interest in novices versus experts initially focused on intellectual pursuits like chess playing, identifying, amongst other things, what marks out the capabilities

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ISSN 0950-0693 (print)/ISSN 1464-5289 (online)/12/040545–43

http://dx.doi.org/10.1080/09500693.2011.642325

of skilful, accomplished individuals. Now, the idea of a novice-expert continuum is regularly posited in several fields of education, sometimes in relation to what may be known, and what skills may be acquired, in a particular domain or subject area; sometimes in relation to the extent of the professional expertise which an instructor may possess. In school and university teaching, these necessarily link, whereby a teacher (as expert) needs to know what he or she intends to teach and with experience gets better at imparting that knowledge to students (those deemed novices). As ever, interest focuses upon how novices may be made more expert. We commonly assume that teachers know more than their students; that a primary teacher's grasp of basic science will exceed that of young children; that a secondary teacher's grasp of basic biology, chemistry and/or physics will exceed that of teenage students; and so on. In each case, the common presumption is that the university teacher knows more than the secondary teacher who knows more than the primary teacher, though that is not necessarily the case. Measures of attainment used in schools and universities accord with that presumption. We think in terms of *levels* of understanding of specialised knowledge, roughly age-related. Certificated academic qualifications are devised and used to reflect that notion of growth—at least in general terms. However, within well-defined areas of knowledge or domains, there is relatively little evidence to confirm this line of thinking; that progression *is* steadily made from novice to expert; that the specialised knowledge of the expert is *significantly greater* than that of the novice; that gaps or overlaps are not major. Nor do we know very much about the *relative* expertise of specialist (or amateur) scientists vis-à-vis university teachers, nor about the lack of knowledge in particular domains of significant others, like pupils' parents and guardians.

The research described in this article looked at the domain of astronomy knowledge, at what people know about the shape and motion of the Earth, the Sun and the Moon; and associated concepts of time, day/night, seasons, eclipses and gravity—in the case of school pupils, to what is normally referred to in the literature on *children's cosmologies*; and, in the case of undergraduates, parents, teachers, physicists and astronomers (adults), to what may be termed *general astronomy knowledge*. Using a semi-structured interview strategy based around a common set of questions, we investigated what was known by samples of people in the categories shown in Figure 1 (across the novice-expert continuum). Our main goal was to give a complete overview across the continuum based on groups (with ages ranging from 3 to 80 years) we had access to in New Zealand (NZ) and China, two countries with contrasting cultures and differing emphases upon basic science teaching in schools. The analysis would complement the cross-cultural findings reported in earlier publications (Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007). Importantly, it would enable comparisons to be made between the categories and thus to reflect closely on the extent of the expected gains to be made from the novice (pre-school pupils) to the expert (astronomers and physicists), and to examine carefully how large were the gaps or overlaps in what people know. As our literature review will show, we had reason to be concerned about the extent of the deficiencies in the basic astronomy knowledge of teachers and how these might compare with student knowledge.

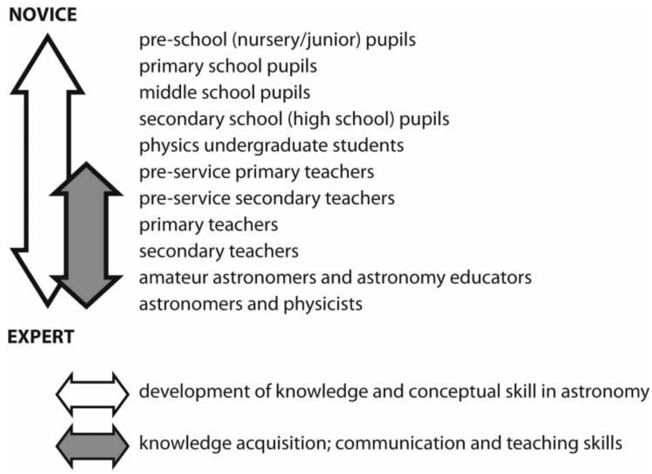

Figure 1. The novice-expert continuum in the present study

Why Astronomy Knowledge?

The importance of astronomy and astronomy education as part of any basic teaching in science has been eloquently stated by Percy (1998):

> Astronomy is deeply rooted in the history of almost every society, as a result of its practical applications and philosophical implications. It still has everyday applications to timekeeping, seasons, navigation and climate, as well as to longer-term issues such as climate change and biological evolution. Astronomy not only contributes to the development of physics and the other sciences, but is an important and exciting science in its own right. It deals with the origin of the stars, planets, and life itself. It shows our place in time and space, and our kinship with other people and species on earth. It reveals a universe which is vast, varied and beautiful. It promotes curiosity, imagination, and a sense of shared exploration and discovery. It provides an enjoyable hobby for millions of people . . . In a school context, it demonstrates an alternative to the 'scientific method'—the observation *vs.* theory approach. It can attract young people to study science and technology—both of which are important in all countries both developed and developing. (p. 2)

Thus, astronomy education is advocated not only for its intrinsic value in terms of scientific knowledge but also because it can act as a catalyst offering 'a unique opportunity for promoting scientific teaching' through approaches which focus on experimentation and observations of natural phenomena. This may help to alleviate what some researchers describe as 'a crisis for the teaching of scientific subjects everywhere', a conclusion referring to the lack of basic *scientific* knowledge, based on discussions with science teachers from 17 European countries (Gouguenheim & Gerbaldi, 1998, p. 257).

There is also substantial goodwill on the part of amateur astronomers to become involved in teaching astronomy in schools providing teachers with invaluable in-service training; and school communities with access to 'master' or 'expert' astronomy practitioners (many of whom own portable telescopes which can be used for observational astronomy with children) at relatively low cost (see British Astronomical Association, 2009; Pasachoff & Percy, 2005). More needs to be said about what researchers have found by way of the astronomy knowledge held by pupils and teachers. First, however, we need to look into greater detail about what is meant by expertise in any particular domain.

Expertise as Knowledge in Domains Versus Intuitive Thinking

Expertise has been a rich but complex field for researchers, particularly in respect of how much of it can be put down to experts simply knowing more, and how much of it is due to altered thinking where the expert *perceives* problems in different ways and uses quite dissimilar strategies to those of the novice. The latter involves intuitive thinking (thinking that comes to mind quickly and without apparent reason or reflection) and is intriguing because the general conclusion from research about expert knowledge is that it is *domain-specific*, rather than general (Chase & Simon, 1973; Gobet, 1998; de Groot, 1946/1965; de Groot & Gobet, 1996). The expert who readily solves problems in one domain is no more competent in another domain. However, the intuitive skills remain elusive in nature; we have difficulty in saying what they are or how they come to work for the person who has mastered an area of knowledge. Didierjean and Gobet (2008), for example, regard intuition as a form of 'knowledge of an implicit, non-verbalised kind' and that it is the foundation of cognitive expertise (pp. 118–121). Certainly experts build up their experience over time and, while their way of perceiving things in their own domains may be attributed to training—which alters what kinds of things they choose to memorise—their 'know how' is little verbalised in contrast to their declarative knowledge, their 'know that'.

Research into expertise in physics identifies intuition as a feature of the expert's reasoning processes. For example, Chase and Chi (1981) consider that the advanced problem-solving skill of physics experts involving 'physical intuition' is analogous to the enhanced perceptual recognition skill of chess masters—'chess intuition'—and is non-analytical rather than visual. Hence, in addition to three elements identified by accumulated research on chess masters (experts fixating on domain-specific images; experts seeing relationships between concepts in parallel rather than serially; experts having a larger visual span), Chase and Chi identified two further characteristics of expert performance. Experts group problems according to underlying abstract principles, whereas novices group them according to concrete physical features. And this advanced performance is reflected in long-term memory schemata (p. 116). Nersessian (1995) believes that, while physics experts differ from novices in their domain-specific knowledge and reasoning, some of their reasoning and visual modelling is domain-independent. Reiterating the conclusions that experts' knowledge is deeper and more flexible, Bransford, Brown, and Cocking (2000) note also that its applicability seems to be part of the learning and progressive understanding which individuals acquire; those who become expert learn to teach themselves as part of the transition.

Expertise and Knowledge Restructuring

The changes that take place in cognition as beginners or novices gain experience to become experts—the process sometimes described as the *novice-expert shift*—have received wide attention, particularly expertise in chess and problem-solving skill in physics, especially in mechanics (see Carey, 1985; Chi, Glaser, & Rees, 1982; de Groot, 1946/1965; Larkin, 1979; McCloskey, 1983; White, 1983). With regard to the knowledge which people acquire and the conceptual changes which (can) take place, the shift can be interpreted as either:

(1) *weak restructuring* where experts (a) form *different kinds of relationships between their concepts* compared with novices as a consequence of the former's richer knowledge base and (b) create new concepts and conceptual organisations from patterns in these new relationships through *dynamic perception*, an advantage that novices lack (see Carey, 1985; Chi et al., 1982; Didierjean & Gobet, 2008; de Groot, 1946/1965).
(2) *radical restructuring* where the differences in interpretation of phenomena between them is such that there are no shared concepts between novices and experts, hence they represent *different theories of interpretation*. The actual structure, the explanatory phenomena and the concepts involved are different.

Importantly in (2), the embedded relationship between concepts and theories appears to be such that they are interdependent to a degree of inseparability (see Blown & Bryce, 2010; Murphy & Medin, 1985).

Expertise as Skill in Concept Creation

More recent theories of knowledge acquisition and conceptual change interpret *concepts* as *simulators or skills* enabling the creation of images of reality consistently over a range of modalities (verbal description, drawing, model making, etc: see Barsalou, 2003; Blown & Bryce, 2010), rather than as recall from semantic memory. This has led to some writers using the expression *knowledge-skill* to indicate just how complex or sophisticated we should think of it rather than simply 'knowing' about things. From the perspective of *metacognitive skill*, this alternative view means that to be able to impose a conceptual structure around knowledge and scientifically reason about it, experts have both a *conceptual* and a *perceptual advantage* over novices. Experts' *extensive domain-specific knowledge-skill* enables them to *recognise relationships between concepts* in *linguistic* and *schematic* forms and their dynamic perceptions afford a *perceptual advantage*. Also, experts can be said to possess *higher-order theory* in terms of the *conceptual structures* they create and the *enriched scientific reasoning* they display (see Carey, 1985; Chi, Feltovich, & Glaser, 1981; Chi et al., 1982; de Groot, 1946/1965; Holding, 1992; Larkin, 1979, 1985; Larkin, McDermott, Simon, & Simon, 1980; Murphy & Wright, 1984; Wiser & Carey, 1983). Second, considering what we know about the effects of teaching, enhanced conceptual skill can occur through the acquisition and use of *scientific language* (see Cromer, 1987; Kuhl, 2000). Third, in relation to particular teaching methods, pupils are encouraged to apply *concepts as simulators* through thought-experiments involving mental imagery and concrete modelling activities (see Clement, 1994; Nersessian, 1995). All of these have implications for what we should look for in trying to distinguish between experts and novices in a given domain of knowledge. It is worth considering language in some more detail.

The Role of Language in the Acquisition and Development of Expertise

Although knowledge of chess is thought to have been originally transmitted orally (see Anand, 2008), skill in verbal language does not play a significant role in chess expertise because 'chess thinking is typically non-verbal' (de Groot, 1946/1965, p. 335). However in many other domains, verbal and written language and expertise are intricately interwoven—witness (a) the role of experience in the accelerated acquisition of language; (b) the importance of skill in scientific language for the acquisition of scientific knowledge and (c) the skill evident in the creation of complex concepts though precision in language. These all continue to attract the attention of researchers, for example, (1) in infants and children as enhanced conceptualisation and perception through linguistic memory and experience (see Cromer, 1987; Kuhl, 2000); (2) in students, as improved understanding of science (see Wellington & Osborne, 2001) and (3) in scientists, as affording the sharing of complex ideas in physics such as those of quantum mechanics (as discussed in Pais, 1991).

Metacognitive mechanisms such as talking aloud and self-explanation are also commonly thought to play an important role in the acquisition of expertise, e.g. in Conan Doyle's novels, Sherlock Holmes often thought through cases aloud using Dr Watson as 'a whetstone to his mind' (Didierjean & Gobet, 2008, p. 118). However, there has been little research of this strategy in adult expertise. Although de Groot (1946/1965) recorded verbal protocols of chess players as they thought through their moves, he found that they did not reflect metacognitive processes: 'It is the *contents* of thought, not the *structures* of thought, that really makes the difference in quality of outcomes. And we suggest that the contents of thought are mainly these *perceptual* structures that skilled chess players retrieve, for the most part, from long term memory' (Chase & Simon, 1973, p. 268, our emphasis). Verbal self-explanation has however been used successfully by children learning chess (see Horgan, 1992) and also in science (see Driver & Bell, 1986); mathematics (see Raiker, 2002) and problem-solving skills (see Chi, De Leeuw, Chiu, & La Vancher, 1994).

The literature reviewed here thus emphasises the expectations that the groups (outlined in Figure 1) should therefore be reflective of increasing scientific language sophistication as we move through the novice-expert continuum. Along that continuum, *knowledge-skill* should be mirrored in the vocabulary which people use for astronomical concepts; in the relationships between concepts which they reveal in their explanations (whether written, spoken, drawn, or in captions they apply to drawings); in the higher concept categories which they do or do not use; in how they respond to questions asking how or why everyday occurrences like sunrise and seasons take place, as well as infrequent but predictable events like eclipses.

The Knowledge of Basic Science and Astronomy in Teachers

While teachers are one of children's major sources of scientific knowledge (see Bryce & Blown, 2006), there is substantial evidence that pre-service and practising teachers in both primary and secondary schools have an *inadequate* knowledge of basic science and lack confidence in teaching astronomy. Bull, Gilbert, Barwick, Hipkins, and Baker (2010) found that, compared with their international colleagues, 'New Zealand primary teachers had relatively low levels of pre-service specialisation in science and received less on-going professional development' (p. 22). In the case of pre-service primary teachers the main concerns are: (a) inadequate scientific *subject matter knowledge* akin to the impoverished knowledge base of novices; (b) lack of scientific *pedagogical content knowledge* (PCK); (c) dearth of scientific *curriculum knowledge* and (d) deficiency in *teaching confidence, competence and self-efficacy* (see Appleton, 1992; Bleicher, 2006; Bull et al., 2010; Education Review Office, 2010; Ginns & Watters, 1995; Kalkan & Kiroglu, 2007; Ministry of Education, 2000; Ojala, 1997; Shallcross, Spink, Stephenson, & Warwick, 2002; Trumper, 2003). Fortunately, many of these shortcomings can be overcome by pre-service training (see Henderson, 1992; Trumper, 2006; Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). Similar concerns are reported for pre-service secondary teachers with pedagogical knowledge foremost; and methods to address inadequacies through in-service training have been proposed (see Craven & Penick, 2001; Education Review Office, 2010; Ogan-Berkiroglu, 2007; Trumper, 2001; Tytler et al., 2008).

In the case of new primary and secondary teachers, areas of inadequate subject matter knowledge have been identified (see Bolstad & Hipkins, 2008; Bull et al., 2010; Education Review Office, 2010; Mant & Summers, 1993; Shea & Greenwood, 2007; Traianou, 2006; Tytler et al., 2008; Varrella, 2000; Watson, 2006). Specific areas of *expert-novice teacher comparison* include the following: (a) astronomy (see Barba & Ruba, 1992, 1993); (b) conceptions of learners' prior knowledge (see Meyer, 2004); (c) pedagogical reasoning (see Jay, 2002); (d) physics (see Dufresne, 1988) and (e) science investigation skills (see Hackling & Garnett, 1992).

The PCK of science teachers has also been studied in depth internationally as follows: (a) in Australia, by Loughran, Mulhall, and Berry (2008), Tytler et al. (2008) and Vlaardingerbroek and Taylor (2003); (b), in Holland, by Henze, van Driel, and Verloop (2008); (c) in Sweden, by Nilsson (2008); (d) in NZ, by Bolstad and Hipkins (2008), Bull et al. (2010) and Lewthwaite and MacIntryre (2003) and (e) in USA, by Lee and Luft (2008). There is a general consensus that the concept of PCK as an integration of children's scientific understandings and ways in which these can be developed through innovative teaching remains a useful tool in educational psychology and methodology. However, in all of the studies there have been concerns about the adequacy of current teacher training. With regard to what good teaching does achieve, Bereiter and Scardamalia (1993) urge us to recognise that there is a '*growing edge*' to expertise and that, accordingly, science teachers should adopt a 'progressive problem-solving approach'; as far as possible being responsive to how pupils are intellectually progressing in their thinking.

The *subject matter knowledge* and skills required for effective teaching of science in general and astronomy in particular have also been investigated internationally as follows: (a) in Australia, by Broadfoot and Ginns (2005), Tytler et al. (2008) and Vlaardingerbroek and Taylor (2003); in China, by Feng (1990); (b) in Israel, by Trumper (2001, 2003, 2006); (c) in NZ, by Lewthwaite and MacIntryre (2003); (d) in Turkey, by Kalkan and Kiroglu (2007); (e) in UK, by Mant and Summers (1993); (f) USA, by Barba and Rubba (1992, 1993), Hemenway (2005), Sadler and Luzader (1990) and Schoon (1995). As in the case of PCK, these studies have drawn attention to inadequacies in the subject matter knowledge of pre-service and beginning teachers of science. Research (particularly in the USA) indicates serious shortcomings in the scientific knowledge of students after over 10 years of primary and secondary education by qualified teachers with standardised science textbooks and teaching resources. These inadequacies are reflected in the knowledge of pre-service teachers (see Schneps & Sadler, 1987). For example, in a recent survey (National Science Foundation, 2006), only 41% of high-school students were able to give *Correct answers to Scientific literacy questions*. Similarly, in a later survey (National Science Foundation, 2008), when asked: *Does the Earth go round the Sun or does the Sun go round the Earth?* only 51% of high-school students expressed a Copernican view: and when asked *How long does it take for the Earth to go around the Sun: one day, one month, or one year?*, only 33% of high-school students gave a heliocentric response.

Differences in Curricular Emphases

Differences in emphasis on science in society are reflected in curriculum structure and time allocations at secondary school and pre-service teacher level. In China, science education is given high priority hence all secondary students study science as compulsory subjects to age 18, whereas in NZ science has relatively low priority and thus becomes optional from age 15.

These differences in the value of science are reflected in teacher training. In China all high-school students are required to study Biology, Chemistry, Geography (including Astronomy), Maths and Physics to university entrance level. And, if they go on to become teachers, both pre-service primary and secondary teachers study further science content and science teaching methodology at university (D. Xing, Education Bureau of Changchun Municipality; L.Q. Niu, Fujian University of Technology, personal communications, 5 April 2011).

Because of differences in priority, time allocation is also more generous in China. For example, for astronomy and Earth science topics at secondary school, there are 32 h over 4 years in China compared with 16 h over 1–2 years in NZ. At pre-service teacher level in China from one to two-thirds of all curriculum time is spent on teaching science content: up to 50% of allocated university curriculum time for future primary teachers; and up to 70% for future secondary teachers (T.-X. Li, North Eastern Normal University, personal communication, 12 February 2011). The comparable figures from NZ show that the time allocation for science content and pedagogy for teaching future teachers is minimal: 32 h over 4 years for primary undergraduates of which only 1/2 h is devoted to teaching how to teach astronomy; 10 h over 1 year for primary graduates; 30 h over 4 years for secondary undergraduates and 20 h over 1 year for secondary graduates (Victoria University of Wellington, 2011). This puts great pressure on science educators preparing their students for teaching science (R. Bartholomew, personal communication, 31 January 2011).

There has also been a trend in recent years to de-emphasise science in favour of language and mathematics (literacy and numeracy) both at the political and curriculum planning level; and by individual teachers in the classroom. According to Tytler et al. (2008),

> This is because science is often the subject that primary teachers feel least confident to teach and many avoid teaching science; because equipment is seen as time consuming and difficult to organise; and because the curriculum is seen as crowded, with literacy and numeracy having a higher priority and being mandated in the early years of primary school. (p. 62)

Science educators do their best to cope with the task of teaching pre-service teachers from diverse science backgrounds with equally varied content knowledge and the pedagogy of teaching science in the limited time available—a task akin to 'turning specialists [secondary graduates] into GPs and GPs [primary graduates] into specialists' (R. Bartholomew, personal communication, 31 January 2011).

Note. A GP is a General Practitioner (Family/Community Doctor).

Overall

These findings all suggest that any survey of astronomy knowledge is likely to reveal small differences between the knowledge possessed by secondary pupils and that by their teachers, possibly even overlaps in detectable expertise. We should remember the conclusions of Kruger and Summers (1988), who reported that '... many primary teachers and trainees hold scientific ideas which are closer to those of children than scientists' (cited in Shallcross et al., 2002, p. 1293). Furthermore, *Earth and beyond* was the least covered and least confident area (Shallcross et al., 2002, pp. 1298–1299).

Who Are the 'Novices' and the 'Experts'? Some Terminological Inexactness

Research into the novice-expert continuum in physics is hampered by considerable variation in how researchers have used the expressions *novice* and *expert* in their various researches. For example, Larkin (1979) in her seminal chapter on the expert/novice shift, defined her experts as 'experienced physicists' and her novices as 'beginning physics students' (p. 113). Chi et al. (1981) described their experts as '8 advanced PhD students', and novices as '8 undergraduates who had just completed a semester of mechanics' (p. 31). Discenna (1998) defined her experts as 'university professors who had been involved in teaching and research in physics for at least 10 years', intermediates (between expert and novice) as '1st or 2nd year graduate students who had completed a bachelor's degree in physics, but had not yet completed comprehensive examinations in physics', and novices as 'students who had completed only one semester of classical mechanics at the introductory level' (p. 10). diSessa (1983) discussed three levels of knowledge: 'naïve', 'novice' and 'expert'. He did not specify his naïve group but rather uses the term 'physics-naïve students' in the context of formal physics, which implies that he is thinking of school pupils. His novices were 'four MIT undergraduates taking freshman physics'; and his experts were 'physicists' (pp. 15–17). For the purposes of this research, we have taken *novice* to mean *an inexperienced person*; *a beginner*, *a learner*, e.g. a student; *expert* to mean one who has *gained skill from experience*; or one whose *special knowledge or skill causes him to be regarded as an authority*; *a specialist*, e.g. an astronomer or experienced teacher; and *expertise* to mean *expert knowledge or skill in a particular branch of study*, e.g. astronomy or teaching science. We use *master* synonymously with *expert* as in *chess-master*, *an expert chess player*, e.g. a master-teacher. However, to assist interpretation, in the case of astronomers and physicists, we have distinguished between amateurs and professionals by using *master* for amateur astronomers and non-university astronomy educators (e.g. planetarium teachers); and *expert* for professional astronomers and physicists (university professors, lecturers and research scientists).

Purpose, Rationale and Research Questions

The current study set out to investigate the nature of expertise and to explore its development in the domain of astronomy knowledge, taking into consideration the *knowledge-skill* interpretations described earlier. We looked at its growth from childhood to adulthood with children, students and parents; from novice to master teacher with pre-service to experienced teachers; and from tertiary physics student to Earth science, physics and astronomy specialist with physics undergraduates, physicists and astronomers. The first strand of the study examined the development of knowledge and conceptual skill in physics in general and astronomy in particular from junior *novice* (pre-school children and primary school pupils), through senior *novice* (secondary school students) and tertiary *novice* (undergraduate students), to *master* (amateur astronomers and astronomy educators) and *expert* (physicists and astronomers). The second strand of the study examined expertise in knowledge acquisition and communication exemplified by the skills needed to be an effective, innovative teacher with particular focus on the transition from *novice* to *master* science teacher. Because of their role as sources of knowledge about the world, parents of participant children were also included. The study enquired into the knowledge of Earth science and astronomy held by pre-service primary and secondary teachers and experienced primary and secondary teachers, and did so in two different countries (China and NZ), in the hope of identifying possible, common shortcomings in teacher education in these two quite different cultures. To tackle these enquiries we developed:

(a) an astronomy *vocabulary scheme* (to analyse verbal and written responses by participants);
(b) an astronomy *concept schematic scheme* (to analyse participants' drawings and captions);
(c) a general astronomy *concept category scheme* (to analyse linguistic and schematic responses to interview questions) and
(d) a *How/Why? category* scheme to analyse linguistic and schematic responses.

These will be described in due course. They enabled several hypotheses to be operationalised. By *schema* we mean a *conceptual organisation* (not necessarily pictorial in nature). And by *schematic* we mean *a* physical *drawing* of concepts (e.g. a drawing of the motion of the Earth): thus a *schematic schema* is a drawing of a group of related concepts: e.g. a drawing of the shape and motion of the Earth–Sun–Moon system; habitation and identity with Earth (see Figure 1). Our categorisation schemes depict series of such schema of elements of astronomical knowledge: e.g. Earth shape, Earth motion; to form *schemata* (after Piaget) in ordinal scales from least to most scientific. These have both a descriptor (a *linguistic schema*); and a thumb-nail sketch of the essence of the concept (a drawing or *schematic schema*) (Blown & Bryce, 2006, 2010; Brewer & Nakamura, 1984; Bryce & Blown, 2006, 2007).

Hypotheses Capable of Quantification and Statistical Analysis

In light of the research literature presented earlier, we hypothesised that:

(1) Expertise as *extensive knowledge-skill in applying scientific language and recognising relationships between concepts* would be demonstrated as higher vocabulary means.
(2) Expertise as *extensive knowledge-skill in recognising relationships between concepts in schematic form* would be detectable as higher concept category means.
(3) Expertise as *higher-order theory* would be indicated by more complex conceptual structures used in interviews.
(4) Expertise as *enriched scientific knowledge* in response to *How?* questions would be detectable through the use of higher concepts.
(5) Expertise as *enriched scientific reasoning* in response to *Why?* questions would be detectable in the links made amongst higher concepts.

In addition, in keeping with previous comparisons conducted by the authors (see Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007), it was anticipated that these five reported forms of expertise would be,

(1) *universal across the two cultures* under investigation, detectable as similar concept category and vocabulary means,

and, where longitudinal comparisons could be made,

(2) survey groups would have *higher concept category and vocabulary means* over their respective control groups.

Method

The methodology was based on what Ericsson and Smith (1991) describe as 'the expertise approach', one of the several approaches to account for outstanding performance, with terms like 'primarily acquired' (i.e. attained by learning, training and experience) in the field of 'domain-specific training and practice' applied to the acquisition of expertise in physics and astronomy; and in skill in teaching science utilising this knowledge. We conformed to the method of the expertise approach which has two distinguishing operational criteria: (a) the design of an instrument 'to capture the relative aspects of superior performance in a domain' and (b) data that afford 'systematic empirical analysis of the processes leading to the superior performance' and 'assessment of critical mediating mechanisms' (pp. 1–8).

The research design of the current study incorporated all of the requirements of the traditional approach (founded on the work of Chase & Simon, 1973; de Groot, 1946/1965). Comparisons were made between the various groups using the *Kolmogorov–Smirnov (K-S) Two Sample Test* to detect significant differences between means using the methodology previously reported (Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007). Because of the nature of the research, control groups were not used with adult groups. However, in the case of the secondary school groups, where survey and control groups had been established in earlier studies, there was an opportunity to test for differences in expertise as a result of repeated interviews to the advantage of the survey groups. Hence, the inclusion of junior secondary—middle-school, and senior secondary—high-school, survey and control groups.

Samples and Surveys

There were 993 participants in all, age 3–80 years. Table 1 shows the numbers of participants in each of the categories. The locations of these participants were as follows:

Children: Wairarapa in NZ; Changchun in China.
Undergraduates: Christchurch in NZ; Beijing and Changchun in China.
Parents of surveyed children: Featherston in NZ; Changchun in China.
Pre-service teachers: Auckland, Christchurch, Hamilton and Wellington in NZ; Changchun in China.
Teachers, Astronomers and Physicists: throughout NZ; Beijing, Changchun and Jilin in China.

Recruitment

In all cases participation was voluntary and in response to invitations issued through teachers and lecturers in local communities known to the second author. The research was carried out in keeping with American Psychological Association and British Psychological Society ethical guidelines and anonymity assured. The pre-school, primary and secondary children were representative of their communities and

Table 1. Survey participants by category, country, gender and age

	Country							
	China			New Zealand				
Educational level	M	F	Total	M	F	Total	Age	Total
Pre-school	19	15	34	18	16	34	5.8	68
Primary school	15	19	34	16	18	34	10.2	68
Middle school	26	22	48	29	35	64	14.4	112
Secondary school (High school)	34	22	56	20	33	53	17.2	109
Physics undergraduates	26	12	38	34	7	41	20.5	79
Parents	17	13	30	13	17	30	41.7	60
Pre-service primary teachers								
Undergraduates	3	27	30	8	27	35	23.3	
Postgraduates	0	30	30	13	28	41	24.5	
Total	3	57	60	21	55	76	23.9	136
Pre-service secondary teachers								
General science	4	26	30	8	23	31	24.3	
Physical science	27	11	38	18	14	32	24.8	
Total	31	37	68	26	37	63	24.5	131
Primary teachers	6	28	34	7	31	38	37.2	72
Secondary teachers	20	20	40	26	12	38	40.7	78
Amateur astronomers/educators	18	7	25	19	6	25	41.6	50
Astronomers and physicists	10	5	15	14	1	15	43.9	30
								993

Note: M, male; F, female; Age is average figure in years.

approached following initial consultation with teachers and parents in schools. They were matched cross-culturally on the basis of socio-metric data. Individual interviews were conducted in school locations, as described in Bryce and Blown (2006). The parents were members of the respective school communities with children in the surveys. They were invited to participate by letter approved by school principals and a follow-up questionnaire. The physics undergraduates were invited to participate by way of a written questionnaire. The pre-service teachers were studying at university and were made aware of the survey through their lecturers and in response to written requests. Questionnaires were administered by the lecturers on behalf of the researcher (2nd author). The teachers were predominantly from the same local communities as the children. They were invited to participate by letter and follow-up visits to schools.

In NZ the amateur astronomers were either known to the second author (an amateur astronomer) or were recommended by other amateur astronomers; and were invited to participate by letter. Whereas in China they were located by Internet and email initially; then by personal visits to their respective universities or places of work by the researcher (accompanied by an interpreter). Similarly, the professional astronomers and physicists in NZ were recommended by an eminent astronomer known to one of us through teaching and research or were suggested by other astronomers or responded to requests by their universities. Invitation was by letter or email. In the case of China, professional astronomers and physicists were located through Internet details supplied by the above-mentioned eminent astronomer who had contacts in China. As in NZ, invitation was by letter delivered by hand by the researcher or his colleague in China.

Instruments

The methodology utilised three data-gathering instruments as follows:

(1) In the case of pre-school and primary school children (age 3–12): Piagetian interviews with three media: verbal language, drawing and play-dough modelling based on an extensive Interview Guide (see Appendix 1).
(2) In the case of middle-school and high-school students (age 13–18): an extensive (17 page) written questionnaire inviting responses in writing and drawing combined with Piagetian interviews and play-dough modelling to clarify ideas (see Blown & Bryce, 2006; Bryce & Blown, 2006).
(3) In the case of adults (age 19–80): a short (3 page) written questionnaire inviting responses in writing and drawing (see Appendix 2).

The different instruments were designed to investigate the *same key questions* on astronomy and Earth science but at different levels of scientific understanding and knowledge-skill expertise by the most appropriate methodology.

- In keeping with traditional Piagetian research (as practised by the majority of workers in the field) verbal interviews, drawing and play-dough modelling were found to be the most suitable for younger children some of whom had limited writing skills.
- Extensive written questionnaires complemented other media were well suited to older children who had the time and writing skills necessary to express their ideas fully.
- Short-written questionnaires (with room for drawing) were congruous for adults (particularly teachers and astronomers) who have limited time for in-depth surveys.

The instruments used a combination of closed and open (How?/Why?) questions to afford different forms of reasoning at all levels of experience. Bell, Osborne, and Tasker (1985) underline the value of incorporating both kinds of questions when working with young people; their confidence can be maintained but at the same time it is possible to establish clearly the way individuals think about the topic in hand. *How?* Questions investigate scientific knowledge and are essentially closed in that they anticipate simple statements about the nature of the phenomena (e.g. How the Earth moves). Whereas *Why?* questions explore scientific reasoning and are, in a sense, open-ended in that they invite more complex responses concerning explanations of the cause of the phenomena (e.g. Why the Earth moves). In our experience, most adults and almost all children give answers to Why? questions and reveal some of their reasoning. For example:

Q. How does the Earth move?
Parent: Round in circles.
Q. Why does the Earth move?
Parent: It orbits the Sun.

We interpreted 'how' as inviting description of some action, e.g.:

Q. How does the Earth move?
Astronomer: In a nearly circular orbit around the Sun.

And we conceptualised 'why' as seeking a reason for a particular phenomenon, e.g.:

Q. Why does the Earth move?
Astronomer (NZ): As a result of the initial angular momentum of the solar nebula.
Astronomer (China): The Earth's revolution is caused by the gravity of the Sun.

We do recognise that there is a philosophical debate concerning the very nature of science and if/whether *Why?* questions can be answered at all, many asserting that science cannot give answers to *Why?* questions. It seems to us that it all depends on how language is used. To the question: *Why do astronomers believe that the universe came into being from a singularity in the Big Bang?* an astronomer might reply: *Because of the evidence of the expansion of the universe and the microwave background radiation*. But to the question: *Why was there a Big Bang?* science cannot answer. Nevertheless, many scientists (including Steven Hawking) do ponder the question and can posit ideas about the nature of phenomena at the frontier of human knowledge which are currently unclear (e.g. *event horizon, dark matter, dark energy, singularity*, etc.); but which will become clearer in time through the asking of *How?* and *Why?* questions (see Waterhouse, 2011). However, our point here is not to take sides with this debate, but to go with the empirical flow of data from surveys with young people who are not concerned by the fine points of the distinction. A few older participants *did* question the use of *Whys?* to probe scientific knowledge and reasoning. One split the *Why?* question into two elements: reason and cause:

Researcher: How does the Earth move?
NZ: Parent: *In an elliptical orbit around the Sun.*
Researcher: Why does the Earth move?
NZ: Parent: *What do you mean by 'Why?'—Reason: it has none; Causes: cosmic forces such as gravitational 'pull' of the sun.*

Another questioned the validity of *Why?* questions in science.

Researcher: *How does the Sun move?*
NZ: Physicist: *Under the influence of the Milky Way's gravitational field.*
Researcher: *Why does the Sun move?*
NZ: Physicist: *ditto—actually 'Why?' not answered in science.*

While these criticisms and reservations about the use of *Why?* questions were rare, they do suggest an unfamiliarity with open-ended questions among some mature individuals. Younger participants were not bothered by such philosophical debate and responded to *Hows?* and *Whys?* with equal comfort.

Data Analysis, Categorisation and Coding

The data from China were translated and transcribed by interpreters familiar with the research methodology and together with the NZ data, they were initially analysed, categorised and coded. The coding and categorisation involved a system of schema for classifying participants' cosmological concepts (e.g. Earth shape, Earth motion) on ordinal scales from least to most scientific to afford statistical analysis. The scheme was based on descriptors and thumb-nail sketches encapsulating the essential features of each concept, represented through a variety of media, and readily understood by coders (see Bayerl, Lüngen, Gut, & Paul, 2003). Similar classification schemes have been used extensively in the field (see Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou & Brewer, 1992, 1994). Our own have been published in articles in this journal (see Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007). The ordinal scales were designed on the recognised premise that astronomy concepts can be ordered from least scientific (category 1) to most scientific (category 10 or 12) (see Siegel & Castellan, 1988). In the figures which follow, therefore, the vertical scale in each case represents increasing sophistication in the understandings of the subjects who were surveyed.

The present research involved creating new categorisation schemes or adapting old ones. For Hypothesis 1, a new *Astronomy Concept Vocabulary Scheme* was created (see Appendix 3). This includes 100 concept words such as gravity, force, Moon's shadow, revolves, orbit., enabling the results to be scored as a percentage of the shared lexicon. In the case of Hypothesis 2, the descriptive aspect of the authors' previous *Astronomy Concept General Categorisation Scheme* was utilised (Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007). Similarly, for Hypothesis 3, the schematic feature of the authors' previous General Categorisation Scheme was adapted to create the *Astronomy Concept Schematic Scheme* (see an example in Figure 2). With Hypothesis 4, responses to *How?* questions were analysed utilising a new *Astronomy Concept How?/Why? Categorisation Scheme* (see Figure 3(a) in relation to How the Earth moves). Similarly, in the case of Hypothesis 5: *expertise as enriched scientific reasoning*: responses to *Why?* questions also used the How?/Why? Scheme (see Figure 3(b) in relation to Why the Earth moves). Similar schemes were developed for How/Why Sun moves? and How/Why Moon moves?

The new and adapted schemes and a range of exemplars from each category were checked by two astronomers from Carter National Observatory in Wellington, NZ, with an inter-coder agreement of 92–96%; *Cohen's* $\kappa = 0.92–0.94$.

Results

Protocols

An indication of the variation in vocabulary and expressions used by respondents across the continuum is given by the examples given in the following two lists where category 1 denotes *least scientific* and category 12 denotes *most scientific*. The

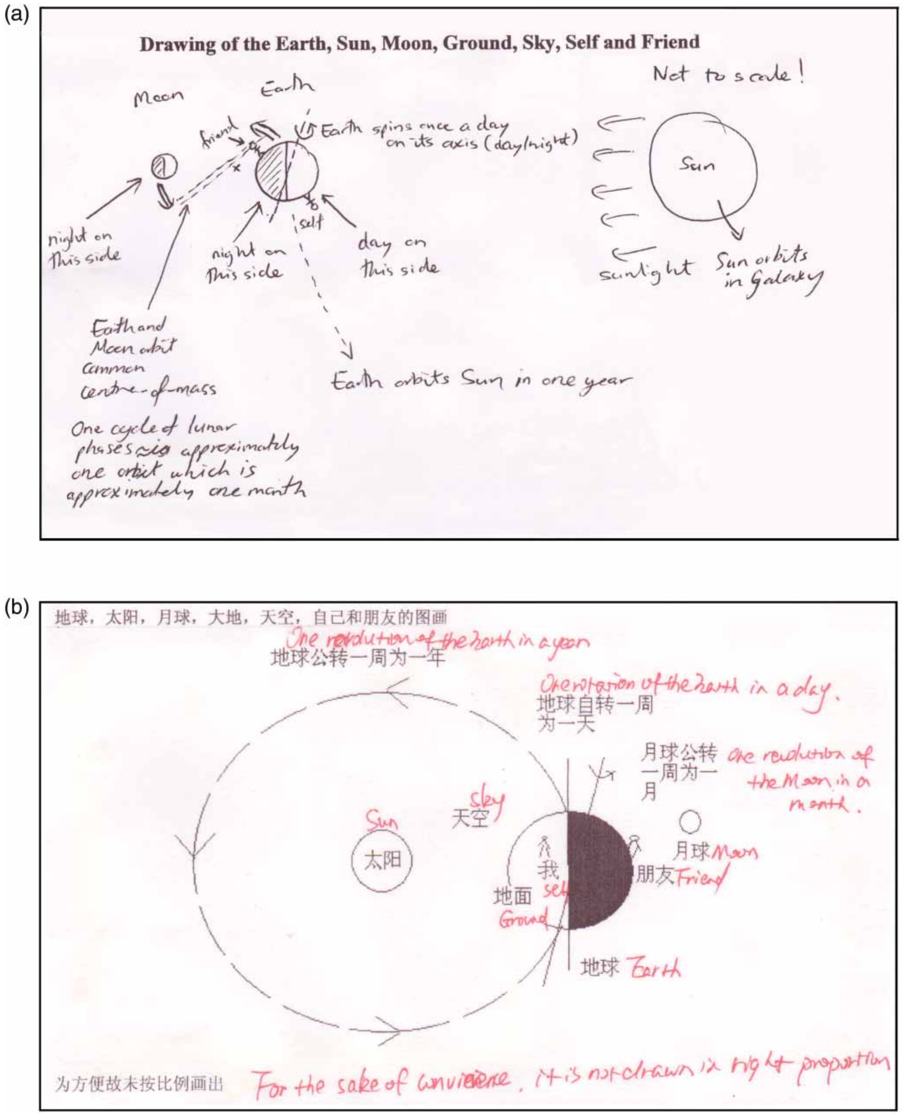

Figure 2. Astonomy Concept Schematic Scheme: Examples from NZ and China. (a) Drawing of the motion of the Earth, Sun and Moon by NZ Astronomer. (b) Drawing of the motion of the Earth, Sun and Moon by China Astronomer

first list gives examples in response to *How?* questions, in particular to: *How does the Earth move?* The second illustrates answers to *Why?* questions, in particular to: *Why does the Earth move?* These exemplify the growth of domain-specific knowledge-skill in recognising relationships between concepts, scientific vocabulary and schematic representations across the novice-expert continuum. Key concepts are given in **bold**.

(a)

12	Rotates on axis and Revolves around the Sun which Revolves around the Galaxy which is in motion in the Local Group of Galaxies
11	Rotates and Revolves around Sun and Galaxy; incl. less scientific terms; e.g., spins, moves round/around; or circles; or orbits
10	Rotates on axis and Revolves around the Sun; incl. less scientific terms; e.g., spins, moves round/around; or circles; or orbits
9	Revolves around the Sun; including less scientific terms; e.g. spins, or moves round or moves around; or circles; or orbits
8	Rotates on axis; including less scientific terms; e.g., spins
7	Revolves around Sun: non-scientific terms; e.g., moves; or confuses terms; e.g. uses rotation instead of revolution (see drawings)
6	Rotates on axis: non-scientific terms; e.g., moves round or around (clarified by drawings)
5	Rotation and/or Revolution uncertain; moves in some way relative to Sun and/or Moon; e.g. Earth revolves around Moon
4	Stationary in relationship to Sun and/or Moon
3	Moves in some way not related to Sun and/or Moon; e.g., moves round and round; or during earthquakes
2	Animate
1	Not sure. No response.

(b)

12	Angular momentum (causing rotation and/or revolution)
11	Gravity of Sun; and/or Moon; and/or Solar System; and/or Galaxy (causing rotation and/or revolution)
10	Gravity; or (Universal) Gravitation; or (Gravitational) attraction; or Gravitational fields; or Gravitational forces; or Gravitational pull
9	Force, pull or energy from Sun (alternative explanations of effect of gravity of Sun and/or Moon)
8	Rotates on axis and Revolves around Sun; including less-scientific terms ; e.g. spins, moves around, orbits
7	Revolves around Sun: including less-scientific terms; may confuse terms; e.g. rotation instead of revolution (clarified by drawings)
6	Rotates on axis; including less-scientific terms; may confuse terms; e.g. use revolution instead of rotation
5	After effects of Big Bang – Expansion of Universe
4	Magnetic energy; Magnetic field; Magnetic force; Electromagnetism; Energy from Sun or other sources
3	Moves in some way (other than rotation on axis and revolution around the Sun)
2	Stationary
1	Not sure. No response. Don't know

Figure 3. (a) Ordinal scale for responses to question: How does the Earth move? (b) Ordinal scale for responses to question: Why does the Earth move?

Responses to: ***How does the Earth move?***

Category 12	NZ: Astronomer: *In a nearly circular **orbit** around the Sun which is also in motion around the **centre of the galaxy**, which in turn is in motion in **Local Group**.* China: Astronomer: *It **rotates** and **revolves** around the Sun and the **Galaxy**.*
Category 11	NZ: Amateur Astronomer: *By **rotating on its axis** and by **orbiting the Sun** which itself is **orbiting the Milky Way**.* China: Amateur Astronomer: *It **rotates** and **revolves** around the Sun in a **circular orbit** with the **Solar System** in the **Galaxy**.*
Category 10	NZ: Secondary Teacher: *In an **elliptical orbit** around Sun, **rotating about axis**.* China: Secondary Teacher: *It **revolves around** the Sun in an **oval orbit** and **spins** as well.*
Category 9	NZ: Physics Undergraduate: *In an **elliptical orbit** about the Sun.* China: High School: *The Earth **revolves** around the Sun.*
Category 8	NZ: Primary Teacher: (It) ***spins on its axis***. China: Pre-Service Secondary Teacher: *The Earth **rotates on its axis**.*
Category 7	NZ: Junior Secondary Student: ***Rotating*** around the Sun [Drew Earth rotating and revolving around Sun]. China: Pre-Service Primary Teacher: *(It) **rotates*** [Drew Earth orbiting Sun].
Category 6	China: Parent: *It moves around the Sun.*
Category 5	NZ: Parent: *Not sure—Earth **rotating** on its **axis** towards and then away from Sun* [Drew Earth revolving around Moon].
Category 4	China: Primary School Pupil: *No* (it doesn't move).
Category 3	NZ: Primary School Pupil: *It's moving around in circles and the Moon is moving and that—turning around.*
Category 2	China: Pre-School Pupil: *It flies in the sky—it never lands on the ground.*
Category 1	NZ: Pre-school Pupil: *I don't know* (what the Earth is).

Responses to: ***Why does the Earth move?***

Category 12	NZ: Astronomer: *As a result of the initial **angular momentum** of the **solar nebula** from which the Earth and other **planets** formed.* China: Astronomer: *The Earth's **revolution** is caused by the **gravity** from the Sun, while its **rotation** is caused by the **initial angular momentum** at its formation.*
Category 11	NZ: Amateur Astronomer: *(A) combination of mass and distance between two bodies. Earth's **orbit** is due to effect of **gravitational force** exerted on it by (a) bigger mass—(that of) the Sun.* China: Amateur Astronomer: *Since the formation of the Earth there has been **angular momentum** (causing) **rotation; gravity,** and the **gravitation** of other heavenly bodies (causing) **revolution**.*
Category 10	NZ: Secondary Teacher: ***Gravity***. China: Secondary Teacher: *Because of **gravity**.*
Category 9	NZ: Primary Teacher: *Pull of the Sun.* China: Primary Teacher: *Maybe the effect of its own magnetic field* (Category 4) *or it is attracted by other forces in the **Solar System*** (Category 9).
Category 8	NZ: Pre-Service Secondary Teacher: *It was 'spun' out when the **Milky Way** was created and kept this motion due to momentum and lack of friction* [Drew Earth rotating on axis and revolving around Sun]. Note: Although similar to Category 12: Angular momentum: the term 'angular' is omitted. China: Parent: *Because of the asymmetry of the Earth caused by the **axis*** [Earth spins and revolves].

Category 7	NZ: Pre-Service Primary Teacher: *It's in (an)* ***orbit of the Sun****: law of motion.* China: Pre-Service Primary Teacher: *It moves along in its* ***orbit****.*
Category 6	NZ: Senior Secondary Student: *(It)* ***rotates on its axis*** *to give day and night.* China: Parent: *If the Earth didn't move (spin) there would be no day and night.*
Category 5	NZ: Undergraduate: *Components that make it up were in motion,* e.g., ***Big Bang****.* China: High-School Student: *All matter in* ***the universe is moving*** *absolutely.*
Category 4	NZ: Parent: *Its (Earth's)* ***magnetic field****.* China: Undergraduate: *Its own* ***magnetic force*** *and the force from the Sun.*
Category 3	NZ: Junior Secondary Student: (It orbits the Sun) *so everywhere (can) have light.*
Category 2	China: Primary School Pupil: *No* (it doesn't move).
Category 1	NZ: Pre-school Pupil: *I don't know (what the Earth is).*

Statistical Findings: Support for Hypotheses

The introductory sections in this article highlighted several dimensions to expertise—as knowledge in domains; its role in knowledge restructuring and concept creation; and how language figures in its development. These generated five hypotheses and the research have revealed evidence relevant to their confirmation/clarification. We also considered the pertinent knowledge of teachers and the differences in curricular emphases which led to hypotheses 6 and 7. Several of the findings bear positively upon their confirmation, as indicated below.

Hypothesis 1. Our initial hypothesis was that expertise as extensive knowledge-skill in applying scientific language and recognising relationships between concepts would be demonstrated as higher vocabulary means. Analysis of the data is demonstrated as follows. The *Astronomy Concept Vocabulary Scheme* was created by summing the astronomy concept vocabulary of all 11 cosmological concepts: Earth motion, Sun motion, Moon motion, time, daytime and night-time, Earth shape, Sun shape, Moon shape, gravity, seasons and eclipses. The vocabulary lexicon was developed from the responses of participants with each concept being scored once only; i.e. repeated use of the same concept was discounted to ensure valid measurement of linguistic expertise; and had to be used by at least two astronomers to be included. For example, the concept (word) *gravity* was not used explicitly by an astronomy 'grandmaster' but was used 11 times by a secondary pupil. Similarly the concept (word) *star* was also not used by the astronomy expert, but was used 12 times by another secondary pupil. Figure 4 displays the astronomy concept vocabulary means for each of the respondent categories shown in the original continuum from novice to expert. Data for Parents of surveyed children have also been included, these being inserted (somewhat arbitrarily) after Physics students at the intermediary between *learners* and *teachers*.

With the first strand (development of knowledge and conceptual skill in astronomy), there was an increase in scientific vocabulary and conceptual skill from novice to expert evident as increase in *K-S Means* [*M*] as follows: pre-school pupils: NZ: $M = 2.09$; China: $M = 1.41$: *K-S*: $p > 0.10$; primary school pupils, NZ: $M = 5.21$; China: $M = 6.00$: *K-S*: $p > 0.10$; middle-school pupils, survey group, NZ: M

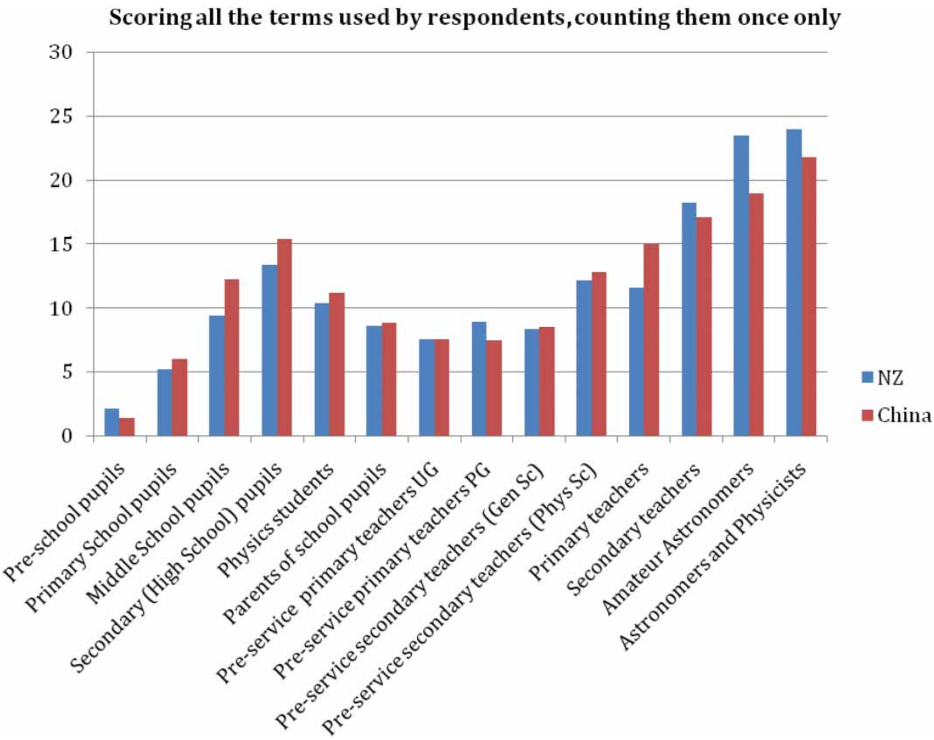

Figure 4. Astronomy concept category means

= 9.41; China: $M = 12.21$: *K-S*: $p > 0.10$; secondary (high-school) pupils, survey group, NZ: $M = 13.34$; China: $M = 15.38$: *K-S*: $p > 0.10$; Physics undergraduates, NZ: $M = 10.37$; China: $M = 11.21$: *K-S*: $p > 0.10$; Amateur Astronomers, NZ: $M = 23.52$; China: $M = 18.96$: *K-S*: $p < 0.005$ (the significant difference to the advantage of the NZ Amateur Astronomers was considered due to their greater experience: the NZ group being older); Astronomers and Physicists, NZ: $M = 27.20$; China: $M = 21.80$: *K-S*: $p > 0.10$: at an α level of 0.05. The vocabulary values for the Astronomers were strongly influenced by the inclusion of the NZ 'grandmaster'. When excluded, the means of the two groups are similar, NZ: $M = 4.00$; China: $M = 21.80$ (as shown in Figure 4). The slight difference in means advantage to the NZ group may be due in part to the NZ group being older and therefore more experienced.

Similarly, with the second strand (knowledge acquisition; communication and teaching skills) there was an incremental increase in scientific lexicon from novice to master teacher manifest as increase in *K-S Means*: pre-service primary teachers (undergraduate), NZ: $M = 7.51$; China: M = 7.57: *K-S*: $p > 0.10$; pre-service primary teachers (graduate), NZ: $M = 8.88$; China: $M = 7.43$: *K-S*: $p > 0.10$; pre-service secondary teachers (General Science), NZ: $M = 8.35$; China: $M = 8.53$: *K-S*: $p > 0.10$; pre-service secondary teachers (Physical Science), NZ: $M = 12.19$;

China: $M = 12.79$: *K-S*: $p > 0.10$; primary teachers: NZ: $M = 11.95$; China: $M = 15.03$: *K-S*: $p < 0.05$ (the significant difference to the advantage of the China primary teachers being considered due to the greater emphasis on science in the curriculum in China); secondary teachers: NZ: $M = 18.24$; China: $M = 17.13$: *K-S*: $p > 0.10$; with parents intermediate: Parents: NZ: $M = 8.63$; China: $M = 8.87$: *K-S*: $p > 0.10$: at an α level of 0.05.

Comparison of the two strands (astronomy concept acquisition and science teaching) indicates that in terms of *linguistic scientific knowledge*, many pre-service primary and secondary teachers have a similar vocabulary to that of their students. In the case of the middle- and high-school survey groups, their *scientific vocabulary* often exceeded that of pre-service teachers and teachers. This strongly suggests the influence of knowledge-skill compounding as a result of linguistic experience through repeated interviews.

Hypothesis 2. Our conjecture that expertise as extensive knowledge-skill in recognising relationships between concepts in schematic form would be detectable as higher concept category means has been borne out, as the following findings indicate. The *Astronomy Concept Schematic Scheme* was based on thumb-nail sketches of concepts in the categorisation scheme developed by the authors (Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007). Figure 2 shows two (sophisticated) drawings of the motion of the Earth, the Sun and the Moon, as illustrated by an NZ astronomer (Figure 2(a)) and a China astronomer (Figure 2(b)). The values of the drawing categories of 11 cosmological concepts: Earth motion, Sun motion, Moon motion, time, daytime and night-time, Earth shape, Sun shape, Moon shape, gravity, seasons and eclipses were summed to give a total value. Figure 5 displays the findings in respect of the astronomy drawings for each of the respondent categories shown in the original continuum from novice to expert.

In the case of the first strand (development of knowledge and skill in astronomy), there was a gradual increase in concept drawing ability from novice to expert evident as increase in *K-S Means* [*M*] as follows. Pre-school pupils, NZ: $M = 3.49$; China: $M = 3.53$: *K-S*: $p > 0.10$; primary school pupils: NZ: $M = 5.87$; China: $M = 5.69$: *K-S*: $p > 0.10$; middle-school pupils, survey group: NZ: $M = 7.42$; China: $M = 7.54$: *K-S*: $p > 0.10$; secondary (high-school) pupils, survey group: NZ: $M = 7.75$; China: $M = 8.21$: *K-S*: $p < 0.05$ (a significant difference to the advantage of China high-school students due to knowledge-skill compounding); Physics undergraduates: NZ: $M = 7.50$; China: $M = 7.61$: *K-S*: $p > 0.10$; Amateur Astronomers and Astronomy Educators: NZ: $M = 8.13$; China: $M = 7.99$: *K-S*: $p > 0.10$; Astronomers and Physicists: NZ: $M = 8.22$; China: $M = 8.25$: *K-S*: $p > 0.10$: at an α level of 0.05.

Similarly, with the second strand (knowledge acquisition; communication and teaching skills), there was an increase in concept drawing skill from novice to master teacher manifest as increase in *K-S Means*: pre-service primary teachers (undergraduate), NZ: $M = 5.39$; China: $M = 5.59$: *K-S*: $p > 0.10$; pre-service primary teachers (graduate), NZ: $M = 6.45$; China: $M = 5.19$: *K-S*: $p < 0.005$ (a significant difference to the advantage of NZ pre-service primary teachers [graduate] due to greater drawing skill); pre-service secondary teachers (General Science), NZ:

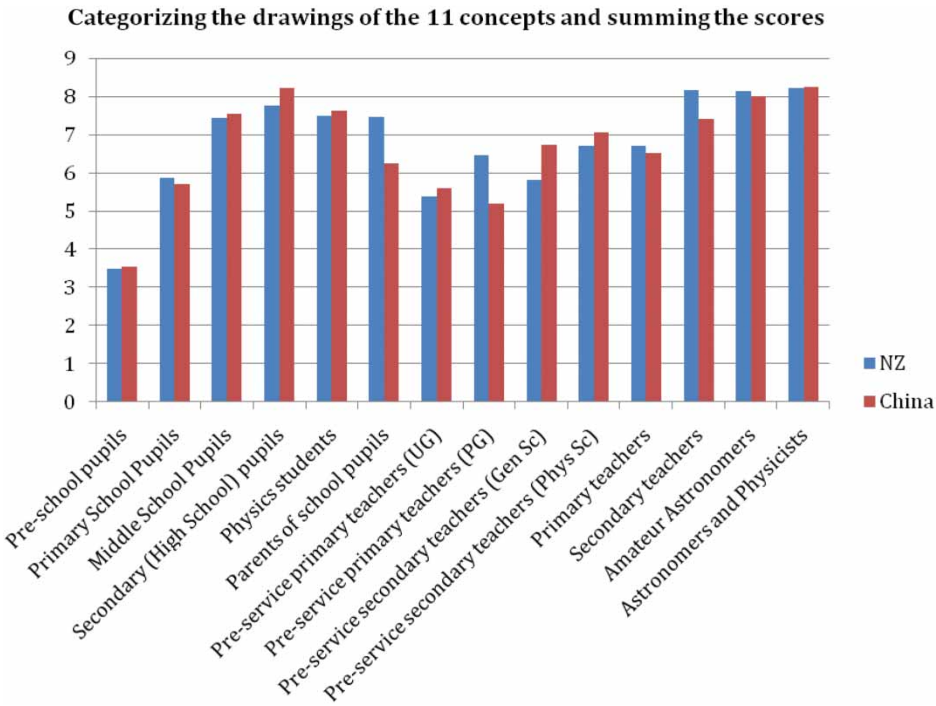

Figure 5. Astronomy concept drawing means

$M = 5.82$; China: $M = 6.72$: *K-S*: $p < 0.025$ (a significant difference to the advantage of China pre-service secondary teachers [General Science] due to greater drawing skill); pre-service secondary teachers (Physical Science), NZ: $M = 6.70$; China: $M = 7.06$: *K-S*: $p > 0.10$; primary teachers, NZ: $M = 6.71$; China: $M = 6.52$: *K-S*: $p > 0.10$; secondary teachers, NZ: $M = 8.15$; China: $M = 7.41$: *K-S*: $p < 0.025$*; with parents intermediate, parents: NZ: $M = .47$; China: $M = 6.25$: *K-S*: $p < 0.001$*.

Note*. The significant differences to the advantage of NZ secondary teachers and NZ parents (at an α level of 0.05) being due to greater drawing skill reflecting differences in cultural emphasis and educational opportunity. Many of the parents in the current survey did not have the chance to attend school. They were taught the basics at 'home' often in the countryside. Writing materials were scarce and freehand drawing was not a priority (X.J. Yang, personal communication, 22 September 2009).

In the case of *schematic scientific knowledge*, comparison of the two strands (astronomy concept acquisition and science teaching) also indicates that many pre-service primary and secondary teachers have a similar schematic schema to that of their students. As with vocabulary, the *schematic knowledge* of middle- and high-school survey groups also tended to be greater than that of trainee teachers and teachers, offering further support to the proposal that knowledge gained from repeated interviews may generate knowledge-skill compounding.

Hypothesis 3. Our third hypothesis, that expertise as higher-order theory would be indicated by more complex conceptual structures used in interviews, led to several trends and cross-cultural comparisons in the data, as follows. The previously reported astronomy categorisation scheme (see Blown & Bryce, 2006, 2010; Bryce & Blown, 2006, 2007) was used to categorise verbal responses from interviews (children) and written responses from questionnaires (adults) for all 11 cosmological concepts: Earth motion, Sun motion, Moon motion, time, daytime and night-time, Earth shape, Sun shape, Moon shape, gravity, seasons and eclipses. These were then summed to give a total value for statistical analysis. Figure 6 displays the Astronomy Higher-Order Concept Means.

In the case of the first strand (development of knowledge and skill in astronomy), there was a gradual increase in ability *to apply astronomical terms when expressing astronomy ideas*, from novice to expert, evident as increase in *K-S Means* [*M*] as follows: pre-school pupils, NZ: $M = 3.81$; China: $M = 3.69$: *K-S*: $p > 0.10$; primary school pupils, NZ: $M = 5.93$; China: $M = 6.15$: *K-S*: $p > 0.10$; middle-school pupils, survey group, NZ: $M = 7.62$; China: $M = 7.66$: *K-S*: $p > 0.10$; secondary (high-school) pupils, survey group, NZ: $M = 8.09$; China: $M = 8.34$: *K-S*: $p < 0.025$ (a significant difference to the advantage of China high-school students due to knowledge-skill compounding); Physics undergraduates, NZ: $M = 8.20$; China: $M = 7.90$: *K-S*: $p < 0.10$; Amateur Astronomers, NZ: $M = 8.88$; China: $M = 8.52$: *K-S*: $p < 0.05$ (a significant difference to the advantage of NZ Amateur Astronomers

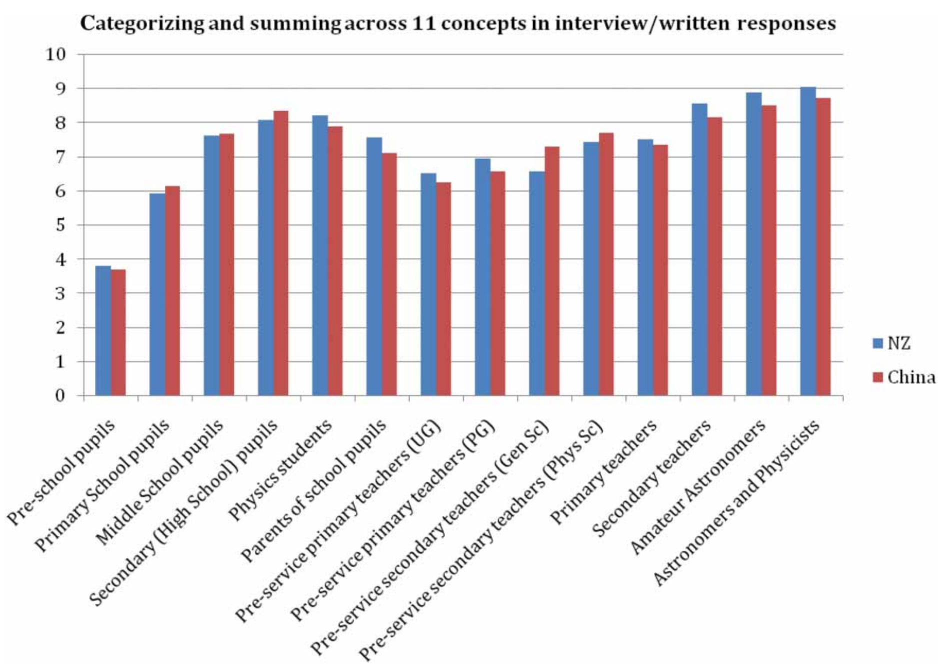

Figure 6. Astronomy Higher-Order Concept Means

due to more experience); Astronomers and Physicists: NZ: $M = 9.05$; China: $M = 8.71$: *K-S*: $p > 0.10$: at an α level of 0.05.

Similarly, with the second strand (knowledge acquisition; communication and teaching skills), there was an incremental increase in *appropriate scientific lexicon* (*theory explanation*), from novice to master teacher, manifest as increase in *K-S Means*: pre-service primary teachers (undergraduate): NZ: $M = 6.52$; China: $M = 6.24$: *K-S*: $p > 0.10$; pre-service primary teachers (graduate): NZ: $M = 6.95$; China: $M = 6.58$: *K-S*: $p < 0.10$; pre-service secondary teachers (General Science), NZ: $M = 6.57$; China: $M = 7.30$: *K-S*: $p < 0.025$ (a significant difference to the advantage of the China pre-service secondary teachers (General Science): due to greater emphasis on science in the curriculum and more science content in the course because of the more generous time allocation); pre-service secondary teachers (Physical Science), NZ: $M = 7.43$; China: $M = 7.70$: *K-S*: $p > 0.10$; primary teachers, NZ: $M = 7.51$; China: $M = 7.34$: *K-S*: $p > 0.10$; secondary teachers, NZ: $M = 8.56$; China: $M = 8.15$: *K-S*: $p < 0.025$ (significant difference to the advantage of NZ secondary teachers possibly due to more experience: the NZ teachers being older on average; with parents intermediate, parents: NZ: $M = 7.57$; China: $M = 7.12$: *K-S*: $p > 0.10$: at an α level of 0.05.

Comparison of the two strands (astronomy concept acquisition and science teaching) reveals that the *scientific theory* means of astronomy pre-service and primary teachers were similar to those of their students and to that of parents. As with *vocabulary* and *schematic knowledge*, the *scientific theory* means of middle- and high-school survey groups were also frequently greater than those of trainee teachers and teachers offering further support to the proposal that knowledge gained from repeated interviews can generate knowledge-skill compounding.

Hypothesis 4. The use of the *How?* questions enabled us to generate data pertinent to the fourth hypothesis, that expertise as enriched scientific knowledge would be detectable through the use of higher concepts. The *How?* strand of the *How/Why Astronomy Concept Scheme* was developed from responses to the questions: *How does the Earth move? How does the Sun move? How does the Moon move?* and summed to give a value (see Figure 3 with respect to the Earth movement categories). Figure 7 displays these findings.

With the first strand (development of knowledge and conceptual skill in astronomy), there was a gradual increase in *descriptive* astronomical terms from novices to expert evident as increase in *K-S Means* [*M*] as follows. pre-school pupils, NZ: $M = 3.57$; China: $M = 3.53$: *K-S*: $p > 0.10$; primary school pupils, NZ: $M = 5.31$; China: $M = 5.82$: *K-S*: $p < 0.10$; middle-school pupils, survey group, NZ: $M = 6.53$; China: $M = 6.76$: *K-S*: $p > 0.10$; secondary (high-school) pupils, survey group, NZ: $M = 6.77$; China: $M = 7.17$: *K-S*: $p > 0.10$; Physics undergraduates, NZ: $M = 7.78$; China: $M = 7.54$: *K-S*: $p > 0.10$; Amateur Astronomers, NZ: $M = 8.33$; China: $M = 8.38$: *K-S*: $p > 0.10$; Astronomers and Physicists, NZ: $M = 8.28$; China: $M = 8.22$: *K-S*: $p > 0.10$: at an α level of 0.05*.

Similarly, with the second strand (knowledge acquisition; communication and teaching skills), there was an incremental increase in *descriptive* scientific lexicon from novice to master teacher manifest as increase in *K-S Means*: pre-service

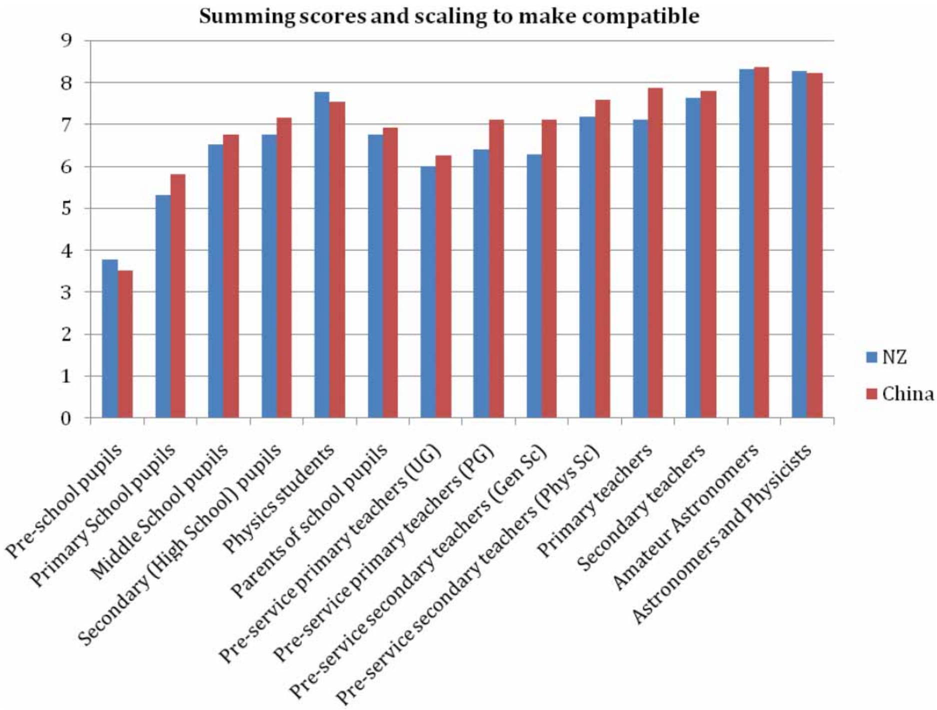

Figure 7. Responses to How? questions

primary teachers (undergraduate), NZ: $M = 6.00$; China: $M = 6.26$: *K-S*: $p > 0.10$; pre-service primary teachers (graduate), NZ: $M = 6.41$; China: $M = 7.11$: *K-S*: $p < 0.10$; pre-service secondary teachers (General Science), NZ: $M = 6.30$; China: $M = 7.11$: *K-S*: $p < 0.025$*; pre-service secondary teachers (Physical Science), NZ: $M = 7.19$; China: $M = 7.59$: *K-S*: $p > 0.10$; primary teachers, NZ: $M = 7.11$; China: $M = 7.87$: *K-S*: $p < 0.001$*; secondary teachers, NZ: $M = 7.64$; China: $M = 7.80$: *K-S*: $p > 0.10$; with parents intermediate, Parents: NZ: $M = 6.77$; China: $M = 6.94$: *K-S*: $p > 0.10$: at an α level of 0.05.

Note. * In each case here, a significant difference to the advantage of China groups most probably due to the greater emphasis on science in curriculum.

In terms of enriched scientific knowledge, comparison of the two strands indicates that both Amateur Astronomers and Astronomy Educators and Professional Astronomers and Physicists have more advanced concepts than all groups of pre-service and practising teachers. This indicates that astronomers are a valuable source of scientific knowledge. As with *vocabulary*, *schematic knowledge* and *scientific theory*, middle- and high-school survey groups showed *enriched scientific knowledge* over some trainee teachers and teachers, indicating evidence of repeated interviews as a factor in knowledge-skill compounding.

Hypothesis 5. The use of the *Why?* questions enabled us to generate data pertinent to the fifth hypothesis, that expertise as enriched scientific reasoning would be detectable in the links made amongst higher concepts. Changes from intuitive notions to scientific concepts were revealed in interviews; these were analysed and categorised into ordinal data, and tested statistically (the conceptual changes being quantified as changes in ordinal mean values) showing major changes taking place between pre-school and high school. The *Why?* aspect of the *How/Why Astronomy Concept Scheme* was developed from responses to the questions: *Why does the Earth move? Why does the Sun move? Why does the Moon move?* And summed to give a value (see Figure 3(b) with respect to the Earth movement categories). Figure 8 displays these findings.

With the first strand (development of knowledge and conceptual skill in astronomy), there was a gradual increase in *explanatory* astronomical terms from novice to expert evident as increase in *K-S Means* [*M*] as follows. Pre-school pupils, NZ: $M = 2.57$; China: $M = 2.25$: *K-S*: $p > 0.10$; primary school pupils, NZ: $M = 2.81$; China: $M = 2.65$: *K-S*: $p > 0.10$; middle-school pupils, survey group, NZ: $M = 4.67$; China: $M = 4.98$: *K-S*: $p > 0.10$; secondary (high-school) pupils, survey group, NZ: $M = 5.68$; China: $M = 6.03$: *K-S*: $p > 0.10$; Physics undergraduates, NZ: $M = 7.68$; China: $M = 7.24$: *K-S*: $p < 0.10$; Amateur Astronomers, NZ: $M = 8.73$; China: $M = 7.72$: *K-S*: $p > 0.10$; Astronomers and Physicists, NZ: $M = 8.75$; China: $M = 8.59$: *K-S*: $p > 0.10$: at an α level of 0.05.

Note. There were no significant differences.

Similarly, with the second strand (knowledge acquisition; communication and teaching skills), there was an increase in *explanatory* scientific lexicon from novice

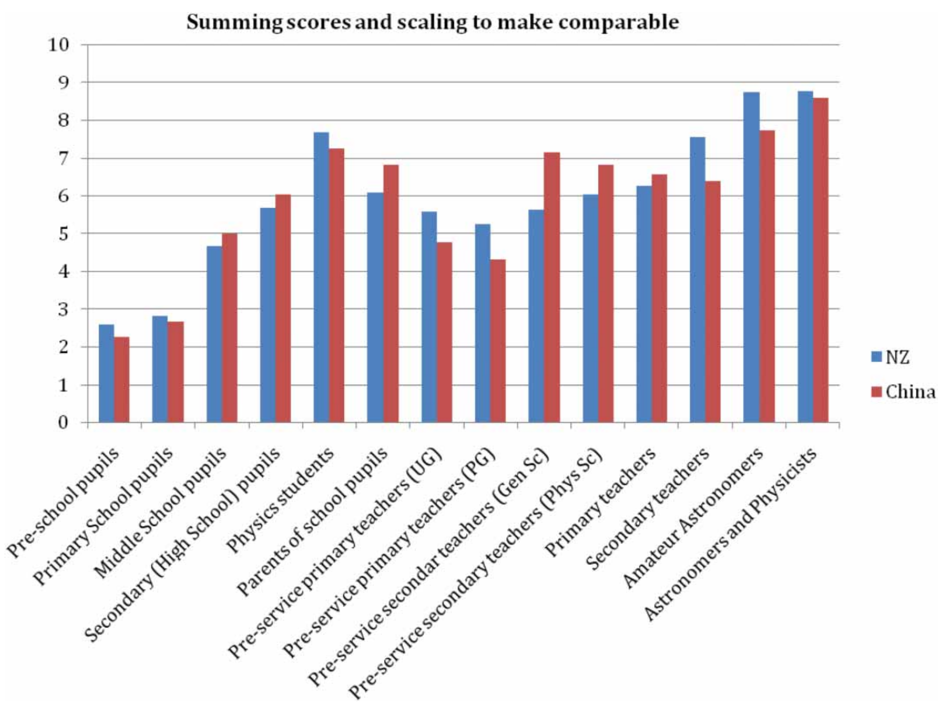

Figure 8. Responses to Why? questions

to master teacher manifest as increase in *K-S Means*. pre-service primary teachers (undergraduate), NZ: $M = 5.56$; China: $M = 4.77$: *K-S*: $p > 0.10$; pre-service primary teachers (graduate), NZ: $M = 5.11$; China: $M = 4.31$: *K-S*: $p < 0.10$; pre-service secondary teachers (General Science), NZ: $M = 5.62$; China: $M = 7.13$: *K-S*: $p < 0.05$*; pre-service secondary teachers (Physical Science), NZ: $M = 6.03$; China: $M = 6.82$: *K-S*: $p < 0.005$*; primary teachers: NZ: $M = 6.26$; China: $M = 6.55$: *K-S*: $p > 0.10$; secondary teachers, NZ: $M = 7.54$; China: $M = 6.38$: *K-S*: $p > 0.10$; with parents intermediate, parents: NZ: $M = 6.08$; China: $M = 6.80$: *K-S*: $p > 0.10$: at an α level of 0.05.

Note: * In both cases here again, a significant difference to the advantage of China groups most probably due to the greater emphasis on science in curriculum.

Comparison of the two strands (astronomy concept acquisition and science teaching) shows that the explanatory scientific reasoning of many pre-service teachers is similar to that of parents, primary teachers and secondary students; whereas that of secondary teachers is similar to that of amateur astronomers. Similar to the results from *vocabulary*, *schematic knowledge* and *scientific theory*, high-school survey groups showed *enriched explanatory scientific reasoning* over trainee teachers and some teachers which may be taken as further evidence of repeated interviews as an important factor in knowledge-skill compounding.

Hypothesis 6. Expertise universal across the two cultures under investigation, detectable as similar concept category and vocabulary means.

There were no cases of significant difference across all five hypotheses (H1–5). In those cases where the *K-S* test did indicate a statistically significant difference (at an α level of 0.05), there were usually other explanations other than cultural difference. However, there were cases of groups in one culture performing consistently better than comparative groups in the other culture in a specific area of skill; e.g. greater drawing ability of NZ parents due to differences in education, or greater ability in science of China pre-service science teachers due to differences in the cultural emphasis reflected in curriculum time (see Blown & Bryce, 2010 and X.J. Yang, personal communication, 22 September 2009).

Hypothesis 7. Where longitudinal comparisons could be made, survey groups would have higher concept category and vocabulary means over their respective control groups.

There were significant differences between the middle- and secondary (high-school) survey groups and their respective control groups in tests of all five hypotheses: H1: *K-S*: $p < 0.005$; H2: *K-S*: $p < 0.005$; H3: *K-S*: $p < 0.005$; H4: *K-S*: $p < 0.025$; H5: *K-S*: $p < 0.005$, suggesting that repeated interviews may be a significant factor in the acquisition of expertise (see Cromer, 1987).

Conclusion

Summary of Results: 11 Main Trends

1. A general increase in expertise from novice to expert manifest in both cultures as increasing means; i.e. in the *learning strand* (*development of knowledge and conceptual*

skills in astronomy) from pupil to student to undergraduate to amateur astronomer to astronomer/physicist; in the *teaching strand* (*knowledge acquisition, communication and teaching skills*) from student teacher, to teacher; with parents of students intermediate between senior pupils and undergraduates/teachers.

2. Substantial overlap between ranges of values, e.g. some pupils and students have more advanced concepts than their teachers (Max pupils/students > Min primary/secondary teachers). This is particularly the case in NZ where science education has been de-emphasised in favour of literacy and numeracy at primary school; and science is optional in senior secondary. If teachers are to maintain their role as sources of scientific knowledge, their inadequacies in this area need to addressed. Primary teacher training is the main area of worry as the dips in the bar graphs show in Figures 4–8. Separately, we may note that some (more experienced) secondary teachers have similar concepts to Astronomers (Max secondary teachers > Min Astronomers and Physicists).

3. The scientific vocabulary, concepts, scientific knowledge and scientific reasoning of many pre-service primary and secondary teachers are similar to that of junior secondary/middle-school students and less than that of senior secondary/high-school students. This is a major cause of concern particularly in NZ where insufficient time is devoted to content knowledge in the science curriculum.

There was no significant difference between the pre-service primary (non-graduate) groups of both cultures. Similarly, in the case of pre-service primary (graduate) groups there was no significant difference in means in four out of five categories. However, NZ students were significantly superior to their China counterparts in drawing ($p < 0.005$).

With both pre-service secondary (General Science) teachers and pre-service teachers (Physical Science), the China groups had higher means in all areas of expertise; and in the latter case the China pre-service Physical Science teachers were significantly more able in answering Why questions ($p < 0.005$); reflecting the greater emphasis on science in China resulting in more curriculum time for the teaching of science content.

4. Middle- and high-school Chinese students tend to have more advanced concepts and greater scientific understanding than similar NZ students as a result of greater emphasis on science in society which is reflected in the curriculum with greater time allocation for topics like physics and astronomy (see section on Differences in curriculum emphases).

5. Middle- and high-school survey groups also show the effect of *Knowledge-Skill Compounding* as a result of repeated interviews. However, this factor is probably not unique to longitudinal studies with repeated interviews, and may be similar to the influence of enthusiastic teachers (particularly those with an interest in astronomy) within a spiral curriculum where topics are re-visited periodically. Thus, although controlled for in these studies, the values given for survey groups may be relatively common in teaching and learning.

6. There were no significant differences between NZ and China Astronomy and Physics undergraduates. This is probably due to the entry level to physical science

courses and the course content being similar for both cultures. And probably this would be true internationally, given the universality of science and the need for scientists worldwide to have similar basic knowledge.

7. NZ and China primary teachers had similar means in Drawing, Interview and responses to *Why?* questions. However, the China primary teachers had significantly higher means over the NZ primary teachers in Scientific Vocabulary ($p < 0.05$) and responses to *How?* questions ($p < 0.001$) as a result of greater emphasis on science in the China primary school curriculum.

8. NZ and China secondary teachers had similar means in three out of five categories: China secondary teachers (like China parents) being slightly less able in Drawing and Interview skills ($p < 0.025$): the former disadvantage probably for the same reason (they were of similar age and therefore would have had similar education in school). These results indicate the universality of science at higher levels in that both are teaching within similar curricula (see Blown & Bryce, 2010) and both are preparing students for entrance to university where standards are similar internationally.

9. Some significant differences between NZ and China Amateur Astronomers could be attributed to age difference, the NZ group being older (and thus more experienced) overall; the NZ group having significantly higher means in *Vocabulary* ($p < 0.005$) and *Interview responses* ($p < 0.05$).

10. There were no significant differences between NZ and China Astronomers and Physicists. However, the vocabulary values for Astronomers in Figure 5 were strongly influenced by the inclusion of the NZ 'grandmaster' (vocabulary = 72): NZ: M = 27.20; China: M = 21.80. When the 'grandmaster' is excluded, the two means of the two groups are more similar: NZ: M = 24.00; China: M = 21.80.

11. There was no significant difference between Amateur and Professional Astronomers. However, the professionals had higher means in four out of five hypotheses in NZ, e.g. *Vocabulary*: NZ Astronomers (M = 27.20); NZ Amateur Astronomers (M = 23.52). And in respect of all five hypotheses in China, e.g. *Vocabulary*: China Astronomers (M = 21.80); China Amateur Astronomers (M = 17.36).

Recommendations for Further Research and Implications for Teaching

The results show that expertise (as scientific knowledge and conceptual skill) is a process of gradual acquisition from childhood to adulthood and from novice to expert. But this growth will not take place without nurturing learning environments created by enthusiastic teachers using innovative methods. For example, involving children and teachers directly in scientific research to capture their imagination through modern technology, e.g. using remote telescopes in the southern hemisphere to observe the heavens from classrooms in the northern hemisphere and vice versa (see Canadian Junior Astronomer Program, 2009; Faulkes Telescope Project, 2009; McKinnon & Mainwaring, 2000; Universe in the Classroom, 2009).

The role of modelling in scientific reasoning needs to be encouraged by teachers and practised by students. As Nersessian (1995) summarised: 'My hypothesis is that we will be more successful in training students to think scientifically if they are taught, explicitly, how to engage in the modeling practices of those with an expertise in physics' (p. 204). Teachers should also be encouraged to invite local amateur astronomers and astronomy educators to teach astronomy during normal class hours or after school, including evening activities with children, parents and teachers observing planets and stars with the naked eye and through telescopes. They should also link up with local and national planetariums, museums and observatories to arrange visits as part of educational science field trips (see British Astronomical Association, 2009; Iwaniszewska, 1990; Pasachoff & Percy, 2005).

The mismatch between teacher training and teaching practice has to be addressed by educational planners and curriculum designers if teachers are to meet the challenge of teaching science with confidence and redress misunderstanding of basic science by recognising that traditional teaching methods are inadequate (see Schneps & Sadler, 1987).

Pre-service and practising teachers, particularly at primary level, need to be educated and trained to a high standard in the sciences to engender confidence about the content and the pedagogy of the science curriculum including adequate scientific vocabulary embracing scientific concepts. As Vlaardingerbroek and Taylor (2003) state '... teachers' competence in primary science arises largely from their own mastery of scientific concepts' (p. 429). The data indicate that pre-service and practising teachers (and their students in the latter case) would benefit from interaction with amateur or professional astronomers as sources of astronomical knowledge. This would enable them to address any shortcomings in their content knowledge and would also provide examples of pedagogy particularly by participating in lessons by astronomy educators at planetariums (see British Astronomical Association, 2009; Iwaniszewska; 1990; Pasachoff & Percy, 2005; Royal Astronomical Society-International Astronomical Union, 2011). The last of these references indicates the Royal Astronomical Society's (RAS) recent intimation of its (global) plan 'to use astronomy as a tool to stimulate development at primary, secondary and tertiary education as well as science research and the public understanding of science'. Significantly, and consistent with our findings here and the implications we have drawn, the RAS has set aside funds to facilitate visits, especially of younger UK-based scientists, to developing institutions on approved projects: Topics include: Teacher training courses; Development and translation of educational material for children; Inspirational semi-popular lectures on astronomy and related technologies and Activities building on the International Year of astronomy 2009 including stargazing and engagement with amateur groups.

These recommendations are consistent with those made about science in general by Tytler et al. (2008) who, in their arguments to government in the Australian context (Tytler & Symington, 2009), state that 'it is imperative that the teacher has access to the community of professionals sharing their discipline base' (p. 5). With respect to content knowledge deficits versus pedagogy, they assert how critical is the latter and that

> ... effective teaching in a subject area requires much more than content knowledge. Teachers need to have an aesthetic understanding of a subject, including a passion for the discipline, a sense of its coherence and meaning, and subject specific ways of making it relevant and engaging to students. (Tytler & Symington, 2009, p. 6/7)

We agree with this and would argue further that these subject-specific dimensions to PCK can be seen as examples of what we have referred to as *knowledge-skill* (Barsalou, 2003; Blown & Bryce, 2010) in that they combine *content knowledge* (knowing what to teach from a rich range of *subject matter content*) and *teaching skill* (knowing how to teach that knowledge effectively). According to Mishra and Koehler (2006):

> Like expertise in other complex domains, ... expertise in teaching is dependent on flexible access to highly organized systems of knowledge ... There are clearly many knowledge systems that are fundamental to teaching, including knowledge of student thinking and learning, and knowledge of subject matter. (p. 1020)

Interestingly, in the investigations by Van Driel, Verloop, and de Vos (1998), while the authors identify teaching experience as the major source of PCK they concede that 'adequate subject-matter knowledge appears to be *a prerequisite*' (p. 673, emphasis added). PCK as knowledge-skill was explored in our own research in response to our first and second hypotheses. Our results show that pre-service primary teachers, practising primary teachers and pre-service secondary teachers in both cultures have inadequate scientific vocabulary and skill in drawing representation. They also lack in-depth content knowledge (our third hypothesis). Similarly, responses to *How?* and *Why?* questions (our fourth and fifth hypotheses) indicate that the knowledge-skill of primary trainees and practising teachers is similar to that of students and parents and below that of secondary teachers and astronomers (as illustrated in Figures 4–8).

Finally

The low levels of scientific knowledge of pre-service primary teachers which we and others have identified and the inadequate ongoing professional development reported by Bull et al. (2010) must be addressed. The assumption that students will enter pre-service teacher courses with sufficient content knowledge to teach science without further enhancement at university is unfounded. The proposal of Vlaardingerbroek and Taylor (2003) that primary teachers should be taught science in a 4-year university course has much to recommend it. However, it should be coupled with all students being encouraged to stay at school until age 18 and studying Biology, Chemistry and Physics as part of a broad curriculum designed to equip them for life in a scientific age. If developed countries like NZ are to remain competitive on the world stage, science education needs to be emphasised throughout the school years following the example of China. Astronomy education has a unique role to play in this process since it embraces all of the sciences and can be appreciated by children of all ages. It can capture the imagination of children from a young age and so nurture an enthusiasm for nature study and science. The science and technology associated with modern astronomy (particularly the computerised networks which enable teachers in classrooms in daylight anywhere in the world to access dark skies in real time at the push of a computer key) offer new opportunities for researchers concerned with learning and expertise.

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Appendix 1. Interview Guide for Children (Abridged)

Questions about the Motion of a Ruler Shadow
1. What causes the shadows?
2. Is the pencil still touching the ruler shadow?
3. Is anything moving?
4. Why is it moving?

Questions about the Motion of the Sun, Earth and Moon
1. Tell me about the Sun?
2. Where is the Sun?
Take care that children do not look directly at the Sun.
3. Has what is happening to the ruler shadow got anything to do with the Sun?
4. Is the Sun moving?
5. How is the Sun moving?
6. Why is the Sun moving?

7. Tell me about the Earth?
8. Where is the Earth?
9. Has what is happening to the ruler shadow got anything to do with the Earth?
10. Is the Earth moving?
11. How is the Earth moving?
12. Why is the Earth moving?

13. Tell me about the Moon?
14. Where is the Moon?
15. Has what is happening to the ruler shadow got anything to do with the Moon?
16. Is the Moon moving?
17. How is the Moon moving?
18. Why is the Moon moving?

19. ***Draw how the Earth, Sun and Moon move*** (on your Motion Drawing).

Time Study
1. What is a year?
2. Does a year have anything to do with the Earth?
3. Does a year have anything to do with the Sun?
4. Does a year have anything to do with the Moon?

5. What is a month?
6. Does a month have anything to do with the Earth?
7. Does a month have anything to do with the Sun?
8. Does a month have anything to do with the Moon?

9. What is a day?
10. Does a day have anything to do with the Earth?
11. Does a day have anything to do with the Sun?
12. Does a day have anything to do with the Moon?

Daytime and Night-time
1. What is daytime?
2. What happens to the Earth in daytime?
3. What happens to the Sun in daytime?
4. What happens to the Moon in daytime?

5. What is night-time?
6. What happens to the Earth at night-time?

7. What happens to the Sun at night-time?
8. What happens to the Moon at night time?
9. ***Draw the Earth, Sun and Moon at daytime and night-time*** (on your Time Drawing).

Shape Study

Earth Shape

1. Tell me about the Earth?
2. What shape is the Earth?
3. What is the shape of the Earth like? Like a . . .
4. ***Draw the Earth*** (on your Shape Drawing).
5. ***Make the shape of the Earth with green play dough.***
6. What shape is your model of the Earth?

Ground & Sky

1. Tell me about the ground?
2. What shape is the ground?
4. ***Draw the ground*** (on your Shape Drawing)..
5. What shape is your drawing of the ground?
6. Tell me about the sky?
7. What shape is the sky?
8. ***Draw the sky*** (on your Shape Drawing).
9. What shape is your drawing of the sky?

Sun Shape

1. Tell me about the Sun?
2. What shape is the Sun?
3. What is the shape of the Sun like? Like a . . .
4. ***Draw the Sun*** (on your Shape Drawing).
5. ***Make the shape of the Sun with red play dough.***
6. What shape is your model of the Sun?

Moon Shape

1. Tell me about the Moon?
2. What shape is the Moon?
3. Is the Moon always the same shape?
4. If the Moon appears to change shape, why does it appear to change shape?
5. What is the shape of the Moon like? Like a . . .
6. ***Draw the Moon*** (on your Shape Drawing).
7. ***Make the shape of the Moon with yellow play dough.***
8. What shape is your model of the Moon?
9. What would the Earth look like from the Moon?

Habitation, Identity & Gravity Study

1. ***Draw yourself*** (on your Shape Drawing).
2. Where did you draw yourself?
3. What are you standing on?
4. How are you able to stand there?
5. ***Draw a friend who lives a long way away from you—as far away as you can imagine.***
6. Where did you draw your friend?
7. What is your friend standing on?
8. How is your friend able to stand there?

9. Imagine that you dropped a ball into a very deep well-hole.
What would happen to the ball?

10. ***Draw the well-hole, yourself, and the ball.***

Seasons Study

1. Tell me about the seasons?
2. What causes the seasons?
3. What are the names of the seasons?
4. Tell me about Winter?
5. Tell me about Spring?
6. Tell me about Summer?
7. Tell me about Autumn?
8. How long is each season?
9. Why do the seasons change?
10. What season is it now?
11. What was the season before this?
12. What season comes after this?
13. Do different places on Earth have different seasons?
14. Why do different places have different seasons?
15. Thinking of your friend who lives in China (New Zealand) on the other side of the Earth: What season would it be where your friend is?
16. Do the seasons have anything to do with the Earth?
17. Why do the seasons have something to do with the Earth?
18. Do the seasons have anything to do with the Sun?
19. Why do the seasons have something to do with the Sun?
20. Do the seasons have anything to do with the Moon?
21. Why do the seasons have something to do with the Moon?
22. ***Draw the Earth and Sun to explain the seasons***
23. ***Model the seasons with your play-dough models of the Earth and Sun.***

Eclipses Study

1. Do you know what eclipses are?
2. Tell me about eclipses?
3. Have you seen an eclipse?
4. What causes eclipses?
5. ***Draw the Earth, Sun and Moon to explain eclipses.***
6. ***Model eclipses with your play-dough models of the Earth, Sun and Moon.***

Appendix 2. Questionnaire (adults)

Questionnaire for Professional Astronomers & Physicists[1]

1. How long have you studied astronomy and what are your main research interests?
2. Does the Earth move?
3. How does the Earth move?
4. Why does the Earth move?

5. Does the Sun move?
6. How does the Sun move?
7. Why does the Sun move?

8. Does the Moon move?
9. How does the Moon move?
10. Why does the Moon move?

11. What is a Day?

12. What is a Month?
13. What is a Year?
14. What causes daytime?
15. What causes night-time?

16. What shape is the Earth?
17. What is the shape of the Earth like?
18. What shape is the Sun?
19. What is the shape of the Sun like?
20. What shape is the Moon?
21. What is the shape of the Moon like?

Draw the Earth, Sun and Moon (label). If they move show how using arrows.
If a day or a month or a year have anything to do with the Earth, Sun or Moon show how.
Indicate daytime and night-time on your drawing.
Draw the ground and sky (label your drawing).
Sketch a little stick figure to represent yourself (label as Self).
Imagine that you have a friend who lives a long way away.
Sketch a little stick figure to show your friend (label as Friend).

22. Imagine that you dropped a ball into a very deep well hole (as deep as you can imagine). There is no water in the well. What would happen to the ball?
23. Why would that happen to the ball?

Draw the well hole, yourself, and the ball.
24. What causes the seasons of the year?

Draw the Earth and Sun to explain the seasons
25. What causes eclipses?

Draw the Earth, Sun and Moon to explain eclipses

Note. [1]The questionnaires for parents, physics undergraduates, pre-service teachers, and teachers were similar apart from the wording of Question 1.

Appendix 3.

Astronomy concepts lexicon from interviews/questionnaires

Accelerate (acceleration, deceleration, of ball falling down deep well-hole)
*Air resistance, friction (acting on ball falling down deep well-hole)
Amplitude (of Simple Harmonic Motion of ball falling through the Earth, *dampening, of)
Angular size (of *Sun, *Moon, from Earth, similar, accounting for Solar Eclipse)
*Antipode(s) (of Earth, in relation to ball falling through hole through the Earth)
*Astronomical Unit, AU, (approximately mean distance from Earth to Sun or radius of Earth's orbit)
Axis (of rotation, rotational axis, spin axis; revolution, revolutionary axis, orbital axis)
Blocking, covering, shielding, shading; Earth by Moon (Solar Eclipse); Moon by Earth (Lunar Eclipse)
Calendar (month, year)
*Capture (origin of Earth-Moon System)
*Centre, core, of the Earth
*Centre of the Galaxy (*centre of Milky Way, galactic centre, galactic core)

Collision (origin of *Earth-Moon System; of Lunar Craters by comet and meteor impacts)
Common Centre of Mass (centre of gravity, Barycentre, of Earth-Moon System; of Solar System)
Conservation of angular momentum (or conservation of energy of Solar System, Galaxy)
Coriolis Effect (acting on ball falling down hole through centre of Earth)
*Craters, other *surface irregularities (mountains) on Moon, caused by comet, meteorite impacts
Direct shining point (subsolar point), highest altitude, latitude (angle) of Sun, causing seasons
*Earth-Moon System
*Earth's shadow (of Moon during Lunar Eclipse, observer in shadow at night-time)
*Eccentricity of Earth's orbit ($e = 0.017$)
*Ecliptic, *Obliquity of (Tilt of Earth's axis, angle between Earth's equator and the ecliptic); plane of
Energy (gravitational, kinetic, potential, solar)
Equator, equatorial bulge (of *Earth, *Sun, shape, due to rotation)
Equinox (Autumnal *March, Southern Autumn; Vernal *Sept., Southern Spring; *First point of Aries)
Force, centrifugal (moving from a centre), centripetal (moving towards a centre), forces (non gravity)
*Galaxy (*Milky Way)
Gravity (gravitation; gravitational attraction, field, force(s), interaction, pull; gravitational constant)
Hemisphere (Northern, Southern; may be implied; e.g., *Northern Summer, Northern Winter)
(Initial) (angular) momentum, motion, inertia (*Earth–Moon System, *Solar Nebula, *Milky Way Disc)
Insolation, variation in Sun's radiation, energy, heat, sunlight, received on ground, causing seasons
*Local Group of galaxies; other galaxies
Lunar Eclipse (*Eclipse of Moon, *partial, *total)
Lunar month
Meridian (*passage, crossing)
Moon's shadow (Lunar shadow, on Earth during Solar Eclipse)
Node (of Moon in *Solar Eclipse; ascending, descending, of month)
*Oblate spheroid (of Earth's shape, geoid)
*Observer (location of person on Earth, e.g., when explaining daytime/night-time, may be tacit)
Oscillation (of *ball about Centre of Earth; of *Sun about Centre of Milky Way)
Orbit; shape (*circular, *elliptical; path (orbit of Earth, Moon, *Sun); orbital plane (of Solar System)
*Penumbra (of shadow during partial eclipse)
Period of revolution, orbital period; of *Earth around Sun, *Moon around Earth, *Sun around Galaxy
Period of rotation; of *Earth; time taken for Earth to rotate or spin once on axis (Day); of Moon (Month)
Perturbations (Jiggle, Wobble; of Earth, Sun, stars, result of gravitational interaction with Moon, planets)
Phases (cycle of, of Moon)
*Planet(s), (may be called "fixed stars" in China), planetary system
Pole(s) of Earth (North, South); polar flattening (of *Earth, *Sun, shape due to rotation)
*Precession of the equinoxes (wobble of Earth about axis, polar wobble)
Radius (of *Earth, *Sun)
Revolve(s), revolution, revolving, *orbit(s), orbiting, orbital motion (motion of one body around another)
*Rotate(s), rotation, on, about, axis; spin(s), spinning (turning of a body about an axis running through it)
Sidereal (*day, *month, *year)
Simple Harmonic Motion (SHM, of ball oscillating about centre of Earth)

Solar Eclipse (*Eclipse of Sun, annular, partial, *total, path of totality)
*Solar Nebula
Solar System
Solstice (*December, Southern Summer; *June, Southern Winter, reverse in Northern Hemisphere)
*Sphere (globe, orb, *spherical)
Spheroid (ellipsoid, elliptical, irregular sphere in China)
*Star(s)
Surface, crust, of Earth, Moon, Sun
Terminal velocity (of ball falling down deep well-hole)
*The other side of the Earth (in relation to day/night or identity or dropping ball into deep well hole)
The side (part) of the Earth facing the Sun (*sunlit hemisphere, Sun above horizon, in daytime)
The side (part) of Earth facing away from Sun (*hemisphere in shadow, Sun below horizon)
Tidal effects (in sea, Earth-Moon System tidally locked, tidal friction, *solid tides in rocks of Moon)
*Tropical year
Tropics, of Cancer ($23\frac{1}{2}^\circ$ North Latitude), Capricorn ($23\frac{1}{2}^\circ$ South Latitude), in relation to seasons
*Umbra (of eclipse shadow during total eclipse)

Note. Concepts (words) used by NZ astronomy grandmaster are indicated* ($n = 72$).
Only concepts which scored a frequency of two or more by Astronomers or Physicists in NZ and China were included. There were 100 concepts in all, including 70 basic concepts as listed and 30 associated concepts (in parentheses) enabling results to be scored as % of shared lexicon. Terms had to be used correctly, e.g., The Earth *rotates* on its axis and *revolves* around the Sun (see Abell, 1969, p. 114). Other sources used to check the vocabulary of astronomy concepts were: Daintith (2009), Morrison, Wolff, and Fraknoi (1995), Pasachoff (1998) and Ridpath (2007).

The common associated concepts were:

Blocking (of Earth by Moon, Moon by Earth)
Equinox (Autumnal, Vernal)
Hemisphere (Northern, Southern)
Initial angular momentum or inertia (of Earth-Moon System, Solar Nebula, Milky Way Disc)
Lunar Eclipse (partial, total)
Orbit, shape of (circular, elliptical)
Oscillation (of ball about Centre of Earth, Sun about Centre of Milky Way)
Period of revolution (of Earth around Sun, Moon around Earth)
Pole(s) of Earth (North, South, flattening)
Sidereal (day, month, year)
Solar Eclipse (annular, partial, total)
Solstice (Summer, Winter)
Tropics (of Cancer, Capricorn)
