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RESEARCH REPORT

Knowledge Restructuring in the Development of Children’s Cosmologies

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The development of children’s cosmologies was investigated over a 13-year period, using multimodal, in-depth interviews with 686 children (217 boys, 227 girls from New Zealand and 129 boys, 113 girls from China), aged 2–18. Children were interviewed while they observed the apparent motion of the Sun and Moon, and other features of the Earth; drew their ideas of the shape and motion of the Earth, Moon and Sun, and the causes of daytime and night-time; then modelled them using play-dough; which led into discussion of related ideas. These interviews revealed that children’s cosmologies were far richer than previously thought and surprisingly similar in developmental trends across the two cultures. There was persuasive evidence of three types of conceptual change: a long-term process (over years) similar to weak restructuring; a medium-term process (over months) akin to radical restructuring; and a dynamic form of conceptual crystallisation (often in seconds) whereby previously unconnected/conflicting concepts gel to bring new meaning to previously isolated ideas. The interview technique enabled the researchers to ascertain children’s concepts from intuitive, cultural, and scientific levels. The evidence supports the argument that children have coherent cosmologies that they actively create to make sense of the world rather than fragmented, incoherent “knowledge-in-pieces”.

Introduction

The longitudinal studies reported here investigated New Zealand and Chinese children’s cosmologies, their concepts of the motion and shape of the Earth, Sun, and Moon, and associated ideas about time and gravity over a 13-year period. Although some aspects of the cosmologies of New Zealand children were known from the work of Osborne and Freyberg (1985), the current research is the first of its kind on the cosmologies of children in China. Thus, they give an insight into the conceptual

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development of children from an ancient culture with a rich astronomical heritage that has undergone dramatic social change and that has an increasingly important role to play in the world. The studies have concentrated on several research problems, including the acquisition and development of children’s cosmologies through knowledge restructuring (the focus of this paper), and the influence of language, culture, and environment on these changes (Bryce & Blown, 2006). The investigation of these problems illuminates the initial concepts that children hold about the world, the acquisition of knowledge from both the local and the global culture, and the characteristics of knowledge restructuring (in various ways, including dynamic restructuring) leading to a more scientific view of worldly phenomena. Taken together, the studies offer a reconciliation to the conflicting interpretations that have figured in recent research as detailed herein.

Knowledge Restructuring and Conceptual Change

Central to the debate on developmental and conceptual change is how existing schemata are altered by new experiences. Rumelhart and Norman (1978) identified three types of schematic modification: accretion and tuning (similar to Piaget’s assimilation and accommodation, respectively), and restructuring (involving the creation of new knowledge structures). In Piaget’s theory, stages constrained knowledge acquisition in all domains. For this reason it is an example of global restructuring. In response to evidence that Piagetian theory is inadequate as an explanation of intellectual development (see Donaldson, 1984), and developmental change (see Carey, 1985a; Driver & Easley, 1978), several researchers replaced stage theory with one based on domain-specific restructuring (see Carey, 1985b; Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1982). In a seminal paper on knowledge restructuring, Vosniadou and Brewer (1987) described two types of domain-specific restructuring: a weak form characterised by changes in knowledge representations, and the creation of new, higher-order relations between concepts exemplified by the differing knowledge representations of the expert–novice shift in which experts have more complex and more abstract interrelations between concepts (see Chi, Feltovich & Glaser, 1981; Larkin, 1979, 1981). And a strong or radical form (also evident in the differing theories of experts and novices) characterised by fundamental changes or revolutions in schematic organisation, analogous to paradigm shifts or revolutions in the evolution of science (see diSessa, 1982; Kuhn, 1970; McCloskey, 1983). Outlining the rationale for their research into children’s cosmologies to find exemplars of restructuring phenomena, Vosniadou and Brewer (1987) postulated that “the change from a geocentric schema in which the earth is conceptualized as flat and motionless to a heliocentric schema in which the earth is conceptualized as spherical and rotating, appears to meet all the criteria for radical restructuring” (p. 60).

Knowledge Restructuring and Children’s Cosmologies

Their theory hypothesises that children’s early (initial or intuitive) concepts of the Earth are based on a categorisation system that children use to make sense of physical objects by way of rudimentary assumptions or presuppositions based on experience; for example, concerning Earth shape, children know a ground that affords stability because it is generally solid, stable, and flat—and they identify with the ground as the place where people live. Such experience leads to the flatness constraint or presupposition in that the largest physical object children know is flat. Similarly, concerning Earth motion and gravity, unsupported objects fall downwards, which leads to the support constraint or presupposition and related up–down gradients associated with playing with balls and other objects under the influence of gravity. These intuitive constraints or presuppositions mediate new knowledge about the world so that, for example, when they are told that the world is “round”, they imagine it to be “round” and flat or disc-shaped. Or similarly when they “learn” that the Earth is a spherical planet in space, they may imagine that the Earth is like a ball cut in half and that people live on the flat part of the “hollow sphere”, so creating an alternative framework (see Driver & Easley, 1978) or a synthetic model (see Vosniadou & Brewer, 1992).

The significance of such alternative or synthetic cosmologies is not only that they indicate how children try to make sense of conflicting theories about the world, but also that they emphasise in some cases that the early intuitive concepts are difficult to modify and may become an entrenched feature of the child’s world view (see Vosniadou, 1992). The research of Vosniadou and Brewer (1992, 1994)—and the work of Nussbaum (1979), Nussbaum and Novak (1976), and Sneider and Pulos (1983) on which it is based—has recently been challenged by Ivarsson, Schoultz, and Säljö (2002), Nobes et al. (2003), Schoultz, Säljö, and Wyndhamn (2001), and Siegal, Butterworth, and Newcombe (2004) on both theoretical and methodological grounds (see Agan & Sneider, 2004; Bryce & Blown, 2006; Hayes, Goodhew, Heit, & Gillan, 2003; Vosniadou, Skopeliti, & Ikospentaki, 2004).

Knowledge Acquisition: “Theory theories” versus “knowledge-in-pieces theories”

The main theoretical point in contention is how it is possible for children to learn by acquiring new knowledge from experience. This presents a developmental dichotomy: whether children have holistic views that make sense of the world (Donaldson, 1984; Driver & Easley, 1978), or coherent and systematic theory-like structures (see Carey, 1985a, b, 1991), or naïve theories (see McCloskey, 1983), or children’s theories analogous to those of novice scientists (see Brewer & Samarapungavan, 1991), or mental models of the Earth (see Vosniadou & Brewer, 1992, 1994), or Earth notions (see Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983), or whether their ideas of the physical world are disconnected fragments of knowledge or knowledge in pieces (see diSessa, 1983, 1988, 1993).

The former constructivist view is based on the premise that children have coherent theories about the world and that the processes of conceptual change involve...
modification to these theories in the light of experience. Sneider and Ohadi (1998) capture the essence of this interpretation when they state: “The process of learning involves a cognitive change, in which students must actively modify or reject their personal views in order to construct new models and theories” (p. 267). Carey (1985a, b, 1991) argues that children have coherent theories that they modify through processes of conceptual change featuring episodes manifest as radical restructuring (see Schnotz & Preuß, 1997).

The latter view is encapsulated by the work of diSessa (1988), who argues against what he describes as the “theory theories” epitomised by the work of McCloskey (1983), and proposes instead that “intuitive physics consists of a rather large number of fragments rather than one or even any small number of integrated structures one might call ‘theories’” (p. 52). Recent research highlights the ongoing debate: Nobes et al. (2003) concluded that children’s knowledge of the Earth was fragmented, whereas Hayes et al. (2003) found “some degree of coherent structure within children’s beliefs about the earth’s shape and that such beliefs represent more than collections of fragmented facts” (p. 268).

While “fragmented” versus “theorized” may be polar opposites helpful to our considerations of how thinking works, they are not categorical alternatives in practice. For both developmental researchers interested in children’s cosmologies and for instructional researchers concerned to teach more effectively, we are dealing with degrees of theorising; with the extent of coherence (diSessa’s “systematicity”) among children’s current ideas; and with how connected their thinking is when they reason forwards in interestingly presented and challenging practical situations. With regard to worldly events that they constantly encounter and live with (the ideas commonly researched under the heading of cosmologies), children’s thinking cannot be wholly fragmented—although we must ask how much coherence is detectable and how valid our enquiry strategy has been in search of that coherence. To that end, thinking should be explored multi-modally and in depth to see what consistency there is when ideas are expressed by young people in different ways (verbally and non-verbally). Fragmentation would favour differences between modes; theorised thinking would favour similarities across modes. Furthermore, in-depth longitudinal designs are required to check the consistency of concepts over time, where new ideas are shown to be built on earlier ideas. Such research should also incorporate controls when coherence is explored across time, for we need to know what has been acquired through life experiences and not through interventions themselves. And of course there has to be demonstrable consistency in those categorisations of children’s thoughts claimed to be reflecting the extent of “joined-up” thinking. It is also vital for research to adopt features of ethnographic research with researchers spending long periods of time with each child (in this research up to 2 h in total per child during each of the surveys in the longitudinal design), having become accepted in their country and culture over many months. Otherwise “knowledge in pieces” may be a reflection of “fragmented methodology” where only short periods of time are spent “testing” children. It is not surprising that researchers who make brief visits to schools to conduct research come to different conclusions from those who spend months there.
Knowledge Restructuring and Children’s Cosmologies

Cultural Mediation

According to Piaget, one of the early pioneers in the field of children’s cosmologies (see Piaget, 1929, 1930), “the same logical structures are to be found in some stage of development in all cultures and environments” and children “will therefore structure their experience, including their experience of physical phenomena in the same ways” (Driver & Easley, 1978, p. 76). Piaget’s prediction was confirmed by the work of Mali and Howe (1979, 1980), who found that Nepalese children held similar Earth notions to those of American children but at an older age (see Nussbaum & Novak, 1976; Sneider & Pulos, 1983). One of the objectives of Vosniadou’s team was to search for evidence of universal initial (intuitive) concepts that would be held by young children in all cultures before the children acquired culture-specific cosmologies (see Vosniadou & Brewer, 1990, p. 607); or were influenced by the scientific world-view (see Brewer & Samarapungavan, 1991). In the cross-cultural research reported here and in Bryce and Blown (2006), New Zealand was selected because the first author taught there and the cosmologies of the New Zealand European and Maori cultures were relatively well known (see Brailsford, 1994; Orchiston, 1996; Rikihana, Andrews, Fisher, & Carter, 2001). China was selected as the second comparative culture because it was relatively remote. The traditional cosmologies of China were known through the work of Henderson (1984) and Needham (1975). However, the cosmologies of modern China were unknown. In Bryce and Blown (2006) we have shown that, with an appropriate research strategy, it is possible to elicit responses from children from all “levels” of their conceptual organisation: intuitive, cultural, and scientific.

Method

Piagetian Clinical Interview Technique: Open-ended research versus structured teaching

The main methodological point of disagreement among researchers concerned with children’s cosmologies concerns the utilisation of Piagetian interviews where great variation in outcome has been reported between those researchers who use Piagetian interviews with few props (see Bryce & Blown, 2006; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou & Brewer, 1990, 1992, 1994) and those who use less open-ended interviews with model Earth-shapes as props (see Ivarsson et al., 2002; Nobes et al., 2003; Schoultz et al., 2001; Siegal et al., 2004). This critique prompted further research by Vosniadou and her team to defend their theory, methodology, and research findings (see Vosniadou et al., 2004). The criticism of Vosniadou and Brewer’s work also attracted a response from Agan and Sneider (2004), who advised readers caution when interpreting the findings of those researchers who used physical models as props and claimed to have found no evidence of intuitive or synthetic Earth Notions or Mental Models. Vosniadou and Brewer (1992) questioned whether mental models are stored in long-term memory or whether they are constructed during the interview (p. 575). In this context, the use of models (e.g., globes) as interview
props should be treated with caution since their introduction before children’s concepts are known may limit the conceptual depth and level of responses (see Interview Attunement Hypothesis in Bryce & Blown, 2006). There is substantial evidence in the literature that children should be given opportunities to actively construct understanding from experience building on their own intuitive ideas. Rather than being conceptually uniform, children have a rich variety of alternative frameworks in their cosmological schema requiring innovative teaching to encourage reconstruction (see Driver & Easley, 1978; Sneider & Pulos, 1983; Trumper, 2001). Although Piaget’s theory has been controversial, his interview technique, which has been used to research children’s cosmologies since 1929, remains a lasting legacy to his sensitivity towards children’s worlds and appears to afford researchers the most effective method of investigating children’s ideas. However, Piaget never intended his clinical method to be used as a teaching strategy, or as a method of rapid assessment of children’s ideas akin to class examinations or quick tests. He was very much against both ideas as is clear from Claparède, in the introduction to Piaget (1926):

The clinical method is the art of questioning: it does not confine itself to superficial observation, but aims at capturing what is hidden behind the immediate appearance of things. It analyses down to its ultimate constituents the least little remark made by the child. It does not give up the struggle when the child gives incomprehensible answers but only follows closer in chase of the ever-receding thought … (p. xiv)

The experience of the current research spanning over a decade is that Piagetian interviews take a great deal of time, but when coupled with an ethnographic approach, they are most effective.

Influence of Longitudinal Field Research on Cosmological Development

Such a strategy requires a rapport to be established between teachers, parents, and children—the culture of the school and community—and the researcher. From the perspective of domain-specific knowledge, acquaintance with the domain under investigation, through a series of interviews in an earlier survey, could enhance a child’s awareness of the world and lead to them performing significantly more scientifically than their control group peers who had not been previously interviewed. And from a linguistic perspective, Cromer’s (1987) work indicated that experience gained from being asked questions—“linguistic exposure” to use Cromer’s term—“may accelerate specific acquisitions. Furthermore, language is a highly structured system, and changes in one part of the system will cause changes to occur in other parts of the system” (p. 228). Cromer reached that conclusion after comparing a longitudinal group, which he surveyed at quarterly intervals over a 1-year period, with a cross-sectional group, which he surveyed only once. And this enhanced performance was independent of any feedback from teachers or researchers concerning the correctness or otherwise of responses. Although repeated questioning of the same concepts is characteristic of longitudinal research, the time span between surveys in the research reported here (5 and 6 years between the Main Surveys
carried out in New Zealand and in China, respectively) was such that it was thought unlikely that the children would recall the earlier questions and would not therefore have any concern about repetition being necessary because their earlier responses were “incorrect” (see Siegal, 1999; Siegal, Waters, & Dinwiddy, 1988). Nor was it thought that investigating the same concepts using similar questions with different media would lead to inconsistency, or any long-term advantage or disadvantage to participants. Crucially, the research incorporated control groups in its longitudinal design, these falling in the same years as the second (follow-up) surveys in both countries.

Participants

The sample for the First New Zealand Survey (1987) consisted of 155 children, aged 3–9, of whom 78 were boys and 77 were girls ($M = 5.93$ years, $SD = 1.84$). The participants for the Second New Zealand Survey (1989) consisted of 111 children, aged 3–11, of whom 60 were boys and 51 were girls ($M = 6.69$ years, $SD = 2.65$). The participants were distributed by age as presented in Table 1.

The sample for the New Zealand Main Survey (1993) consisted of 127 children, aged 2–12, of whom 62 were boys and 65 were girls ($M = 7.61$ years, $SD = 3.15$). The participants in the China Main Survey (1994) consisted of 113 children, aged 2–12, of whom 57 were boys and 56 were girls ($M = 7.52$ years, $SD = 3.10$). The age distribution was as presented in Table 2.

The sample for the New Zealand Longitudinal (Follow-up) Survey (1998) consisted of 82 children (who had been in the New Zealand Main Survey and were now aged 8–18), of whom 38 were boys and 44 were girls ($M = 13.24$ years, $SD = 3.07$). The sample for the New Zealand Longitudinal (Control) Survey (1998) consisted of 82 children, aged 8–18, who had not participated in the New Zealand Main Survey, of whom 39 were boys and 43 were girls ($M = 13.12$ years, $SD = 2.98$). These were distributed by age as presented in Table 3.

The participants in the China Longitudinal (Follow-up) Survey (2000) consisted of 89 children (who had participated in the earlier China Main Survey and were now aged 8–18), of whom 47 were boys and 42 were girls ($M = 13.62$ years, $SD = 3.02$). The participants in the China Longitudinal (Control) Survey (2000) consisted of 89 children (aged 8–18) who had not participated in the China Main Survey, of whom

Table 1. 1st and 2nd New Zealand Surveys (1987, 1989)

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<th>Age (years old)</th>
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<td>n (First New Zealand Survey)</td>
<td>17</td>
<td>42</td>
<td>31</td>
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<td>n (Second New Zealand Survey)</td>
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48 were boys and 41 were girls (\(M = 13.68\) years, \(SD = 3.00\)). These were distributed by age as presented in Table 4.

Those children who participated in both of the First and Second New Zealand Surveys (1987, 1989) formed a New Zealand Pilot Longitudinal Group. This was treated as a separate group (including having its own control group) because it was a possible source of evidence of the effect of multiple interviews over time since the children were surveyed up to four times (in 1987, 1989, 1993, and 1998). The participants in the New Zealand Pilot Longitudinal Group originally (1989) consisted of 69 children (aged 5–11), of whom 38 were boys and 31 were girls (\(M = 7.65\) years, \(SD = 3.31\)). By the time of the New Zealand Main Survey (1993), the number of participants had reduced to 37 children, aged 7–12, of whom 17 were boys and 20 were girls (\(M = 10.37\) years, \(SD = 1.44\)). And by the time of the New Zealand Longitudinal (Follow-up) Survey (1998) the number of participants had reduced to 17 children, aged 14–17, of whom 5 were boys and 12 were girls (\(M = 15.47\) years, \(SD = 0.89\)). The New Zealand Pilot Longitudinal Control Group (1998) had a similar composition (\(M = 15.38\) years, \(SD = 0.93\)). Other children from both cultures participated as research instrument trial groups and reserves, making the total number of participants 686.

The children from New Zealand attended a State Kindergarten and two State Primary schools in Featherston and Masterton, in Wairarapa, an agricultural region in the southern North Island of New Zealand. The children from China attended a State Kindergarten and two State Primary Schools in Changchun, in Jilin Province, an agricultural region of North East China. All participants in the Main Surveys were randomly selected after being twinned or matched by class teachers on the basis of age, gender, ethnicity, general ability, and socio-economic status based on parental occupation using the Standard Occupational Classification of the UK (Office

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<th>Table 3. New Zealand Longitudinal Survey (1998)</th>
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of Population, Census, & Surveys, 1991) as guiding criteria (not all of which could be met in all cases). Of the “matched pairs” so created, one was randomly selected to participate in the Survey Group and the “twin” was placed in the Control Group to be interviewed 5 years later if accessible (if not, a new twin was selected from the same class).

Apparatus

The apparatus for the motion study consisted of (a) a shadow-stick made from a metre ruler attached to a wooden block; (b) A4 cartridge paper, pencils, and coloured pens, to draw the motion of the Earth; and (c) rag dolls to familiarise younger children with the concept of “shadows”. In the shape studies, the equipment consisted of (a) play-dough in three colours (green, red, and yellow) for modelling the shape of the Earth, Sun, and Moon, respectively; and (b) A4 cartridge paper and coloured pens to draw the shape of the Earth, “Ground”, “Sky”, Sun, and Moon. For the habitation and identity studies, the apparatus consisted of (a) small model figures in the form of wooden pegs or model basketball players to represent “Self” and “Friend” (who lived on the other side of the Earth); and (b) rag dolls of Muppets, a Koala Bear, and a Kangaroo, to help children to associate with the concept of “the other side of the Earth” (the Muppets were used in New Zealand to associate with America; the Koala and Kangaroo in China to associate with Australia: New Zealand being unfamiliar).

Multimedia-multimodal Interviews within Triangulation of Measurement Rationale

Most previous research in this field has involved Piagetian interviews where the medium is verbal language. This approach, however, is problematical with very young children because of the disparity in world-views between the researcher and the child; and the consequent difficulty in sharing conceptual understanding. For example, to the question “What shape is the Earth?”, a child might respond “Round”. To a teacher or researcher this might suggest that the child holds a spherical Earth concept, but closer questioning may reveal that the child considers the Earth to be disc-shaped. For this reason several media were utilised in this research including verbal language, play-dough modelling, and drawing materials such as paper and coloured pens. Use of a multimedia approach (i.e., interview, drawing,
play-dough) within a methodological model of triangulation of measurement (see Isaac & Michael, 1981, p. 92)—where the data from each of three media was coded independently, initially, then used to integrate a final category—ascertained with greater precision than traditional methods the position held by children with respect to particular elements of their cosmologies.

**Instrument**

The instrument was in the form of an interview guide covering all aspects of children’s astronomy and Earth science concepts: the current paper focuses on questions related to the shape and motion of the Earth. Although the same basic questions were asked, for younger children the language was simplified by consultation between the first author (who had worked as an elementary school teacher) and class teachers. For example, in the Earth Motion Study, while observing the divergence of the shadow of a shadow stick from a pencil placed on the ground, there were a series of preliminary questions to set the scene and to put younger children at ease: “Have you ever studied or looked at shadows before?”, “Do you have a shadow?”, “Can you show me your shadow?”, “Can you see the doll’s shadow?”, “What gives you your shadow?”, “What gives the doll its shadow?”, “Does the ruler have a shadow?”, “What causes the shadows?”, “Is anything changing (down there by the pencil)?”, “Is the pencil still touching the ruler shadow?”, “Is anything moving (down there by the pencil)?”, “What is moving?”, “Why is it moving?”, “Has what is happening got anything to do with the Sun?”, and “Is the Sun moving?” These questions, and their responses led into questions such as “Is the Earth moving?”, “How is the Earth moving?”, and “Why is the Earth moving?” Similarly, in the Earth Shape Study, the questions put to younger children were in the everyday language of the child; for example, “Tell me about the Earth?”, “What is the Earth?”, “Do you know what the Earth is?”, “What is the Earth made of?”, “Where is the Earth?”, “What shape is the Earth?”, “What colour is the Earth?” (probing ideas about land, water), and “Why is the Earth that (those) colour(s)?” If the child indicated that they did not know what the word “Earth” meant, then the interview was modified accordingly, usually by exploring synonyms such as “world” and if that failed “ground”. This technique enabled all children, including 2 year olds, to share their ideas in a meaningful way.

However, it should be emphasised that one of the reasons for the multi-media design (utilising verbal language, drawing, and play-dough modelling) was recognition by the first author based on experience as a junior class teacher (the interview guide was trialled on a group of 5 year olds) and parent; that young children are not as able to express themselves as older children are. For use in China, these guides were translated into hanzi (Chinese characters) and pinyin (a system of phonetic spelling for transliterating Chinese). A similar approach was adopted by Brewer, Herdrich, and Vosniadou (1987) for their Samoan studies, where the interviews were conducted in Samoan by a native speaker. In China, assistance was required from interpreters trained by the first author. In the first studies and Main Surveys, observational astronomy of the apparent motion of the Sun using the shadow stick
was done with all children, and, when visible, the Moon and its various phases and position in the sky were observed in daytime. In the Longitudinal (follow-up) Surveys, there were time limitations caused by the number of children to be interviewed doubling as a result of the need for control groups, and the first author being a visitor rather than a resident of New Zealand (in 1998) and of China (in 2000). Because of this the instrument was modified for the follow-up surveys and the observational astronomy of the Sun and Moon could not be undertaken in either culture. However, by that time, all of the children were 5 years older than in the Main Surveys and were able to respond to all of the essential questions of the instrument on the Motion and Shape of the Earth without the initial introduction using the shadow stick with no loss of data. This was just as well because when the first author arrived in North East China (in April 2000) to conduct the second survey, he was greeted by an un-seasonal blizzard blowing from Siberia that lasted for 2 weeks and negated any chance of doing observational astronomy: thus highlighting one of the problems of fieldwork in Northern China.

Nevertheless it was possible to conduct individual Piagetian interviews utilising the media of verbal language, drawing and play-dough modelling as in the Main Surveys despite the larger number of participants. During the First New Zealand Survey (1987) the motion of the Earth was observed directly using a Foucault Pendulum (see Abell, 1969, p. 114), and indirectly using a Cork Dust Bowl (see Roberts, 1960, p. 13). However, these were not used in the later studies because the facilities to do so were not available. This was not considered to be too great a loss since the shadow stick observations provided an adequate introduction to the motion of the Earth and apparent motion of the Sun for younger children (see interview). The interview took between 1 and 2 h depending on the age of the child; there being four sections of approximately equal duration (Motion, Shape, Habitation, and Gravity Studies respectively). For a 2–4 year old at Kindergarten each session might last 10–15 min (taking account of their more limited attention span), making 40–60 min in all. For a 10–12 year old at Primary School each session might last 20–30 min, making 80–120 min in all. Generally older children required less time. The extension studies that took place during the Main Surveys with children age 8–12 covered general aspects of Earth science and astronomy; they took approximately 60 min in two 30-min sessions.

**Interview: Earth motion study**

For the first studies and the Main Surveys (when the children were age 2–12) the researcher and the child being interviewed sat in the school or kindergarten playground by a shadow stick (metre ruler) in sunshine. The child then placed a pencil so that the tip of the pencil was touching the ruler shadow. With kindergarten children, time was spent introducing the concepts of shadows and the motion of shadows using rag dolls. After observing the divergence of the ruler shadow, the child was asked a series of questions about the motion of the Sun, Earth, and Moon in that order. Care was taken not to look at the Sun, but the Moon was observed when
visible. After the observation session, the child was asked to draw the Earth, Sun, and Moon and to describe and draw their motion (if any) using coloured pens and A4 paper. Later, following play-dough modelling of the shape of the Earth, Sun, and Moon, the child was asked to model their motion with their own play-dough models. Thus three sets of data were obtained from each child on their Earth Motion cosmology: interview, drawing, and play-dough modelling (the latter being photographed) for later triangulation analysis.

**Interview: Earth shape and habitation study**

In the first studies and the Main Surveys, researcher and child sat by a small desk or table outdoors or indoors by a window with a clear view of the ground and sky. The child was asked to draw the Earth including the Ground and Sky. The child was then asked some questions about habitation of the Earth: “Are there people on the Earth?”, “Are you on the Earth?”, “Where are you on the Earth?”, and “Can you point to the Earth?” They were then asked to draw where they thought they were on the Earth, or, in the case of children who could not identify with the Earth, on the Ground. The child was then introduced to the idea of a new friend who did not live nearby. If the child had shown a spherical Earth concept, then the friend was said to live on the other side of the Earth. If, on the other hand, the child did not hold the Earth to be spherical or was uncertain of the concept “Earth”, then they were asked to imagine that their new friend lived a long way away and to draw them accordingly.

The child was then given a piece of play-dough about the volume of a tennis ball and asked to make the shape of the Earth. The researcher then introduced model people: “Self” representing the child, and “Friend” representing their friend who lived “on the other side of the Earth” or “a long way away”. The child was then asked to put the model of themselves and the model of their friend where they thought they should be in relation to the Earth either on the child’s play-dough model or on their drawing. Thus, a further three sets of data were obtained, giving each child’s cosmology of Earth Shape and Habitation in the media of verbal description, drawing and play-dough. These, and other, generative questions (see Osborne & Wittrock, 1983) afforded children an opportunity to reflect upon their Earth shape and habitation notions in a concrete rather than an abstract way involving multiple modalities. For example, the simple question of asking children to point to the Earth gave an indication as to whether or not children identified with planet Earth: if a child pointed upwards into the sky it suggested a dual-Earth cosmology; particularly if they had drawn themselves on a flat ground with a circular-shaped Earth above. Whereas if they pointed downwards, or said “We’re sitting on the Earth”, and had drawn and modelled themselves standing on a spherical Earth rather than a flat ground, it was a good indication that they identified with planet Earth. However, models of Earth shape were not introduced to clarify children’s responses. This is in contrast to Vosniadou and Brewer’s (1990) approach where children were asked to select an Earth shape from a range of models, the choice of which compared favourably with what they had said in generative dialogue. [All of
the children ignored a control shape (a cone) “which shows that children’s selections were not random but reflected their beliefs regarding the shape of the earth” (Vosniadou & Brewer, 1990, p. 615). Although the current paper supports Vosniadou and Brewer’s claim that children have coherent notions about the shape of the Earth, it was felt that the introduction of models could inhibit rather than assist the investigative process.

Results: Data acquisition, coding, reliability, validity, and analysis

When all data had been collected—and in the case of Chinese data, transcribed and translated—they were categorised, using a scheme developed from the work of Nussbaum and Novak. In each case a thumb-nail sketch was created and a descriptor was invented to capture the essential features of the cosmology they described. These formed ordinate rows from least scientific (Concept Category 1) to most scientific (Concept Category 10). Columns of age groups enabled children to be placed by name in the category matching their cosmological concept, forming Identified Subject Histograms (see Figures 1 and 2) that could be used not only to illustrate children’s concepts as expressed in several media (interview, drawing, play-dough), but also to track changes over time providing data (ordinal changes) for statistical analysis. The initial coding was done by the first author who also conducted the interviews, with the assistance of interpreters in China.

Control Group Design and Statistical Analysis

The research design incorporated two main elements:

(1) To detect the fine detail of cosmological development and evidence of knowledge restructuring, appropriate non-parametric statistical tests were required that took into account the ordinal nature of the data as classified in the taxonomy of cosmological concept categories, and the longitudinal nature of the studies. These requirements were satisfied by the Spearman rank-order correlation coefficient $r_s$ for age versus cosmological category correlations; and the Kolmogorov–Smirnov two-sample test for longitudinal group comparisons.

(2) To measure any changes due to repeated interviews over extended intervals (2 years between the First and Second Surveys; 5 years between the Main Surveys and their Follow-ups) the research design needed to incorporate both survey and control groups. This criterion was met by Solomon’s (1949) Four Group Design. The treatment was the interview instrument that was administered to the New Zealand Pilot Longitudinal Survey Group four times (1987, 1989, 1993, 1998); the New Zealand Main Survey Group twice (1993, 1998); and the China Main Survey Group twice (1994, 2000). The same instrument was applied to the New Zealand Pilot Longitudinal (Control) Survey Group, the New Zealand Longitudinal (Control) Survey Group in 1998; and the China Longitudinal (Control) Survey Group in 2000.
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<thead>
<tr>
<th>Category Ordinal</th>
<th>Thumb-nail Sketch</th>
<th>Concept Descriptors and Exemplars</th>
<th>Age</th>
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<tr>
<td></td>
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<td>Earth planet in space Rotates (spins) on axis Revolves (orbits) around the Sun or around Sun and Moon</td>
<td>3-4 5-5 6-7 7-8 8-9 9-10</td>
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<td>Ryan Daniel</td>
<td>Hayden Lee</td>
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<td>Earth planet in space Revolves (orbits) around Sun or Moon or Sun and Moon Does not spin or spin uncertain</td>
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<td>Earth planet or ball-shaped object in space Rotates (spins) on axis Does not Revolve (orbit) around Sun or uncertain e.g., Sun and/or Moon revolve (orbit) around Earth</td>
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<td>Space Orbit? S E Sky Earth planet or ball-shaped object Located in space or sky Stationary</td>
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<td>Earth flat or disc-shaped or uncertain Location also uncertain Moves continuously in some way e.g., round and round or up and down Follows us when we move (inanimate)</td>
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<td>Edna Barry Alistair Michelle Karl Kere Andrew Jeffrey Taweti</td>
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<td>Earth of uncertain nature Location also uncertain Motion irregular or intermittent e.g., only moves at night-time Never moves in the wind</td>
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<td>Daniel Vanita Bridget Crystal Carlos Michelle Haley Jonathan Claire Timu</td>
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<td>Earth animate moves just like a person who walks, runs, sleeps at night-time Does not spin at night because it is tired</td>
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<td>Melissa Nanaua</td>
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<td>Earth flat or uncertain in nature Location also uncertain Stationary Moves only during earthquakes</td>
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<td>Adon Scala Lance Grant Timothy Nikolai Katie Daniel</td>
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<td>Earth plane or nature or meaning of Earth</td>
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<td>Marie Aroha Kelly Belinda Emma Gray Keryel Allison Brock Linda</td>
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<td>Figure 1. Children’s concepts of the Motion of the Earth: First New Zealand Survey</td>
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**Knowledge Restructuring and Children’s Cosmologies**

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<th>Category Ordinal</th>
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<th>Concept Descriptors and Examples</th>
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<th>Age 4-5</th>
<th>Age 5-6</th>
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<td>People live all over the curved surface</td>
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<td>People live on the curved top surface</td>
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<td>The lower part of the Earth is shaped like a ball but is half with a transparent dome</td>
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<td>Ground, inner part of the Earth</td>
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<td>People live &quot;inside&quot; the Earth on flat ground</td>
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<td><img src="image" alt="Sketch" /></td>
<td>Earth is flat and structured in some way, like road, or path or rectangular, or square, or a thick regular slab</td>
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<td>People live on flat surface of Earth or Ground</td>
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<td>Uncertain of meaning of Earth</td>
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<td>Unable to identify with Earth</td>
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<td>Play-ground model in form of irregular shape(s)</td>
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Figure 2. Children's concepts of the Shape of the Earth: First New Zealand Survey. **Note:** “S” and “F” refer to the position of “Self” and “Friend” as described, drawn, and modelled by children as part of the Habitation Studies.
Exemplars of the Cosmological Concept Categorisation Scheme

Earth motion exemplars. Sample responses (from each culture) to questions about the motion of the Earth with the appropriate Earth Motion (EM) Cosmological Concept Category (see Figure 1) are as follows (children’s ages are given in years and months, thus (4, 1) means 4 years and 1 month).

- **EM 1**: Uncertain of motion or nature or meaning of Earth: China.

  Researcher: Does the Earth move?
  Ji Cheng (4, 1): Yes.
  Researcher: Why does the Earth move?
  Ji Cheng: The Earth moves until there is no electricity … the Earth needs electricity to move … the Earth can fly in the sky and will not fall down—there are batteries in it … the Earth is made of sticks and paper and can fly in the sky.

- **EM 1**: Uncertain of motion or nature or meaning of Earth: New Zealand.

  Researcher: Does the Earth move?
  Tanya (3, 2): I’m not sure.
  Researcher: Do you know what the Earth is?
  Tanya: No.

- **EM 2**: Earth flat and stationary: moves only during earthquakes: China.

  Researcher: Does the Earth move?
  Wang Yi Hui (3, 0): The Earth moves up and down (referring to recent earthquakes).

- **EM 2**: Earth flat and stationary: moves only during earthquakes: New Zealand.

  Researcher: Does the Earth move?
  Gene (3, 5): Yes.
  Researcher: How does the Earth move?
  Gene: It moves up and down.
  Researcher: Why does the Earth move up and down?
  Gene: Because of earthquakes.

*Note:* Earthquakes are common in both China and New Zealand.

- **EM 3**: Earth animate: moves just like a person who walks, runs, sleeps at nighttime: China.

  Researcher: Is the Earth moving?
  Jia Li Li (5, 3): Yes.
  Researcher: How is the Earth moving?
  Jia Li Li: The Earth doesn’t spin at night-time because it is tired.

- **EM 3**: Earth animate: moves like a person who walks, runs, sleeps at night: New Zealand.

  Researcher: Is the Earth moving?
  Matthew (5, 0): The Earth runs!
  Researcher: Does the Earth run like we run?
  Matthew: Yes.
Knowledge Restructuring and Children’s Cosmologies

- **EM 4:** Earth of uncertain nature and location: motion irregular or intermittent: China.
  
  Researcher: Does the Earth move?
  Sun Qing Qing (8, 3): The Earth is under the ground: the Earth goes round the Sun in daytime but stays still at night-time.

- **EM 4:** Earth of uncertain nature and location: motion irregular or intermittent: New Zealand.
  
  Researcher: Does the Earth move?
  Keegan (3, 8): The Earth moves at night-time.

- **EM 5:** Earth flat or disc-shaped: moves continuously in some way: inanimate: China.
  
  Researcher: Does the Earth move?
  Li Hong Gang (5, 7): The Earth follows us when we walk.
  Researcher: Does the Earth walk too?
  Li Hong Gang: No … it’s in the sky.

- **EM 5:** Earth flat or disc-shaped: moves continuously in some way: inanimate: New Zealand.
  
  Researcher: Does the Earth move?
  Samantha (3, 1): The Earth moves round and round.

*Note:* Child modelled Earth as disc-shaped

- **EM 6:** Earth planet or ball-shaped object in space/sky: stationary: China.
  
  Researcher: Does the Earth move or does the Earth stay still?
  Hou Yu (8, 9): The Earth is under the ground: it stays still because it is very big.

- **EM 6:** Earth planet or ball-shaped object in space/sky: stationary: New Zealand.
  
  Researcher: Does the Earth move?
  Hadley (5, 0): No.

*Note:* Hadley believed that the Earth was ball-shaped and in the sky.

- **EM 7:** Earth planet in space/sky: moves continuously in some way: China.
  
  Researcher: Does the Earth move?
  Yu Chang Long (5, 4): The Earth moves in a circle but does not move around anything.

- **EM 7:** Earth planet in space/sky: moves continuously in some way: New Zealand.
  
  Researcher: Does the Earth move?
  Danielle (5, 1): It moves round.
  Researcher: How does it move around?
  Danielle: Like that [indicates circular motion with hand].
  Researcher: Does it go around something?
  Danielle: No.
  Researcher: Does it spin?
  Danielle: No.
● **EM 8:** Earth planet in space: spins on axis: does not orbit around Sun: China.

  **Researcher:** Is the Earth moving?
  Zhao Jing (5, 5): It moves in a circle [indicates spinning motion with hand].
  **Researcher:** Is it going around something or just spinning?
  Zhao Jing: It spins.

● **EM 8:** Earth planet in space: spins on axis: does not orbit around Sun: New Zealand.

  **Researcher:** Is the Earth moving?
  Bridget (4, 11): Yes.
  **Researcher:** How is the Earth moving?
  Bridget: It turns around.
  **Researcher:** Why is the Earth moving?
  Bridget: Because it’s in space, and space makes it turn around.
  **Researcher:** Is it spinning?
  Bridget: Yes.
  **Researcher:** Does the Earth move in any other way?
  Bridget: No.

● **EM 9:** Earth planet in space: orbits around Sun: does not spin on axis: China.

  **Researcher:** Is the Earth moving?
  Feng Yan (4, 7): Yes.
  **Researcher:** How is the Earth moving?
  Feng Yan: The Earth goes round the Sun.

● **EM 9:** Earth planet in space: orbits around Sun: does not spin on axis: New Zealand.

  **Researcher:** Is the Earth moving?
  William (6, 9): It goes around the Sun.
  **Researcher:** Does the Earth move in any other way?
  William: No.
  **Researcher:** Does the Earth spin?
  William: No.

● **EM 10:** Earth planet in space: spins on axis and orbits around Sun: China.

  **Researcher:** Does the Earth move?
  Chen Zhuo (10, 8): Yes.
  **Researcher:** Show me how the Earth moves with your play-dough models?
  Chen Zhuo: [Models Earth spinning on axis and revolving around the Sun].
  **Researcher:** How long does it take to do that?
  Chen Zhuo: A day to spin—a year to orbit the Sun.

● **EM 10:** Earth planet in space: spins on axis and orbits around Sun: New Zealand.

  **Researcher:** Does the Earth move?
  Manaia (10, 0): Yes.
  **Researcher:** How is the Earth moving?
  Manaia: It spins and also goes around the Sun.
  **Researcher:** How long does it take to spin once?
  Manaia: A day.
  **Researcher:** How long does it take to go round the Sun once?
  Manaia: A year.
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Earth shape and habitation exemplars. Sample protocols about the Shape and Habitation of the Earth with the appropriate Earth Shape (ES) Cosmological Concept Category (see Figure 2) are as follows:

- **ES 1**: Uncertain of meaning of Earth: unsure of Habitation of Earth: China.
  
  Researcher: Tell me about the Earth?
  
  Liu Mei Chen (3, 6): I don’t know what the Earth is.

- **ES 1**: Uncertain of meaning of Earth: unsure of Habitation of Earth: New Zealand.
  
  Researcher: Tell me about the Earth?
  Victoria (3, 9): I’m not sure.
  Researcher: Where are we now?
  Victoria: Outside.
  Researcher: Outside where?
  Victoria: Outside at the Kindy.
  Researcher: Where is the Kindy?
  Victoria: Here ... we’re at the Kindy.
  Researcher: What are the children standing on [pointing to other children]?
  Victoria: The ground.

  *Note:* It was common for very young children like Liu Mei Chen and Victoria not to know the meaning of the word “Earth”, but they all knew the meaning of “Ground” and “Sky”.

- **ES 2**: Earth flat and unstructured like a thin irregular slab or pancake: China.
  
  Researcher: What shape is the Earth?
  Wang Yi Hui (3, 0): The Earth looks like a noodle.

  *Note:* Wang Yi Hui modelled his Earth in play-dough as an irregular oblong shape.

- **ES 2**: Earth flat and unstructured like a thin irregular slab or pancake: New Zealand.
  
  Researcher: Make the shape of the Earth with the play-dough.
  Kym (8, 9): [Spreads play-dough as thin layer on her drawing].
  Researcher: Is that the Earth?
  Kym: Yes ... can I have some more?
  Researcher: More play-dough?
  Kym: Yes ... I want to cover it [cover her drawing with a thin spread layer].

  *Note:* Kym was given more play-dough and made her “Earth” as a thin spread layer.

- **ES 3**: Earth flat and structured in some way like oval, or rectangular, or square: China.
  
  Researcher: Make the shape of the Earth with the play-dough.
  Lu Bo Da (3, 1): [Makes a rectangular-shaped Earth].
  Researcher: What shape have you made your Earth?
  Lu Bo Da: Flat and long.
ES 3: Earth flat and structured in some way like oval, or rectangular, or square: New Zealand.

Researcher: Make the shape of the Earth with the play-dough.
Melissa (4, 2): [Rolled four pieces of play-dough and placed them one by one to create the sides of a square which she called the Earth].

ES 4: Earth disc-shaped like a crumpet or pancake: people live on top surface: China.

Researcher: What shape is the Earth?
Li Yao (5, 11): The Earth is round.
Researcher: What do you mean by “round”? Round like a disc or round like a ball or round in some other way (e.g., cylindrical, elliptical, oval)?
Li Yao: Like a disc.

Note: A similar procedure was adopted in all cases to clarify the meaning of “round”.

ES 4: Earth disc-shaped like a crumpet or pancake: people live on top surface: New Zealand.

Researcher: What shape is your [play-dough] model of the Earth?
Emma (6, 1): It’s flat [a thick disc or bun shape].

ES 5: Flat/Ball Dual-Earth: people live on the lower (ground), upper, or both Earths: China.

Researcher: Are we on the Earth?
Jia Li Li (5, 3): No.
Researcher: Where are we then?
Jia Li Li: We are not on the Earth because the Earth is in space … we can’t fly so we can’t go to the Earth.
Researcher: Where are we now?
Jia Li Li: On the Ground.

Note: Jia Li Li drew a circular Earth between a rectangular ground and a rectangular sky.

ES 5: Flat/Ball Dual-Earth: people live on the lower, upper, or both Earths: New Zealand.

Researcher: Tell me about the Earth?
Kaelah (5, 7): It’s next to the Moon.
Researcher: What is the Earth?
Kaelah: A round ball.
Researcher: Where is the Earth?
Kaelah: In space.

Note: Kaelah drew the Ground horizontally below and the Sky horizontally above with the circular Earth sandwiched between. She drew herself and her “Friend” on the upper Earth with their feet pointing towards the lower ground indicating a dual-Earth cosmology.
ES 6: Curved/Ball Dual-Earth: people live on lower, upper, or both Earths: China.

Researcher: Where have you drawn yourself and your friend?
Zhang Shuang (12, 2): On top.
Researcher: What are you standing on?
Zhang Shuang: The ground.
Researcher: What shape is the ground?
Zhang Shuang: Curved.

Note: Zhang Shuang drew herself and her friend standing on a flat ground drawn as a tangent to the top surface of a spherical Earth like two people standing on opposite sides of a see-saw. Although she modelled her Earth as spherical with play-dough, and placed herself and her friend on top of the Earth, she had difficulty in reconciling the everyday experience of a flat ground to the scientific concept of a spherical Earth: thus she held a dual-Earth cosmology.

ES 6: Curved/Ball Dual-Earth: people live on lower, upper, or both Earths: New Zealand.

Researcher: What shape is your play-dough Earth?
Adam (5, 8): Like a ball.
Researcher: Where have you drawn yourself?
Adam: On the ground.
Researcher: What shape is your drawing of the ground?
Adam: Like that [indicates curve with finger on table].
Researcher: Is the ground on the Earth?
Adam: No.

Note: Adam drew himself standing on the surface of a curved ground like the top surface of a dome. Above him he had modelled a spherical play-dough Earth in the sky, on which he had placed the model of himself. His dual-Earth cosmology indicated a confusion of identity with planet Earth that is typical of children who are having difficulty in merging scientific concepts such as a spherical Earth with the everyday experience of a flat or curved ground.

ES 7: Earth like a ball cut in half: people live inside on flat ground: sky inside dome: China.

Researcher: Where have you drawn yourself and your friend?
He Chong (9, 10): On the ground.
Researcher: Are you inside or outside the Earth?
He Chong: Inside.
Researcher: Where have you drawn the sky?
He Chong: Inside, above.

Note: He Chong believed that the Earth was like a hard-boiled-egg with the top three-quarters cut-off. He drew himself and his friend standing on the “Ground” formed by the flat surface of the lower quarter. The “Sky” was drawn as a line near the top of the circular Earth. He modelled the Earth as spherical with play-dough but said that people lived inside.
ES 7: Earth like a ball cut in half: people live inside on ground: sky inside: New Zealand.

Researchers: Where have you drawn yourself?
Nikki-Lee (9, 7): On the ground inside the Earth.
Researchers: Where have you drawn the sky?
Nikki-Lee: Inside the Earth.

Note: Nikki-Lee also believed that the Earth was like a hard-boiled-egg with the top three-quarters cut-off. She drew herself standing on the “Ground” of the lower quarter with the “Sky” forming an upper quarter. In play-dough she modelled the Earth as ball-shaped with “Self” and “Friend” standing upright (relative to the desk top) on the equator.

ES 8: Earth like a ball cut in half: people live inside on flat ground: space/sky outside: China.

Researchers: Where have you drawn yourself and your friend?
Cao Xiao Xi (9, 9): Inside the Earth.
Researchers: What are you and your friend standing on?
Cao Xiao Xi: The ground.
Researchers: Where have you drawn the sky?
Cao Xiao Xi: The sky is all around the Earth.

Note: Cao Xiao Xi drew his ground as a horizontal line two-thirds of the way up a circular Earth. He modelled the Earth as ball-shaped and placed “Self” and “Friend” on top. He said that people lived inside the Earth and that the sky was like a dome outside the Earth.


Researchers: Where have you drawn the ground?
Jacquelin (7, 5): Inside the Earth.
Researchers: Where have you drawn yourself and your friend?
Jacquelin: Inside the Earth.
Researchers: Why have you drawn yourself there?
Jacquelin: We live inside the Earth.

Note: Jacquelin believed that the Earth was like a half-ball with a dome top. She drew herself standing on the “Ground” formed by the lower disc-like surface and indicated with an arrow that her friend lived on “the other side” of the Earth. She drew the sky horizontally above but outside the Earth. She modelled the Earth as ball-shaped and placed the models of “Self and “Friend” on top but she said that they should really be inside standing on the ground.


Researchers: Where have you placed the models of yourself and your friend?
Liu Fei (10, 9): On top of the Earth?
Researchers: Why have you placed them there?
Liu Fei: Because people live on top of the Earth.
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Note: Liu Fei modelled the Earth as ball-shaped and placed his model people on top.


<table>
<thead>
<tr>
<th>Researcher:</th>
<th>Is the Earth moving?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikolai (10, 7):</td>
<td>Yes.</td>
</tr>
<tr>
<td>Researcher:</td>
<td>How is the Earth moving?</td>
</tr>
<tr>
<td>Nikolai:</td>
<td>It’s going around a circle.</td>
</tr>
<tr>
<td>Researcher:</td>
<td>What shape is the Earth?</td>
</tr>
<tr>
<td>Nikolai:</td>
<td>Round.</td>
</tr>
<tr>
<td>Researcher:</td>
<td>Round like ... ?</td>
</tr>
<tr>
<td>Nikolai:</td>
<td>Round like a ball.</td>
</tr>
<tr>
<td>Researcher:</td>
<td>In what way is the Earth moving?</td>
</tr>
<tr>
<td>Nikolai:</td>
<td>A ball spinning.</td>
</tr>
</tbody>
</table>

Note: Nikolai’s Earth Shape concept was clarified to illuminate his Earth Motion concept, eliminating any need for the Researcher to introduce the spherical Earth concept. This approach was used to maximise the child’s expressive ability. The use of cultural artefacts such as geometric-models of Earth shape was avoided. Nikolai later placed “Self” and “Friend” as living on top of the Earth, which he had modelled as spherical with play-dough.

- ES 10: Earth ball-shaped (spherical): people live all over the curved surface: China.

<table>
<thead>
<tr>
<th>Researcher:</th>
<th>What shape is the Earth?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Du We Wei (11, 11):</td>
<td>Like a ball.</td>
</tr>
</tbody>
</table>

Note: Du We Wei drew the Earth as circular and modelled it in play-dough as spherical. She also drew and modelled “Self” and “Friend” as living on opposite hemispheres, so demonstrating total understanding of the concept of human habitation of a spherical planet.


<table>
<thead>
<tr>
<th>Researcher:</th>
<th>What shape is the Earth?</th>
</tr>
</thead>
</table>

Note: Jared also showed complete understanding of the shape and habitation of the Earth.

Initiating Validity and Reliability of the Categorisation Scheme: First New Zealand Survey (1987)

To ensure the reliability and validity of the categorisation scheme used in the First New Zealand Survey (1987), a random selection of two exemplars of each cosmological category in each media (including play-dough models, drawings, and tape transcripts) was prepared for external coding. The selected examples included 19 of
151 cases or 12.6% of Earth Motion data, representative of 10 categories (see Figure 1); and 17 of 86 cases or 19.8% of Earth Shape data, representative of nine categories (see Figure 2); there being 155 cases in all in the First New Zealand Survey sample (see Participants section). The sample data were delivered to two independent groups of coders, familiar with the context of the studies: These were the Senior Astronomy Education Officer of Carter National Observatory in Wellington; and two Senior Lecturers at Massey University in Palmerston North, New Zealand.

The coders were provided with three scoring sheets for each study to provide triangulation. These had Cosmological Concept Categories similar to those shown in Figures 1 and 2, with thumb-nail sketches and descriptors on the left-hand side and room for the child’s name on the right to create Identified Subject Histograms as described earlier. For example, for the Earth Motion studies, the coder would inspect the tape transcript and if necessary listen to the tape of the Earth Motion interview before scoring on the Earth Motion Interview scoring sheet. The coder would then look at the child’s drawing of the motion of the Earth and score that on the Earth Motion Drawing score sheet. Finally, the coder would look at a description and photographs of the child’s play-dough modelling of the motion of the Earth, decide to which category it belonged, and enter the child’s name on the Earth Motion with Play-dough score sheet. Similarly, for the Earth Shape studies, the coder would inspect the tape transcript and if necessary listen to the tape of the Earth Shape interview before scoring on the Earth Shape Interview scoring sheet. The coder would then look at the child’s drawing of the Earth and score that on the Earth Shape Drawing score sheet. Finally the coder would look at a child’s play-dough model of the Earth, decide to which category it belonged, and enter the child’s name on the Earth Shape in Play-dough score sheet.

Because of the nature of the first studies (the main purpose of which was to ascertain the broad scope of children’s cosmologies by a multi-media methodology and to design a suitable categorisation scheme reflective of different types of data from different modalities responsive to these media), the concepts of Earth Motion and Earth Shape were triangulated by global consideration of the three media (interview, drawing, play-dough), giving a single integrated category placement for each child. The validity and reliability of the categorisation scheme was confirmed by the degree of intercoder agreement triangulated from the three media, which was as follows: Earth Motion categorisation, intercoder agreement 89.5% (Cohen’s kappa $\kappa = 0.88$); and Earth Shape categorisation, intercoder agreement 88.2% (Cohen’s kappa $\kappa = 0.87$). Disagreements in coding were discussed and resolved by a merging of two of the original Earth Motion categories, and by slight modifications to the Earth Shape category descriptors. The scheme was then applied to categorising the Second New Zealand Survey, 1989.

Maintaining Validity and Reliability: Longitudinal aspects (Second New Zealand Survey, 1989)

During the second study new categories emerged (indicating that the latent structure was probably continuous), and these were integrated into the categorisation schemes
in an appropriate place. To ensure the reliability and validity of the categorisation scheme after these changes, a second random selection of data representative of each cosmological category was made and, as in the case of the first study, these were delivered to two independent coders: in this case the astronomy educator at Carter Observatory and a science teacher in Israel with a long time interest in the field (to obtain an overseas perspective). For practical reasons, original play-dough models, drawings, and audio-tapes were not sent overseas: instead, photographs of the models and drawings and transcripts of the interviews were substituted. The selected exemplars included 21 of 111 cases or 18.9% of Earth Motion data, representative of 11 categories; and 19 of 111 cases or 17.1% of Earth Shape data, representative of 10 categories; there being 111 cases in all in the Second New Zealand Survey sample (see Participants section). The reliability and validity of the modified categorisation scheme was supported: Earth Motion categorisation, agreement 90.5%, $\kappa = 0.89$; and Earth Shape categorisation, agreement 94.7%, $\kappa = 0.94$. The first area of disagreement (concerning Earth Motion categories) was discussed and resolved by merging two of the original (1987) categories and modifying the ordinal sequence to accommodate this change. The second area of disagreement (concerning Earth Shape categories) was resolved by merging two of the lower (1987) categories to eliminate ambiguity in interpretation/coding.

**Validity and Reliability of the Categorisation Scheme: Main surveys (cross-cultural aspects)**

The categorisation scheme developed during the early studies was applied to the data from the Main Surveys and Follow-ups in New Zealand (1993–1998) and China (1994–2000) with few modifications. The main changes were based on cross-cultural considerations, particularly the need to attune the interview guide to Chinese culture to enhance the sensitivity of the methodology to cultural-specific concepts expressed through different modalities working through the three investigative media (interview, drawing, play-dough) as before. To this end the original study categories were re-designed so that all three media of a particular cosmological element (e.g., Earth Shape) could be scored on identical criteria defined by descriptors incorporating exemplars from all three media rather than being expressed in a single medium as in the First and Second Surveys (1987–1989). In this way it was possible to obtain data on a single cosmological concept that were capable of statistical analyses across media and modalities; e.g., Earth Shape categories for interview, drawing, and play-dough modelling had identical descriptors with identical ordinal values (see Figure 2).

Initial coding of the main New Zealand data was done by the first author in China with the assistance of four research assistants/interpreters (who usually worked in pairs), who were graduate teachers from Changchun and Jilin Universities. This served the dual purpose of giving an independent check of reliability on the categories and also familiarising the interpreters with all aspects of the research methodology and terminology. It also provided an opportunity to identify any modifications that might have been necessary to the interview guide to enable the same instrument
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to be applied in China (the Chinese version of the guide was written by the senior research assistant/interpreter). Although there was complete consensus between the coding of the data of the Main New Zealand Survey (1993) by the first author and the research assistants, it was decided that in addition to English and Chinese characters (Hanzi) each line of the translated guide should also be written in Pinyin—a system of romanised spelling for translating Chinese (Hanyu, Putongwha or Mandarin)—to make it easier for the researcher and interpreters to follow interview questions and responses. The coding sheets from New Zealand were similarly translated, and both the interview guide and the coding procedure were trialled with a small group of Chinese and French Canadian children (who were resident in China at that time) before being applied to the main body of Chinese data. The procedure involved the first author and the pair of interpreters translating, transcribing, and coding children’s cosmologies in the evening following the day-time interviews. Care was taken to ensure that the words used in the interviews and transcriptions had precise meaning in Chinese. For this purpose, technical English–Chinese and Chinese–English dictionaries were used to clarify understanding. Advice was also given by professors of English at Changchun University Foreign Languages College.

For example, although the word “earth” has several meanings in English—such as one of the planets of the solar system, land, ground (fell to earth), soil, clay, mould, the present abode of humankind as distinct from heaven or hell—the Chinese word for Earth, di qiu in Pinyin, has a precise meaning, namely planet Earth. On the other hand, Chinese, like Maori, but unlike English, has more than one word for the Earth’s Moon. The everyday moon, the phases of which govern the festive year and sets celebrations such as Spring Festival (Chinese New Year) or chun jie is known as yue liang. Whereas the scientific moon, which is always spherical in conception (akin to a Platonic form), about which children are taught at school is known as yue qiu. During several years living in China the first author became familiar with these and other astronomical terms and was able to detect them in the questions put by interpreters and the responses of children during interviews. But, in order to afford children the full range of their linguistic repertoire, the first author always used interpreters during interviews.

Each cosmology was discussed with the small team of interpreters in a similar manner to that adopted in New Zealand until full agreement was reached. Similarly, the data from the New Zealand Longitudinal (Follow-up) Survey (1998) and the China Longitudinal (Follow-up) Survey (2000) including the two control groups (see Participants section) was initially coded in China by the first author with the assistance of two new interpreters from Changchun University Foreign Languages College, the original (1994) interpreters being unavailable. As in the Main Surveys, there was a high degree of agreement between the coding of the first author and the two graduate research assistants/interpreters, all disagreements being resolved by discussion.

**Indexing Influence of Coder Drift on Reliability—and validation of cross-cultural coding**

In view of the longitudinal, cross-cultural nature of the studies, involving some coding by interpreters, it was deemed prudent to subject a random selection of the
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data from both New Zealand and China to further evaluation in New Zealand following the follow-up survey. This served the dual purpose of checking for possible reduction in reliability as a consequence of coder drift; and as a measure of validation of the two versions of the instrument and coding procedures (English and Chinese). The post-survey coding was conducted independently by two astronomy educators at Carter National Observatory, one of whom had coded the original data in 1987 and 1989 (so providing a measure of internal consistency to the coding scheme). The procedure adopted was essentially the same, but in this case (as in the initial coding of the Main Surveys by the first author and his interpreter/research assistants) the codings of the three media (interview, drawing, and play-dough) were kept separate (for later triangulation by the first author). In this case the selected exemplars included 20 of 164 cases or 12.2% in each media of Earth Motion and Earth Shape data from New Zealand (there being 82 children in the Survey Group and a similar number in the Control Group); and 20 of 178 cases or 11.2% in each media of Earth Motion and Earth Shape data from China (there being 89 children in the Survey Group and a similar number in the Control Group). The results confirmed the adequacy of the research instrument and the accuracy of the coding design with high intercoder agreement ranging from 80% to 100%, and corresponding acceptable values of Cohen’s kappa ranging from $\kappa = 0.78$ to $\kappa = 1.0$.

The final coding results in each study and media were as follows:

- Earth Motion Interview (New Zealand): agreement 92.5%, $\kappa = 0.92$.
- Earth Motion Interview (China): agreement 95.0%, $\kappa = 0.94$.
- Earth Motion Drawing (New Zealand): agreement 87.5%, $\kappa = 0.86$.
- Earth Motion Drawing (China): agreement 87.5%, $\kappa = 0.86$.
- Earth Motion Play-Dough (New Zealand): agreement 90.0%, $\kappa = 0.89$.
- Earth Motion Play-Dough (China): agreement 95.0%, $\kappa = 0.94$.
- Earth Shape Interview (New Zealand): agreement 100 %, $\kappa = 1.0$.
- Earth Shape Drawing (New Zealand): agreement 85.0%, $\kappa = 0.83$.
- Earth Shape Drawing (China): agreement 90.0%, $\kappa = 0.89$.
- Earth Shape Play-Dough (New Zealand): agreement 92.5%, $\kappa = 0.92$.
- Earth Shape Play-Dough (China): agreement 80.0%, $\kappa = 0.78$.

These figures confirm three cross-cultural trends (corresponding to the three media) found during the studies using the multimedia-multimodal approach. Firstly, there was little difference in the ability of Chinese and New Zealand children to express their cosmologies in verbal language. Secondly, in complex drawing, such as the Earth’s shape, Chinese children were slightly more dextrous (possibly as a result of the intensive hand/eye coordination and kinesthetic, tactile, and proprioception modal skills developed during the acquisition of a pictographic script of characters compared with an alphabetic script). And thirdly, in play-dough modelling, New Zealand children had an advantage because of greater familiarity with the media of play-dough, which is common in Kindergartens and Primary Schools in New Zealand but uncommon in similar schools in China. On completion of the coding of the
selected exemplars, both coders independently looked through photographic records of children’s play-dough models, original drawings, and the interview tape transcripts to identify any cosmologies that did not fit the classification scheme. Three were identified in the 1987 New Zealand data (Nicola, Lucy and Anthony, all age 4, who had to varying degrees depicted the Earth as animate). Following discussion these were successfully categorised.

**Statistical Analysis**

Following categorisation, the data from the rows and columns of the Identified Subject Histograms (see Figures 1 and 2) were converted to Scatterplots (see Figure 3), which could be used to determine trends in the correlations between *Cosmological Concept Category* and *Age* over time using *Ordinal Pattern Analysis* (see Thorngate & Carroll, 1986). For example, tracking the cosmological development of *Earth Motion Concepts* of Linda: (age 8, 5 in 1987) who was placed in *Earth Motion Cosmological Concept Category 1: Uncertain of motion, nature or meaning of Earth* (see Figure 1, columns 8–9, row 1, where Linda is marked with an asterisk), which translated to the first row of the corresponding Scatterplot (see Figure 3a where Linda is labelled and indicated by a dot enclosed in a square). By the time of the Second New Zealand survey, in 1989, Linda (now age 10, 5) was categorised as holding *Earth Motion Cosmological Concept Category 10: Earth planet in space: rotates on axis and revolves in orbit around Sun* (see Figure 1), which translates to row 10 of the corresponding Scatterplot (see Figure 3b...
where Linda is again labelled and indicated by a dot enclosed in a square). Inspection of the Earth Motion categories (see Figure 1) shows that 6 to 7 is the transition from stationary or motion uncertain to moving around in some way—so in a 2-year period Linda’s cosmology of the Motion of the Earth has changed from uncertainty to the scientific conception.

Similarly, tracking the cosmological development of Earth Shape Concepts of Racheal (age 9, 1 in 1987) over the same period, Racheal was initially placed in Earth Shape Cosmological Concept Category 5: Flat/Disc Dual-Earth (see Figure 2, columns 9–10, row 5, where Racheal is marked with an asterisk; and Figure 4a, where her 1987 cosmology is illustrated), which translates to the fifth row of the corresponding Scatterplot (see Figure 3c where Racheal is labelled and indicated by a dot enclosed in a square). By the time of the Second New Zealand Survey, in 1989, Racheal (now age 11, 1) was categorised as holding Earth Shape Cosmological Concept Category 9: Earth ball-shaped: people live on the top curved surface (see Figures 2 and 4b, where her 1989 cosmology is illustrated), which translates to
Figure 4. Changes in Racheal’s cosmology over a 2-year period. (a, upper) Racheal (age 9 years 1 month) modelled her play-dough Earth as New Zealand, with herself and her friend at opposite ends. She drew herself on the play-dough approximately where Featherston is (left is North). However, she also drew herself standing on the “Ground” horizontal below, and the “Sky” is similarly above. Her models and drawings indicate that she held a Flat dual-Earth cosmology. (b, lower) Racheal (age 11 years 1 month). Two years on, Racheal now holds a Spherical Earth cosmology. She and her friend are now modelled and drawn on opposite sides of a ball-shaped Earth. The “Ground” and “Sky” are drawn on the Earth, and the Sun and Moon accompany the Earth in space.
row 9 of the corresponding Scatterplot (see Figure 3d, where Racheal is again labelled and indicated by a dot enclosed in a square). Examination of the Earth Shape categories (see Figure 2) shows that 5 to 7 is the transition from flat Earth cosmoologies to spherical Earth cosmologies in terms of Earth Shape—so in a 2-year period Racheal’s cosmology of the Shape of the Earth has also changed from uncertainty about her place in the world (as highlighted by her dual-Earth cosmology) to close to the scientific conception. [Note: Although the 10th row of Figure 2 shows empty cells (in 1987), by the Second Survey (1989) three children were placed in this category.]

The difference between the Cosmological Concept Category Ordinate Values for the children between surveys (e.g., between 1987 and 1989) gives a \( \Delta \) Ordinate value (which can be negative, positive, or zero). In the case of Linda, her Earth Motion Cosmological Concept changed from 1 in 1987 to 10 in 1989, giving a \( \Delta \) Ordinate value of +9. Similarly, in the case of Racheal, her Earth Shape Cosmological Concept changed from 5 in 1987 to 9 in 1989, giving a \( \Delta \) Ordinate value of +4. The database also facilitated statistical analysis of the data, the ordinal nature of which is implicit from the taxonomies developed by Nussbaum and Novak (1976), Sneider and Pulos (1983), and Vosniadou and Brewer (1992). For example, the ordinal assumption of development of the concept Earth Shape is sphere > disc > flat, where “>” means “a more scientific model than”. According to Siegel and Castellan (1988) “if the relation > holds for all pairs of classes so that a complete rank ordering of classes is possible, then we have an ordinal scale” (p. 25). From the analysis of \( \Delta \) Ordinate values it was possible to create a taxonomy of knowledge restructuring for Earth Motion and Earth Shape concepts showing changes in the concepts of each child over time and the frequency and percentage of change in each category over time (see Tables 5 and 6, discussed later).

**Evidence of Knowledge Restructuring in Concept Development**

The results strongly support the hypothesis that children’s cosmologies gradually develop towards the scientific view by the child actively creating mental structures that evaluate new information by cognitive processes dominated by the need to make sense of the world. Changes in these structures are evident from differences in responses to questions, drawings, and models over time, manifest as changes in cosmological concept categories. The general nature of such changes are described in the literature on schema modification: these include accretion, tuning, and restructuring (see Rumelhart & Norman, 1978). Of these, restructuring seems to be most relevant to these studies since it involves the creation of new knowledge structures analogous to the categories of the cosmological concept taxonomy. The two forms of restructuring (weak and radical) described in the literature were found to be inadequate to classify the data of conceptual change. Two further restructuring forms, defined as moderate and strong respectively, were necessary, thus creating a restructuring spectrum with four elements: weak, moderate, strong, and radical, in order from least to greatest degree of conceptual change. Although the term “strong” has been
### Table 5. Ordinal pattern analysis of Earth Motion data from the Pilot Longitudinal Survey

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<td>03, 08</td>
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Summary: \(n (Δ \text{ordinate positive: positive restructuring}) = 49 (85\%), n (Δ \text{ordinate negative: negative restructuring*}) = 3 (5\%), n (Δ \text{ordinate zero: no conceptual change**}) = 6 (10\%). N = 58 (100\%).

Note: *Linda, a case of positive “radical” restructuring (see text).
Table 6. Ordinal pattern analysis of Earth Shape data from the Pilot Longitudinal Survey

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Summary: $n$ (Δ ordinate positive: positive restructuring) = 47 (81%), $n$ (Δ ordinate negative: negative restructuring*) = 1 (2%), $n$ (Δ ordinate zero: no conceptual change**) = 10 (17%). $N = 58$ (100%).

Note: *Racheal, a case of positive “radical” restructuring (see text).
used synonymously with “radical” in the literature, it is felt that a distinction is necessary between them to emphasise the degree of radical change. Statistical analysis of the changes in cosmological concepts in the initial studies indicated that the restructuring categorisation scheme was adequate (see Tables 5 and 6). The extent of the changes are summarised by the following figures showing the proportion of positive \( \Delta \text{Ordinate} \) values:

  
  - Earth Motion: \( N = 58; \Delta \text{Ordinate positive}, 85\%; \Delta \text{Ordinate negative}, 5\%; \Delta \text{Ordinate zero}, 10\% \).
  
  - Earth Shape: \( N = 58; \Delta \text{Ordinate positive}, 81\%; \Delta \text{Ordinate negative}, 2\%; \Delta \text{Ordinate zero}, 17\% \).

- **Spearman rank order correlation coefficient** \( r_s \): New Zealand Pilot Longitudinal Survey (1987–1989):
  
  - Earth Motion (1987): \( r_s = .78, t = 9.40, N = 58, p < .001 \).
  
  - Earth Motion (1989): \( r_s = .71, t = 7.63, N = 58, p < .001 \).
  
  - Earth Shape (1987): \( r_s = .65, t = 6.42, N = 58, p < .001 \).
  
  - Earth Shape (1989): \( r_s = .83, t = 11.33, N = 58, p < .001 \).

These statistics are also illustrated in the Scatterplots (see Figure 3).

The results also indicated that the various types of restructuring are modulated by differing time spans, which vary from child to child, independent of age. For example, the weak form may constitute a gradual realisation over several years that the ground is part of the surface of the Earth. The second type of restructuring, the moderate form, may involve the gradual creation of alternative frameworks (see Driver & Easley, 1978) or synthetic models (see Vosniadou & Brewer, 1992; Vosniadou et al., 2004) before taking the conceptual leap to the scientific concept. The radical or strong form is where cosmological concepts undergo radical changes over relatively short time spans (e.g., the child’s concept of Earth shape changes from a disc to a ball, or concepts of the motion of the Earth–Sun System change from geocentric to heliocentric). However, the current studies revealed that the concept of Earth shape is relatively meaningless without a concept of identity: it is one thing to be taught that the Earth is a spherical planet in space; it is a conceptual leap of identity to realise that we live there! Hence the change from Earth Shape Concept Categories 5 and 6, where the existence of planet Earth is known but “we” live on the flat ground “here”, to Earth Shape Concept Categories 9 and 10, where the ground is recognised as the surface of a spherical planet called Earth is a truly radical change—a paradigm shift of revolutionary nature (see Kuhn, 1970). This highlights the need for teachers to be cautious when introducing globes to teach the scientific Earth Shape concept unless they also introduce model people to heighten a sense of identity with planet Earth.

The time period between radical changes might be from a few months to 1 or 2 years. For example, the knowledge restructuring indicated by changes in Linda and
Racheal’s cosmologies of the Motion of the Earth and the Shape of the Earth, respectively, over a 2-year period indicates radical conceptual change. These changes formed part of the pattern of high correlation between Age and Cosmological Concept Category described earlier when discussing the First and Second Surveys, and were evident in the statistical results from the Main Surveys:

- **Spearman rank order correlation coefficient** $r_s$: Main Surveys (1993, 1994), Earth Motion Concepts.
  - New Zealand: $N = 127$, $r_s = .69$, $t(N-2) = 10.67$, $p < .001$.
  - China: $N = 113$, $r_s = .75$, $t(N-2) = 11.77$, $p < .001$.

- **Earth Shape and Habitation Concepts**.
  - New Zealand: $N = 127$, $r_s = .82$, $t(N-2) = 16.17$, $p < .001$.
  - China: $N = 113$, $r_s = .85$, $t(N-2) = 17.15$, $p < .001$.

**Dynamic-interactive Restructuring**

Besides conceptual changes that could be interpreted as evidence of the weak, moderate, strong, and radical forms of restructuring, these studies revealed a hitherto unreported new form of restructuring characterised by very rapid changes of cosmological schemata, which were observed during interactive interview. This dynamic-interactive form of restructuring is exemplified by the following extracts from the transcripts of Philippa (17, 7) and Zhang (5, 8). Philippa, who first participated in these studies at age 6, had developed (at nearly 18 years) an almost complete scientific cosmology for the motion of the Earth–Sun–Moon system, which she drew and modelled with play-dough. She knew that the Earth spun on its axis in a day and revolved around the Sun in a year; and that the Moon orbited the Earth in a Month. However, Philippa thought that the Moon took a day to spin once; and she was not sure whether or not the Sun rotated. What troubled her were the causes of eclipses.

[Before the relevant part of the protocol is provided, some comment upon the interview methodology is worth stating at this point. Normally, when interviewing children who might be interviewed a second or subsequent time, the researcher avoided as far as possible any teaching or tutoring of astronomical concepts. His policy was to interview, interact, and, if asked, to answer children’s questions as honestly as possible without giving them information that might give them an advantage over control group children at a later date. His usual response to direct questions was to tell children to ask their teacher or their parents or the school or town librarian. When, however, as here in Philippa’s case, the child was nearing 18 years of age, and was unlikely to be surveyed again, the researcher was more inclined to utilise Socratic dialogue to resolve cognitive dissonance. However, it should be noted that although the researcher’s questions may have opened the way for restructuring by bringing conflicting concepts from different conceptual layers into consciousness (see Bryce & Blown, 2006), he did not induce the conceptual conflict, but rather encouraged its resolution.]
Knowledge Restructuring and Children’s Cosmologies

Researcher: Does the Sun move?
Philippa: The Sun moves around the Moon.
Researcher: How long does it take for the Sun to go round the Moon once?
Philippa: I don’t know—but when they meet there’s an eclipse—and the eclipses are not very often—so it must be quite a long time.
Researcher: Are you sure it’s the Sun that goes round the Moon, and not the Moon that goes round the Sun?
Philippa: The Moon goes round the Earth—can the Moon go round the Sun as well?
Researcher: Well—you’ve got the Moon going around the Earth [referring to her Motion Diagram—see Figure 5a: Philippa’s initial cosmology]—but you’ve [also] got the Earth going around the Sun—so the Moon must go round the Sun—with the Earth. It’s difficult to show with the play-dough—one needs three hands—but you can show it. If that’s the Sun there—and that’s the Earth there—and there’s the Moon—the Moon’s going round the Earth and the Earth’s going round the Sun—so effectively the Moon is going round the Sun.

Philippa knew all of the elements of the motion of the system but had not yet seen them moving together as a whole in her mind’s eye.

Philippa: As well—yes!
Researcher: And that’s why you can get eclipses—like that [researcher demonstrates using the play-dough models].
Philippa: Yes!
Researcher: So you have to think about whether this [her drawing of the Sun orbiting the Earth and Moon—see Figure 5a: Philippa’s initial cosmology] is really necessary [applying Occum’s Razor]—here [pointing to her drawing of the Sun’s orbit around the Earth].
Philippa: OK [starts to re-draw with doubtful look].
Researcher: So you’re not sure about this?
Philippa: No—but if I look at this one [referring to her drawing of her initial cosmology—see Figure 5a]—when you’ve got the Sun going round the Moon and you’ve got the Earth in there as well [revolving around the Sun] ...

Within a few minutes Philippa had restructured the Earth–Sun–Moon system in a scientific way (see Figure 5b: Philippa’s final heliocentric cosmology), and remarked that she could “see” it now—moving together as a whole.

Another example of rapid dynamic restructuring of the motion of the Earth–Sun system was that of Zhang (5, 8) while observing shadows:

Researcher: Has what is happening got anything to do with the Sun? Is the Sun moving?
Zhang: The Sun moves in a circle in a day. [EM Category 8]
Researcher: Does the Sun move in any other way?
Zhang: [Looks closely at shadow stick and pencil—deep in thought]. The Earth is moving.
Researcher: When you say the Sun goes in a circle in a day—is it going around something? Or is it just going around on its own?
Zhang: The Earth goes around the Sun. [EM Category 9]
Researcher: Go on …?
Zhang: [Looks at the sky—still deep in thought]. The clouds are moving every day.
Researcher: And the Earth is going around the Sun?
Zhang: Yes. [EM Category 9]

**Note:** Zhang was initially EM Category 8 (one count) but changed to EM Category 9 (two counts).

To triangulate children’s ideas the interview was designed to ask the same question in at least three different ways: in this case, the second way was as follows:

Researcher: Tell me about daytime?
Zhang: The Sun rises in daytime and there are white clouds in the sky. [Day/Night Category 6]
Researcher: What happens to the Earth in daytime?
Zhang: I’m not sure.
Researcher: What happens to the Sun in daytime?
Zhang: In the morning the Sun rises in the East—and in the evening the Sun sets in the West—and at noon the Sun is directly above us. [Day/Night Category 6]
Researcher: What happens to the Moon in daytime?
Zhang: The Moon goes away.
Researcher: Tell me about night-time?
Zhang: The Moon and the stars are bright at night-time—and the people on the Earth go to bed.
Researcher: What happens to the Earth at night-time?
Zhang: I didn’t ask my Mother this question!
Researcher: What happens to the Sun at night-time?
Zhang: The Sun sets at night-time. [Day/Night Category 6]
Researcher: What happens to the Moon at night-time?
Zhang: The Moon appears at night-time. [Day/Night Category 6]

Note: Day/Night Category 6: In daytime it is light and/or sunny because the Sun is shining on our side of the Earth. At night-time it is dark because the Sun is shining on the other side of the Earth. When we have daytime the other side of the Earth has night-time. At night-time the Moon shines on the dark side of the Earth. The Sun goes to other countries at night-time. Zhang consistently responded in Day/Night Category 6 (four counts).

The second bearing of the triangulation did not reveal any fresh insights into the motion of the Earth and Sun, although it did confirm that Zhang is a keen observer of nature. Many older children are not certain of where the Sun rises or sets; and even some adults are not aware that the Sun is at its highest point at (solar) noon. China is on one time zone—Beijing time—so that there can be a big difference between the time at which the Sun reaches its zenith and local noon. Concepts such as sunrise and sunset are embedded in the English and Chinese languages, and do not necessarily imply that the Sun is revolving around the Earth: they are part of everyday language as opposed to the language of science.

The third bearing of the triangulation was explored by asking direct questions about the motion of the Earth, Sun and Moon:

Researcher: Does the Earth move or does the Earth stay still?
Zhang: The Earth moves.
Researcher: How does the Earth move?
Zhang: The Sun moves in a circle every day. [EM Category 8]

There is a switch back to the old geocentric structure—possibly because the researcher and child have been thinking and talking in everyday language about sunrise, sunset, daytime, night-time and so on—and it takes time for Zhang to think scientifically again.

Researcher: The Earth or the Sun?
Zhang: The Sun. [EM Category 8]
Researcher: Does the Sun move or does the Sun stay still?
Zhang: The Sun moves—the Sun has its own orbit.
Zhang meant orb or arc across the sky, not the same as an older boy—Liu (12, 6)—who said that the Sun revolved in an orbit around the centre of the galaxy.

Researcher: How does the Earth move?
Zhang: The Earth goes around the Sun. [EM Category 9]

Zhang’s cosmology switches back from geocentric to heliocentric—she is thinking scientifically again—but not necessarily as an astronomer would do.

Note: In this section of the interview Zhang was initially EM Category 8 (two counts) but changed to EM Category 9 (one count). Thus, overall, her Earth Motion Interview score was EM Category 8 (three counts), EM Category 9 (three counts)—which is even—but she started on EM Category 8 and ended on EM Category 9 in each section of the protocol, which would place her in EM Category 9. In addition, her Earth Motion drawing indicated EM Category 9, and her Earth Motion in play-dough similarly was coded as Earth Motion Category 9. Thus, by triangulation of her three media (interview, drawing, play-dough modelling), Zhang was placed in Earth Motion Category 9: Earth planet in space: orbits around Sun: spin uncertain. Zhang also said that the Earth was ball-shaped, drew it as circular, drew herself and her friend in a way that identified with Earth, modelled the Earth as spherical in play-dough, and placed the models of herself and her friend on top of the Earth about 45° apart. This consistency suggests a coherent cosmological theory rather than “knowledge in pieces”.

Zhang’s native language was Mandarin Chinese and, although the need to rely on mediation by interpreters restricted the full range of nuances and verbal probing (available to the researcher when interviewing participants such as Philippa directly in her native English), there is considerable evidence from these extracts that Zhang also was changing her cosmology dynamically in very short time-spans, analogous to the switches of figure and ground of interest to Gestalt psychologists.

Evidence of Cultural Mediation of Knowledge Restructuring in Concept Development

Apart from the use of the Lunar calendar to regulate the festive year—a feature that Chinese have in common with the Maori people of New Zealand (Rikihana et al., 2001)—there was little evidence of indigenous cosmologies such as those reported by Henderson (1984) or Needham (1975). This is not surprising given the recent social history of China and the emphasis given to acquisition of the scientific interpretation of the universe. Nevertheless there were some examples of the influence of ancient beliefs, such as one student who believed that the Sun and Moon were disc-shaped because Confucius said they were “like plates in the sky” (alluding to disc-shaped dining plates). There was also some evidence of cultural difference in the analogies children used when describing the motion of the Earth (e.g., Ji Cheng’s description of the Earth as kite-like) and when drawing and modelling the shape and habitation of the Earth (e.g., the way in which Zhang Shuang drew herself and her friend standing on a flat ground drawn as a tangent to the top surface of a spherical Earth). But in general the similarities between the
two cultures were much greater than the differences. Changes in the concepts of each child in each culture and the frequency and percentage of change in each category showed the fine detail of cultural mediation. Reviewing Earth Motion Concepts, it was found that each category has representatives from each culture but some category changes are more common in one culture than another (e.g., the 5 to 10 and 6 to 10 category changes had fewer cases in New Zealand than in China). Similarly, reviewing Earth Shape Concepts, all categories were represented in both cultures but some were more popular in one culture than another (e.g., the 6 to 10 and 7 to 10 category changes had no representatives in New Zealand but seven of each in China). These differences may reflect differences in the way in which relevant topics are introduced in the respective school syllabi (which are almost identical). Overall the pattern of conceptual change was remarkably similar. [Tables showing the analysis of restructuring of concepts may be obtained from the second author.]

  - Earth Motion (New Zealand): \( N = 82; \Delta\text{ Ordinate positive}, 76\%; \Delta\text{ Ordinate negative}, 6\%; \Delta\text{ Ordinate zero}, 18\%. \)
  - Earth Motion (China): \( N = 89; \Delta\text{ Ordinate positive}, 79\%; \Delta\text{ Ordinate negative}, 5\%; \Delta\text{ Ordinate zero}, 16\%. \)

  - New Zealand: \( N = 82; \Delta\text{ Ordinate positive}, 65\%; \Delta\text{ Ordinate negative}, 8\%; \Delta\text{ Ordinate zero}, 27\%. \)
  - China: \( N = 89; \Delta\text{ Ordinate positive}, 66\%; \Delta\text{ Ordinate negative}, 10\%; \Delta\text{ Ordinate zero}, 24\%. \)

**Note**: The higher values of \(\Delta\text{ Ordinate zero}\) in the Main Surveys compared with those of the earlier studies result from the plateau effect as children’s cosmologies coincide with the scientific view so that conceptual change becomes minimal.

**Evidence of Children having Coherent Theories versus Knowledge in Pieces**

The results of the first Longitudinal Survey (1987–1989) in New Zealand, and the Longitudinal Main Surveys in New Zealand (1993–1998) and China (1994–2000) provide ample evidence that children have coherent theories or cosmologies. These theories were apparent in the responses that children gave to the same questions in the same or similar settings years apart. Being able to consistently categorise children’s cosmologies, with demonstrated good inter-rater reliability supports the appropriateness of the categorisation and runs counter to the idea of fragmented knowledge. In many cases their drawings and models contained elements of earlier ideas, which is difficult to explain if they have no theory or no mental model or notion to recall.
There was evidence that a small proportion of children (2–10%) regressed in their cosmological concept development (see \( \Delta \) Ordinate negative cases in Tables 5 and 6), but these backward steps were temporary rather than permanent, as shown by evidence in tracking a group of children (the New Zealand Pilot Longitudinal Group) for over 11 years involving four repeated interviews (1987, 1989, 1993, 1998) where all children eventually reached the scientific world view or very close to it. There were also cases where children paused in their cosmological conceptual development (see \( \Delta \) Ordinate zero cases in Tables 5 and 6), but, again, in the case of younger children (age 2–12) the proportion was relatively small (10–17%) and temporary; and furthermore could in many cases be accounted for by children’s concepts reaching the plateaux of the scientific world view. This phenomenon is particularly noticeable with older children (age 8–18) in the Main Surveys where the proportion of such case increases to 16–18% for Earth Motion Concepts and 24–27% for Earth Shape Concepts. In the vast majority of cases (81–85% in the earlier studies where the plateaux effect was minimal) children showed an increase in cosmological concept development between surveys, with distinct traces of their prior knowledge being built upon to form their new cosmology. There was no evidence of the random pattern that would emerge if children were responding in an ad hoc manner to the interview over time.

**Effectiveness and Validity of Longitudinal Field Research with Repeated Interviews**

There was no evidence that repeated interviews caused the Longitudinal Survey Group to exhibit more accelerated development of cosmological concepts than the Longitudinal Control Group in either culture. No significant differences were detected between the groups in Kolmogorov-Smirnov tests (\( p > .10 \)); and the differences in means between groups were less than one cosmological concept category.

- **Kolmogorov-Smirnov two-sample test**: Longitudinal (follow-up) Survey New Zealand (1998), China (2000):
  - **Earth Motion**.
    - New Zealand Longitudinal Survey Control Group (1998): \( N = 82, M = 10.35, SD = 1.05 \).
    - China Longitudinal Survey Group (1994–2000): \( N = 89, M = 10.88, SD = 0.54 \).
    - China Longitudinal Survey Control Group (2000): \( N = 89, M = 10.93, SD = 0.25 \).
  - **Earth Shape and Habitation**.
    - New Zealand Longitudinal Survey Group (1993–1998): \( N = 82, M = 10.61, SD = 2.61 \).
    - New Zealand Longitudinal Survey Control Group (1998): \( N = 82, M = 10.79, SD = 2.22 \).
Further support for this conclusion came from comparison of the cosmological development of the New Zealand Pilot Longitudinal Group over time. This group of young people were interviewed in 1987, 1989, 1993 and 1998. Thus, if Cromer’s (1987) findings were applicable, it would be anticipated that this group would exhibit accelerated conceptual development in Earth science and astronomy, over that of any group who had fewer interviews. However, at the end of the follow-up survey their cosmological concepts were found to be similar to those of a control group of their peers created to measure this effect.

- **Kolmogorov-Smirnov two sample test:**
  - *Earth Motion.*
    - New Zealand Pilot Longitudinal Group (1987–1998): \( N = 17, M = 10.76, SD = 0.66. \)
    - New Zealand Pilot Longitudinal Control Group (1998): \( N = 17, M = 10.59, SD = 0.94. \)
  - *Earth Shape and Habitation.*
    - New Zealand Pilot Longitudinal Group (1987–1998): \( N = 17, M = 11.06, SD = 0.24. \)
    - New Zealand Pilot Longitudinal Control Group (1998): \( N = 17, M = 11.18, SD = 0.33. \)

**Conclusion**

The research hypothesis of the current studies was that children’s cosmologies gradually develop towards the scientific view by the child actively creating coherent, evolving, mental structures that evaluate new information by cognitive processes dominated by the need to make sense of the world. Furthermore, the evidence supports the hypothesis that the thought processes of children have many similarities with those of adults. This view is not new, having been put by one of Piaget’s contemporaries: “There are no differences in kind between the thinking of children and the thinking of adults” (Hazlitt, 1929, cited by Oakes, 1947, p. 2). More recently Carey (1985b) has expressed the same view: “... considered judgement dictates that young children and sophisticated adults think alike” (p. 514). Donaldson (1984) puts the same argument from a developmental perspective:

> Children are not so limited in ability to reason deductively as Piaget—and others—have claimed ... At least from the age of four, then, we must again acknowledge that the supposed gap between children and adults is less than many people have claimed. (p. 59)

The results confirmed that their cosmological concept development follows defined phases, the essence of which is captured in the *Taxonomy of Cosmological Concept*
Categories. These phases are in broad outline essentially as described by the Earth Notions of Nussbaum and Novak (1976) and Nussbaum (1979); the Earth Shape and Gravity Scales of Sneider and Pulos (1983); and the Mental Models of Vosniadou and Brewer (1992, 1994). This should not be taken as implying that all children go through all phases (as in Piagetian stage theory), but rather that whatever their starting point young people are highly likely to progress from a lower phase of scientific understanding to a higher phase. And there is substantial evidence that this development is common across cultures that have similar natural habitats (such as houses or apartments, trees and gardens), because of the latent similarity of children’s everyday surroundings where they interact with nature and their social “play” worlds, despite apparent environmental differences. Thus their intuitive ideas about the world have much in common. Likewise, provided that they attend school, their sources of information about the scientific world also have remarkable similarity. Only at the conceptual interface between intuitive and scientific ideas, the zone of conceptual conflict as children attempt to make sense of conflicting theories from their own observations, the lore of their culture, and the increasingly pervasive scientific world view, is there evidence of distinct cultural difference, but even so this is not widespread across the culture (see Bryce & Blown, 2006).

However, the nature of the processes involved in conceptual change remain elusive. Although there is overwhelming evidence of schematic modification from triangulation of data from young people’s verbal language, their drawings, and their play-dough models, the researcher has to interpret these data without being able to see directly the conceptual images that children are attempting to share. Nevertheless, there was substantial evidence of weak, moderate, strong, and radical restructuring: the latter exemplified by the drawings and models of Linda and Racheal (see Figures 3 and 4). There were also several cases of an apparently new dynamic form of conceptual change, demonstrated by Philippa and Zhang as described earlier (see Figure 5), whereby children were able to visualise their concepts and manipulate them dynamically by rapid switching of concepts during the interview. There was no evidence to support the contention that children’s knowledge (in this field) is incoherent. On the contrary, these longitudinal studies have found that children do have consistent theories about the world—their cosmologies—which they are able to share through various media. In many cases their interview responses, drawings, and models included elements that were stable over time—vestiges of earlier ideas—which could not occur if they were responding to the repeated interviews years apart in a fleeting ad hoc manner. Rather, the evidence from the current longitudinal studies support the claim that children’s cosmologies or theories about the world are based on coherent, holistic, developing conceptual schemata created by children to bring meaning to their worlds in essentially the same way as the reflections of sophisticated adults.

Features of the research described in this article that underline the strength of these conclusions relate to the scope, range, depth, duration, categorisation, coding, and statistical analysis of the evidence. With respect to scope, 21 elements of children’s concepts in this field have been examined (including motion and shape of the
Earth, Sun and, Moon, time, identity, habitation and gravity). With regard to range and depth, the in-depth interviews carefully exploited multi-media (including children’s observations, their oral language, drawing, and play-dough modelling) with up to 2 h with each child per survey for up to four surveys. In relation to duration, up to 11 years spanned the longitudinal work in New Zealand (1987–1998) and 6 years in China (1994–2000). With regard to categorisation and coding, the taxonomy developed covered all known aspects of children’s cosmologies; afforded robust statistical analysis of data; and independent coding of all of the data (including audio-tape transcripts, drawings, and play-dough models) was secured by professional astronomy educators. The statistical analysis associated with the database of ordinal values allocated to each child in each category of their cosmology over time permitted comparisons between individuals at various ages and various groups, taking into account age, gender, ethnicity, and culture in a longitudinal design that incorporated controls. Importantly, with regard to re-structuring, the percentage summaries reported in each study could not have resulted if children’s knowledge was fragmented.

Implications

The implications of these findings are not inconsiderable. Firstly, from a teaching perspective, all children should have the opportunity to build a holistic scientific world view in harmony with their cultural heritage. Inadequate or inappropriate education (including science taught at the expense of cultural beliefs) is likely to lead to fragmented knowledge. Balanced curricula are required to foster open-mindedness, discourage ethno-centricity, and give recognition to the scientific world view as an important model of structured knowledge. [It is easy to forget that in many parts of the developing world, even primary education is absent or incomplete and so the essential contact with teachers able to provide that knowledge of the scientific world is often actually missing.] Educational environments where the scientific world view and world cultural heritage are put forward as features of human endeavour and achievement, as part of balanced curricula with local cultural input, would go some way towards eliminating the perception of “knowledge in pieces” as a consequence of “fragmented” sources of information about the world. And secondly, from the perspective of research, those who want to know about children’s worlds and to what extent they really do embrace the scientific world, should spend some time in them rather than simply taking fleeting snapshots in “hit and run” mode. Without getting to know the children as young people, such fragmented research will surely result in fragmented data.

References


