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ORIGINAL ARTICLE

Knowledge acquisition in science and the blurred boundary between perception and cognition

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Abstract

This paper provides a critical and detailed study of what researchers in the fields of contemporary cognition and neuroscience have revealed about the blurred boundary between perception and cognition. We set out the arguments with a view to what researchers and teachers should now consider regarding the subtleties of their interrelationship in children's learning, and how individuals may be better helped to grasp difficult ideas. The analysis spotlights children's cosmologies in science education—their acquisition of ideas in basic astronomy concerning the Earth, Sun, Moon and so forth—and we use illustrative examples drawn from our own research to emphasise the implications of what *perceiving* and *cognising* actually mean. The role of carefully exercised Socratic dialogue as part of a constructivist approach to learning lies at the core of our deliberations.

KEYWORDS

children's cosmologies, cognition, knowledge acquisition, neuroscience, perception, Socratic dialogue during interviews

INTRODUCTION

When educational researchers investigate children's conceptual knowledge, they focus on what seems to be understood, or not, as the result of instruction and development. As best may be judged by what children say or write, draw or model with play-dough, or even signal in hand gestures, investigations examine what seems to have been grasped. *What* is

Key insights

What is the main issue that the paper addresses?

The relationships between perception and cognition which have been clarified by recent findings in neuroscience and the implications for teaching and learning.

What are the main insights that the paper provides?

- That educational and cognitive developmental research needs to focus on perceptual considerations as well as cognitive matters.
- That carefully exercised Socratic dialogue can help learners to clarify difficult ideas.

reported is considered to closely reflect what children are ‘seeing in their mind's eye’, even during carefully managed Socratic dialogue when researchers use it. Few studies reveal *what* precisely children are paying attention to when they are responding to questions. When can we be sure that what lies behind their expressions is a close match to what they are actually addressing in the *perceptual* sense?

Socratic dialogue

Socratic dialogue is often considered as a *teaching* and questioning technique employed to probe a child's ideas about a topic while resisting the inclination to teach the child directly.[1] Likewise, during one-to-one Piagetian *research* interviews, the interviewer might diverge from the mainstream of the discussion to investigate a child's concepts in depth. This dynamic questioning is by its very nature individual and unique and cannot be planned in advance. It relies on the researcher having a sound understanding of the domain under investigation and an awareness of the child's likely current level of knowledge in the domain. In our own investigations we use Socratic dialogue as a research strategy to tease out what a child knows, at the time of the interview, with the researcher avoiding teaching directly (as discussed below and in Blown & Bryce, 2022).

From the perspective of perception and cognition, the Socratic method encourages recall from memory, imagination and curiosity about the field, thus enhancing conceptual understanding. Our use of the strategy was determined by the fact that we were engaged in several longitudinal ethnographic studies assessing conceptual development over time and we wished to minimise researcher influence in the interests of objectivity. Children, however, mostly viewed the researcher as a teacher, and cited him as one of their sources of astronomical knowledge (see Blown & Bryce, 2018). Thus the researcher had to balance his role as a researcher with his natural inclination to teach at certain points and did so with the fallback of referring children to the traditional sources of the children's teachers, librarians and parents.

Perception and cognition

At the core of this article, we argue that many teachers and researchers tend to ignore the possible interconnections between perception and cognition, the subtleties of which have been emphasised by several cognition theorists in the last two decades and by recent research in neuroscience. Rather than regarding perceptual and cognitive processes as being separate (bounded and sequential), as they were in traditional psychology, some cognitive and neuroscientists now view them as overlapping (see Clark, 2013; Michel, 2020; Nosta, 2023; Nes et al., 2021; Williams, 2019). Any 'boundary' is indistinct. In this respect, the links between perception and cognition have been underplayed during investigations into the acquisition of knowledge—as has been the dynamic role of memory underpinning what individuals state in response to questions asked of them during lessons or put to them during research interviews. Here, we will outline what has been recently clarified in respect of these matters. We do so from the perspective of science education research (although the arguments are applicable to all forms of knowledge) and we offer some illustrations drawn from our own investigations into children's cosmologies that tie in with the new thinking. These augment what we have recently published in this field and demonstrate that *traditionally separated* notions of perception and cognition require some reconsideration, particularly in relation to the methodology used by interviewers and teachers to determine what children think. We will reflect on what pupils make of observations and visual encounters with events and phenomena, as well as audial and tactile occurrences. *What* should teachers take from pupils when they say (or imply non-verbally): 'I see. I know what you mean'? What does *perceiving* actually mean? When do *perceiving* and *cognising* mean the same thing? And why does it matter?

In view of the multiple interpretations of *perception* and *cognition* in the literature, we emphasise that we write from a cognitive science point of view, reporting and discussing perception and cognition as used in that domain (see Thagard, 2023). Our own interest is the domain of developmental psychology and cognitive development in the tradition of Piaget (1926, 1929, 1930), Bruner (1960, 1985), Vygotsky (1978, 1962, 1987) and Donaldson (1978). The field has evolved from Piaget's theory of ages and stages (critiqued by Donaldson in favour of a more generous evaluation of children's intellectual development), through Bruner's modes of knowledge representation and theories of readiness, the spiral curriculum, scaffolding and discovery learning, and Vygotsky's sociocultural theory and Zone of Proximal Development (ZPD), to modern information processing theory in which the brain is seen as analogous to a computer analysing and processing information from the environment.

Comparing the theories of developmental psychology; it could be argued that Bruner and Vygotsky emphasised children's social environments more than Piaget; and they highlighted the role of adults in developing skills through scaffolding within the ZPD. Bruner and Piaget both proposed stages of intellectual development but Bruner's 'modes' were not as rigid as Piaget's 'ages and stages' (see Guy-Evans & McLeod, 2024). We note Blake and Pope's (2008) careful comparison of Piaget's and Vygotsky's contributions to developmental psychology. They see merits—different merits—in both for teachers willing to incorporate their thinking into classroom teaching strategies and thereby increase students' learning and achievements. See also Burman (2016). In our work we were strongly influenced by Piaget's interview technique, which we used extensively. Donaldson, who gave new insights into developmental psychology, also guided us.

TERMINOLOGY

With regard to the main terminology in this field, key concepts are:

- *Attention* a state in which cognitive resources are focused on certain aspects of the environment rather than on others and the central nervous system is in a state of readiness to respond to stimuli. Because human beings do not have an infinite capacity to attend to everything—focusing on certain items at the expense of others—much of the research in this field has been devoted to discerning which factors influence attention and understanding the neural mechanisms that are involved in the selective processing of information recall (APA Dictionary of Psychology, 2018). Five kinds of attention have been distinguished. Examples from our own work are when children attended to the motion of shadows with a shadow stick in sunshine and when children paid attention to the elements of Ground and Sky observed from the interview room window (see Bryce & Blown, 2006).

- *Cognition* is the 'mental action or process of acquiring knowledge and understanding through thought, experience, and the senses. Cognitive processes use existing knowledge to discover new knowledge' (Lexico, Oxford University Press and Dictionary, 2024).
- *Perception* refers to the act or ability of perceiving, which includes awareness of surrounding objects, conditions or forces through sensation. It is the capacity for understanding (Merriam-Webster Dictionary, 2024). Importantly, a significant distinction is between:
  - *Closed-loop and open-loop perception*—the theory of closed-loop perception focuses on the dynamic motor-sensory process in which information flows through the environment and the brain in continuous loops. Closed-loop perception appears consistent with the fact that perception is typically an incremental process. Repeated encounters with an object, whether conscious or not, enable a person to refine their impressions of that object. This can be achieved more easily with a circular closed-loop system than with a linear open-loop one that lacks continuous feedback and real-time adjustment. Closed-loop perception can explain many of the phenomena that open-loop perception struggles to account for. This is largely because closed-loop perception considers sensory motion such as ocular saccades and head or arm movement to be an integral part of perception, and not an interfering component that must be corrected for. Furthermore, an environment perceived via sensory motion, and not despite sensory motion, need not be further stabilised by internal processes (Ahissar & Assa, 2016). Thus closed-loop perception is continuous, dynamic and interactive and open to cognitive influences.

Bottom-up and top-down perception: information vs. sensation

The understanding of perception as the interaction between sensory stimuli (bottom-up) and conceptual knowledge (top-down) was pioneered by Helmholtz (1860) and continued by Bruner who, starting in the 1940s, studied the ways in which needs, motivations and expectations influence perception, research that came to be known as 'New Look' psychology.

The top-down interpretation of perception is supported by the work of Gregory (1970), who advocated an indirect theory of perception from a constructivist perspective. This was counter to the view of Gibson (1966), who argued for a bottom-up direct theory of perception. More recently Gibson (2002) stated: 'The eye is a biological device for *sampling* the information available in an *ambient optic array*'. His argument was that *bottom-up* sensory perception should be regarded as information-based, not sensation-based.

Although Gibson focused on visual perception his theory has implications for other senses—scent, touch, haptic perception, sound, speech, taste and proprioception. Such a view has import for computer science, artificial intelligence (AI) and robotics where machines mimic and replicate human action (see Nosta, 2023; Pfaffmann, 2024; Philips, 2023; Rao & Ballard, 2013).

- *Imagination*—The production of sensations, feelings and thoughts informing oneself (Liao & Gendler, 2019, Stanford Encyclopedia of Philosophy). The act or power of forming a mental image of something not present to the senses or never before wholly perceived in reality (Merriam-Webster, 2024). Cognitive and neuroscience researchers report strong links between imagination and consciousness (Edelman & Tononi, 2000); imagination and memory (Edelman et al., 2001). See also Bryce and Blown (2021) on mental imagery.

RECENT THINKING ABOUT PERCEPTION

Predictive coding

According to the philosopher and cognitive scientist Andy Clark, understandings of perception have swung to the *predictive coding* properties of the brain, an important implication of which is that:

> the precise mix of top-down and bottom-up influence is not static or fixed … All this makes the lines between perception and cognition fuzzy, perhaps even vanishing.
>
> (Clark, 2013, p. 26 and p. 28)

And furthermore,

> no creature is truly able to perceive anything that, in principle, it cannot imagine.
>
> (Clark, 2015, p. 27)

Other neuroscientists make similar proposals about perception *not* being a passive reception of signals and route into what we attend to in a sequential, initially neutral or unbiased way. Ahissar and Assa (2016) stated that: 'Open Loop perception' has been the conventional assumption that the eye and what we are looking at (in the case of vision) is not affected by ongoing cognitive processing. Such a view needed amendment and they subsequently argued for 'closed loop perception', stating that:

> Perception is a continuous dynamic and interactive process and not a momentary event … it is associated with changes in brain dynamics rather than with the construction of invariant internal representations … and is not necessarily conscious.

Thus they reason that, neurologically and functionally, dynamic motor-sensory processes ensure that information flows from our surroundings to the brain in continuous loops. For Ahissar and Assa (2016), it reconciles 'objective scientific observations and subjective everyday experience via [the] closed-loop dynamics between the perceiver and the perceived' (see the sections 'Summary of the closed loop perception hypothesis' and 'A philosophical angle').

When they analysed research on children's concepts and how they group expressions together, Jones and Smith (1993) concluded that: 'conceptual knowledge encompasses both perceptual and non-perceptual knowledge as equal and interacting partners' (Abstract, p. 113).

Complications

Having considered a range of studies in cognition, Goldstone and Barsalou (1998) stated that: 'conceptual processing is grounded in perception, both for perceptual similarity and abstract rules' (p. 231). And in the following year, Barsalou (1999) argued that since 'cognition is inherently perceptual, sharing systems with perception at both the cognitive and the neural levels …, the divergence between cognition and perception reflects the widespread assumption that cognitive representations are inherently *non-perceptual*, or what I will call *amodal*' (p. 577).[3] He then wrote in 2008 that, *on the contrary*, perception and cognition are intricately interwoven:

> Grounded cognition rejects traditional views that cognition is computation on amodal symbols in a modular system, independent of the brain's modal systems for perception, action, and introspection. Instead, grounded cognition proposes that modal simulations, bodily states, and situated action underlie cognition.
> (Barsalou, 2008, p. 617)

The view of Edelman (1987, 1992) was that memory was non-representational. Later, with colleagues he argued that: 'Perception is not merely a reflection of immediate input but involves a construction or a comparison by the brain' (Edelman & Tononi, 2000, p. 101), and that 'every act of perception is, to some degree, an act of creation, and every act of memory is, to some degree, an act of imagination' (Edelman & Changeux, 2001, p. 56). As Michel (2020) noted more recently, 'Top-down cognitive processes appear to influence even the most basic components of perception, affecting how and what we see' (para. 1). She drew on recent investigations which use neuro-imaging technology to reveal that higher-order cognitive processes can exert significant top-down influences on basic perceptual processes.

Tacca (2011) emphasised the similarities between early vision (as when a pupil is asked to look at something new during a lesson or interview) and higher cognitive systems underlying active thinking about something (see also Cahen & Tacca, 2013). She argued that they *both* involve representations and relate to each other because of their inherent workings (what has been referred to as *systematicity*, cf. diSessa, 1993).

Clark's (2013, 2015) work has underlined how the brain has evolved to produce the most likely interpretation of incoming information and reduce the 'error' between expected and actual states of the world. This initiates a revision of *mental models* (see Section 6) and change in the hierarchy of plausible explanation. Humans are thus able to operate intelligently and at speed. He thus referred to 'probabilistic generative model-based systems' and emphasised the '*deep duality of perception and imagination*' (Clark, 2013, Chapter 4.3). In Clark (2015), he reasoned that generative neural models were 'capable of generating virtual sensory data' (p. 26). This chimes with researchers in science education exploring children's cosmologies where they have used 'generative questions' to probe children's concepts of the Earth. For example, Vosniadou and Brewer's (1992) interview methodology deployed 'factual questions' (e.g. What is the shape of the Earth?) and 'generative questions' (e.g. If you were to walk for many days in a straight line, where would you end up? Would you ever reach the end or edge of the Earth?). The latter required children to explain phenomena which they could not directly observe and had to rely on mental representations in the form of mental models potentially relevant to any answer (see p. 542).

The view from a cognitive psychology perspective (such as Clark's (2013) *predictive coding*) that perception is mediated by cognition (to such an extent that the two are synonymous or at least 'blurred' or 'fuzzy' in meaning) has not gone unchallenged. For example, Firestone and Scholl (2016) asked: 'What determines what we see?' They contrasted 'the traditional "modular" understanding of perception, according to which visual processing is encapsulated from higher-level cognition' with more recent research which 'alleges that states such as beliefs, desires, emotions, motivations, intentions, and linguistic representations exert direct, top-down influences on what we see' (Abstract). They concluded that 'perception proceeds without any direct unmediated influence from cognition' (p. 17).

This was countered by Williams (2019) who, in an article confronting aspects of recent thinking in cognition, challenged those theorists who have advocated 'a unified inferential hierarchy subject to substantial bi-directional message passing' (Abstract). Instead, he emphasised the 'representational reach' of conceptual thought and stated that: 'there is compelling evidence that commonsense reasoning is structured around highly domain-specific intuitive theories that are difficult to situate within a single hierarchy' (p. 1).

The mediating role of cognition in perception and memory has also been supported by deCharms and Zador (2000) who stated:

> the cerebral cortex is one of the primary seats of the internal representations maintained and used in perception, memory, decision making, motor control, and subjective experience, but the basic coding scheme by which this information is carried and transformed by neurons is not yet fully understood. (Abstract)

Their argument is also consistent with Nee and D'Esposito's (2018) report of evidence from neuroscience research that working memory is representational. Conceptual thought does involve imagery of course and it is worth noting that, according to Nes et al. (2021), 'imagery and perception have the same representational format, perceptual representation is analog[ue] too' (p. 11). They reviewed the distinctions between perception and cognition from the several points of view evident in recent papers, including their place in the information flow of the mind and how 'representation' may be better understood by future researchers.

Children's cosmologies

All of this is particularly pertinent to children's understandings about planet Earth and its surroundings, for perceptual and cognitive challenges abound, particularly regarding the daytime and night-time skies. Picture books, stories, film, video, DVD and TV, as well as the language used by adults at home and in school, all contribute to a 'disorganised' sequence of learning for the average child concerning the Earth and its environs (as a planet in space and a member of the Solar System).

For example, it is highly unlikely that children blessed with dark unpolluted skies will identify *planets* by direct observation unless guided by parents and teachers, or those living in a subculture with a particular knowledge and interest in the stars and planets. Dynamic audio-visual illustrations will certainly convey the term *planet* to most young children but, for very many, all the bright objects in the sky are the same (apart from the Moon). This means that *planets* and *stars* are confusingly equated in conversations with young people gazing up at the night sky. Even Venus is unhelpfully described by knowing adults as the *evening star*. For all, the 'disorganised' sequence of perception and cognition about planets is apparent—reading or hearing information about them; perception–cognition (searching for planets in the night sky comparing a natural view with a star chart, physically or mentally or both); perception/emotion, (appreciating the beauty of natural phenomena); direct teaching with considerable variation among pupils, schools, educational systems, and so forth. All this amounts to steps which result in it taking years for (some) individuals to perceive the distinction between planets and stars—the crux being where people are coaxed to actually plot the movement of the *wandering stars* (to use the Ancient Greek expression, see Abell, 1969, p. 14) against the stellar background on a star atlas. Our own investigations have included samples of young people in China and we note with interest that *xīng* is used in Chinese for fixed stars and *xíng xīng* for *wandering stars* or planets.

METHOD

Experimental design

The overall experimental design was based on the work of Solomon (1949). This robust design incorporated survey and control groups in two cultures (NZ and China). The survey groups were interviewed by repeated measures (Piagetian clinical interviews using an interview guide) 2–3 years apart, whereas the control groups were interviewed only once. This enabled measurement of previous participation in the study (mediation by the researcher and the interview experience itself) as a factor in conceptual development. The apparatus and materials used in the interviews are shown in a footnote.[4]

Data collection and analysis

Participants were interviewed individually or in small groups utilising Piagetian techniques by the second researcher. The procedure was recorded on audiotape and in the case of modelling activities recorded on videotape. Play-dough models were photographed as further evidence to support verbal and drawn data. A series of questions about the Shape and Motion of the Earth, Sun and Moon (ESM), Habitation and Identity with Earth, and Concepts of Gravity included drawing the ESM with paper and felt-tip pens, and modelling the ESM with play-dough. An interview guide covering a comprehensive range of questions on basic astronomy in general and the ESM system in particular structured these activities. Where responses invited further questioning to clarify concepts, Socratic dialogue was engaged.

The results were coded initially by the researcher (second author) on ordinal scales from least to most scientific for each cosmological concept such as: Earth Motion and Earth Shape; Habitation and Identity with Earth; Throwing Balls; and Observing Drink Bottles.

A selection of protocols, drawings and photos of play-dough models was then coded by two external coders (astronomy educators) from Carter Observatory in Wellington, New Zealand. The coding exercise resulted in the construction of ordinal scales for the various concepts under investigation, which afforded statistical analysis using non-parametric statistics such as the Kolmogorov–Smirnov two-sample test in Statistica by Statsoft. This enabled changes in cosmological concepts over time to be detected by testing with repeated measures. The results from survey to survey were kept on a database linked to the statistical package, which enabled the cosmological concept development of individual and groups of children to be tracked and compared over time.

The protocol examples of Socratic dialogue illustrating perception–cognition reported below are selected as typical from the wealth of protocols obtained from the interviews. The broader canvas was a study of children's cosmologies and developmental psychology from a constructivist perspective of science education following the tradition of Piaget (1929, 1930), Nussbaum and Novak (1976), Donaldson (1978) and Vosniadou and Brewer (1987). Against this background we have investigated a series of children's ideas related to cognitive and developmental psychology, such as the role of imagination and thought experiments, the value of multi-modal approaches such as drawing and modelling (including gesture) in addition to the spoken word, and the influence of various forms of mediation such as culture and traditional sources of astronomical knowledge. As we write there is a growing feeling of unease that traditional sources of knowledge such as teachers, librarians and parents are under threat from AI such as ChatGPT, inviting further research on how to navigate mediation by AI by reinforcing traditional checks and measures.

In each case as the focus of our investigations changed, we selected the best of the protocols to illustrate points. Significantly, given the focus of the current study, retrospectively our work may be seen as neither *top-theory-down* nor *bottom-data-up* but a combination of the two, as is fitting for a report on the merging of perception with cognition. Had all children held the same cosmologies (perceiving the world in the same way), there would have been nothing to analyse (bottom-data-up); but by recognising (re-cognising informed by other studies) that children become more scientific with age (top-theory-down), we provide the framework for scientific investigation. Our published work should enable replication of our research to date. However we recognise that future researchers may not be able to conduct ethnographic studies in China and New Zealand as the second author did, spending several years in each culture as a teacher and researcher.

FINDINGS

We now provide some brief examples where, for the purposes of this paper, the illustrative extracts of protocols clarify the issues, notes on which are given in square brackets thus: [Perception–cognition note]. Short Protocol comments appear in plain brackets (thus). Longer protocol comments appear as Protocol Discussion in context following Protocols. The Main Discussion follows the Findings (Protocols).

The participants were children from Wairarapa, Wellington Province, New Zealand (NZ), and Changchun, Jilin Province, China. Participant characteristics are given after the child's name in the form (country, ethnicity, gender, age), country being taken to be synonymous with culture. Children were interviewed one-to-one, utilising Piagetian structured interviews supported by Socratic dialogue. Participants described, drew and modelled the shape and motion of the ESM and associated concepts of time and gravity. Audio data were recorded on tape for later interpretation and transcription, with trained interpreters in the case of China (see Bryce & Blown, 2006, 2012). The extracts illustrate the key role of Socratic discussion in building meaning and illuminate the creative interplay of perception and cognition in making sense of the world. In the protocols, Child is abbreviated to 'C' and Researcher to 'R' (and sometimes 'I' informally for the second author (researcher-interviewer)).

Drawing on experience researching children's cosmologies we identify five strategies and interview settings that enable the researcher and child to share ideas in a meaningful way as follows:

1. Honing observation skills through experiments such as studying the motion of shadows with a shadow-stick (see Bryce & Blown, 2006).
2. Promoting skill in what is/may be focused on through observation of Ground and Sky (see Bryce & Blown, 2013).
3. Inspiring imagination to probe concepts of Habitation and Identity with Earth; and Earth Shape through thought-experiments such as imagining that they have a new friend who lives on the other side of the Earth (see Bryce & Blown, 2013).
4. Encouraging children to use their imagination to probe dynamic memory of Earth Shape and Gravity through thought-experiments such as dropping and throwing balls on this and the other side of Earth (see Blown & Bryce, 2013).

5. Inviting children to use their imagination to decentre when responding to questions about novel situations such as viewing the Earth from the Moon (see Blown & Bryce, 2022).

Example in support of Strategy (a): honing observation skills through experiments such as studying the motion of shadows with a 'shadow-stick'

Child: Nikolai (NZ Māori, male, age 10 years 7 months).
Setting: school playground with shadow-stick in the sunshine.
Questions about Motion of the Earth whilst observing motion of shadows with a shadow-stick
C. [Looks closely at shadow-stick and pencil.]
C. [Pauses to reflect on observations.]

Protocol discussion. In thinking about what he is seeing Nikolai engages cognition and memory. He appears to be reflecting on the evidence to revise his mental model of Earth and Sun motion. The perception–cognition process is dynamic and taking place in real time as the shadow stick shadow changes shape with the apparent motion of the Sun across the sky.
R. What causes the shadows?
C. The Sun shines down to (the Earth)—and it's blocking—the Sun's rays to the grass and the concrete.
R. The ruler is blocking it?
C. Yes.
R. Is anything changing (down there by the pencil)?
C. Yes—the shadow of the ruler is moving—we're moving away from the Sun—so the shadow is moving.
[Child continues to make observations and report these in words encouraged by further questioning indicating perception is being consciously mediated by cognition.]
R. What is moving?
C. The shadow—because the wind's blowing it—the shadow (is moving away)—from the pencil.
R. (Nikolai concentrates on what he is immediately observing rather than following his original train of thought about the motion of the Earth with respect to the Sun. There is a slight breeze blowing and the ruler is shaking in the wind).
R. Why is it moving?
C. Because we're moving away from the Sun.
R. (Child returns to his original idea—he is probably thinking of both causes at the same time and decides that the rotation of the Earth is the main cause).
R. Has what is happening got anything to do with the Sun?
C. Yes.
R. Is the Sun moving?
C. No.
R. Has what is happening got anything to do with the Earth?
C. Yes.
R. Is the Earth moving?
C. Yes.
R. How is the Earth moving?
C. It's going around in a circle.
R. (Before probing further I have to find out Nikolai's Earth Shape concepts because I don't want to be the first to introduce a spherical Earth model).

Start Socratic dialogue.
R. What shape is the Earth?
C. Round.
R. Round like …?
C. Round like a ball.
R. (Now that I know that Nikolai believes that the Earth is ball-shaped we discuss concepts such as spinning, rolling, and revolving to clarify what Nikolai meant when he said the Earth went around a circle).
R. In what way is the Earth moving?
C. A ball spinning.
End Socratic dialogue.

[Visual perception and cognition with auditory (speech) perception in response to question.]

[Auditory perception is honed by Socratic dialogue which also heightens visual perception.]

Protocol discussion. Observing the apparent motion of the Sun as a lead into study of the motion of the Earth proved to be a rich source of cosmological ideas and wonder for many children who had not thought about these matters previously. This was in keeping with Vosniadou and Brewer (1987), who identified the domain of 'observational astronomy' as a source of examples of what they described as 'knowledge restructuring' in the field of children's cosmologies (p. 59) (see Blown & Bryce, 2006). Such hands-on experiments are examples of what Nussbaum and Novak (1976) described as 'direct experience with phenomena' which they recommended as the way by which 'advances in children's concepts of Earth take place' (p. 549). They are also examples of direct visual perception being mediated by cognition to produce plausible concepts of Earth and Sun motion.

Second example in support of Strategy (a): honing observation skills through experiments such as studying the motion of shadows with a 'shadow-stick'

Child: Piao Jin Zhu (China, Chao [Korean], female, age 11 years 1 month).

Setting: School playground with shadow-stick in sunshine.

[Child looks closely at shadow-stick and pencil and sky deep in thought.]

Questions about Motion of the Earth whilst observing motion of shadows with a shadow-stick

R. Is anything changing (down there by the pencil)?

C. Yes.

R. Is the pencil still touching the ruler shadow?

C. No.

[Child combines visual perception and cognition with auditory (speech) perception in response to question].

Start Socratic dialogue.
R.: What is changing?
C.: Just before the pencil touched the shadow—now it doesn't.
R.: Is anything moving?
C.: The shadow.
R.: How is it moving?
C.: I'm not sure.
R.: How could we find out for sure what is moving?
R.: If we weren't sure whether it was the pencil or the ruler shadow or both?

C.: Because the ruler is steady but the shadow is moving because the Earth is spinning.
End Socratic dialogue.

[Child utilises perception to observe that something has changed and draws on cognition to ascertain that the change in position of the pencil is related to the rotation of the Earth].

Protocol discussion. Piao Jin Zhu does not really answer the question but gives her explanation for what is happening. In fact the question is difficult to answer. The best demonstration of the Earth's rotation that I have seen is Foucault's pendulum but it requires a tall building for accurate results. A simpler experiment, which can be done in a classroom, is Robert's (1960) Cork Dust Bowl, which I have used as a teacher in NZ, but which I did not use during this study because of my wish to be as impartial as possible, i.e., to do research rather than to teach.

Example in support of Strategy (b): promoting skill in what is/may be focused on through observation of Ground and Sky

Child: Erina (NZ Māori, female, age 11 years 2 months).
Setting: school staffroom with view of Ground and Sky.

Earth Shape interview

R. Can you tell me about the Earth?
C. The Earth is a place where humans live—humans and animals.
R. What is the Earth made of?
C. Water, trees, dirt and stuff.
R. Where is the Earth?
C. It's in the Solar System.
R. Can you point to where the Earth is from here?
C. It's everywhere.
R. What Shape is the Earth?
C. A circle.
R. Is it a circle like a disc or a circle like a ball?
C. Like a ball.
R. What colour is the Earth?
C. Green, blue, all sorts of colours.
R. Why is the Earth those colours?
C. Because those are the colours of the trees and the water and places around.
[Child's reference to different colours indicates recall from memory and cognition acting top-down to compare with observations feeding from bottom-up to influence outcome.]

Earth Shape drawing

R. Draw the Earth.
C. (Draws).
Ground and Sky
R. Looking out of the window—Tell me about the ground?
R. (We observe.)
C. The ground is green—some of it is concrete and grass and dirt.
R. What is the ground made of?
C. Dirt.

R. What shape is the ground?
C. It's all different shapes—it's flat.
R. Looking at the sky—.
R. Tell me about the sky?
C. It's blue and sometimes when it rains—cloudy and the Sun shows up in it during the day sometimes.
R. What shape is the sky?
C. I don't think it has a shape—I don't know.
R. It hasn't got a definite shape?
C. No.
[Child observes ground and sky and responds to questions activating visual perception–cognition.]

Protocol discussion. What children perceive as the ground varies from country to country, school to school, setting to setting, and also over time. At the primary school in China where the majority of interviews were conducted children once looked over a playground with low brick buildings, flower beds and trees, and views over farmland. Now they are surrounded by ferro-concrete and glass tower blocks which must influence the way they see the world. In contrast most NZ children enjoy views of playgrounds with grassed areas and flower beds surrounded by low buildings as China once was.

Drawing Ground and Sky

R. On here then (I indicate child's drawing) can you draw the ground and the sky?
C. (Draws).
R. Where have you drawn the ground?
C. I've drawn it down the bottom of the page.
R. What shape is your ground?
C. It's just flat.
R. Is the ground on the Earth?
C. Yes.

Start Socratic dialogue.
R.: Why didn't you draw it on the Earth here then (I indicate child's drawing of Earth)?
C.: (Pause as child considers). [Child recognises by perception–cognition the conflict represented by her drawing.]
R.: Why did you draw it there (at foot of page) and not there (on the Earth)?
C.: (Unclear).
R.: Where should it be on the Earth?
C.: On there (indicates land mass on surface of Earth).
R.: Is the ground part of the Earth?
C.: Yes—and it's part of the other planets.
R.: Where have you drawn the sky?
C.: (Unclear).
R.: What shape is your drawing of the sky?
C.: These squiggly lines.
R.: Is the sky part of the Earth?
C.: Yes.
R.: So is this (drawing of sky on left hand side of page) meant to be over here somewhere (on the drawing of the Earth)?
C.: Yes.

R.: Where is it meant to be?
C.: Right around the Earth (unclear).
R.: Right around it?
C.: Yes.
R.: Show me with your finger where it's going to go.
C.: Right around there (traces around drawing of Earth).
R.: Draw something like that all around it (the Earth).
C.: (Draws).
End Socratic dialogue.

[Child translates knowledge from visual perception to drawing symbolising spherical envelope of sky utilising cognition to relate drawings to observed reality.]

Earth shape modelling

R. Can you make the shape of the Earth with the green play-dough (I hand the child a lump of green play-dough)?
C. (Models Earth).
R. What shape have you made there?
C. A circle—like a ball.
[Child translates knowledge from teaching and visual perception to model utilising cognition and dexterity].

Modelling Ground and Sky

R. If this was the Earth here (I hold play-dough model of Earth): where would the ground be?
C. All over—everywhere except where the sea is.
R. Show me on here (I indicate play-dough model of Earth)?
C. (Indicates surface of Earth).
R. Where would the sky be?
C. Around it (indicates area around and above Earth).
[Children also used tactile perception when drawing and modelling with play-dough.]

Protocol discussion. Drawing the ground horizontally below Earth and the sky horizontally above or below Earth are thought to be indicators of a flat-Earth cosmology (Nussbaum & Novak, 1976). See also Merleau-Ponty (1962) and Ingold (2007, pp. 9–11). Ground and sky are examples of Gibson's (2015) 'ambient optic array' which underpins his ecological approach to visual perception, supporting his earlier 'bottom-up' argument in favour of perception as 'information' based rather than 'sensation' based (see Gibson, 1966). Gibson's work is particularly relevant to those aspects of our interviews where children were engaged in visual perception observing shadows outdoors and viewing the ground and sky from the interview room window.

Example in support of Strategy (c): inspiring imagination to probe concepts of Habitation and Identity with Earth; and Earth Shape through thought-experiments such as imagining that they have a new friend who lives on the other side of the Earth

Child: Jake (NZ European, male, age 9 years 7 months).
Setting: School interview room.
Questions about Habitation and the other side of the Earth

R. (Child has drawn the Earth and 'self' ('Me') on the Earth: see Figure. 1)
Drawing 'friend'.
R. Do you know someone who lives a long way away?
C. Um (pause as child considers).
[Child responds by searching memory of friends' locations].

Start Socratic dialogue.
R.: Imagine that you went in a jet then and you flew to another country.
R.: Do you know any other countries—like a country North of here that it would take a whole day to get to?
C.: England.
R.: Imagine that you've got a new friend in England.
R.: Could you draw where your friend in England would be on here (I indicate child's Drawing; see Figure 1).
C.: They would be on the other side (of the Earth).
End Socratic dialogue.

Protocol discussion. Child understands the context of the thought-experiment using imagination to visualise the other side of the Earth from top-down information from teachers and bottom-up experience from audial interaction with the researcher and kinaesthetic knowledge from drawing and modelling; cf. Clark's (2015) view that perception depends on imagination.
C. (Draws friend).
Modelling 'friend'.

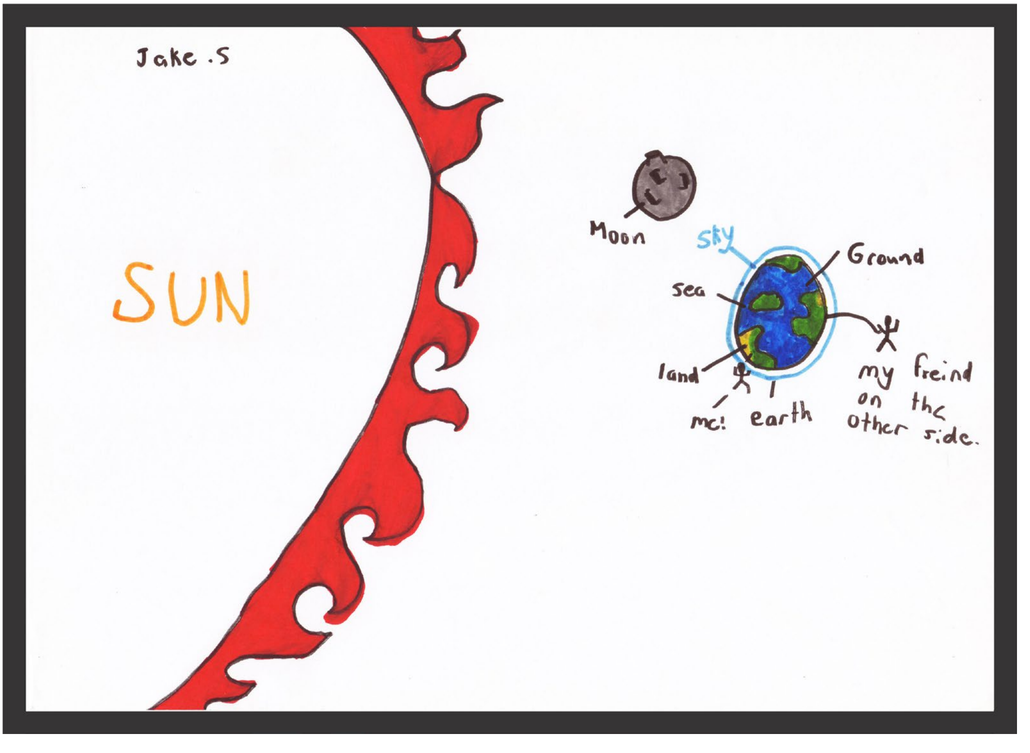

FIGURE 1 Jake (NZ European, male, age 10 years 8 months). Drawing of the Earth, Sun and Moon showing 'self' on 'this side of the Earth' and 'friend' on 'the other side of the Earth'.

R. [Child selects model of 'friend' who lives a long way away and places it on play-dough model of the Earth].

R. Choose one of those (model people) and put them in (on) the play-dough (Earth) where your friend would be.

C. There (places model of friend into play-dough Earth opposite to model of self).

R. What is your friend standing on?

C. On the ground.

R. Is that in England?

C. Yes.

[Here there is interplay between perception and cognition as the child compares his cognitive mental model of the Earth with his drawings and play-dough models in response to questions.]

Second example in support of Strategy (c): inspiring imagination to probe concepts of Habitation and Identity with Earth; and Earth Shape through thought-experiments such as imagining that they have a new friend who lives on the other side of the Earth

Child: Xie Tian (China, Han, male, age 8 years 10 months).

Setting: School interview room.

Questions about Habitation and the other side of the Earth

R. [Child has drawn the Earth and 'self' ('Me') on the Earth: see Figure 2].

R. Do you know a country that is a long way away?

R. So far away that it would take a whole day in a jet aircraft to go there?

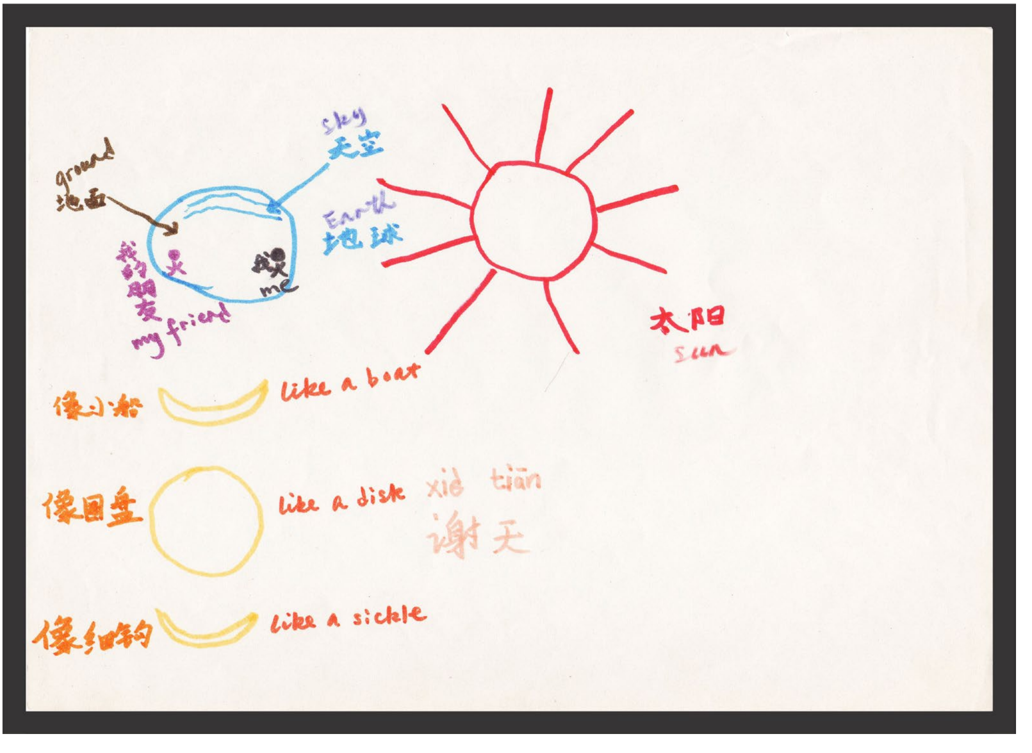

FIGURE 2 Xie Tian (China, Han, male, age 8 years 10 months). Drawing of the Earth, Sun and Moon showing 'self' on 'this side of the Earth' and 'friend' on 'the other side of the Earth'.

R. Or more than four weeks in a train?
C. Africa, North America, Antarctica.
R. [I introduce dolls or models of Kangaroo and Koala Bear (to talk about Australia).]

Protocol discussion. Australia was used with Chinese children rather than NZ because most children knew of Australia whereas many had not heard of NZ. Where possible a country in another hemisphere (northern and southern) was encouraged as this led into questions about the seasons (see Bryce & Blown, 2021).

R. Have you ever seen animals like these before?
C. Yes.
R. Do you know the names of these animals?
C. Kangaroo, Koala.
R. Do you know where these animals live?
C. The tropics.
R. They come from Australia.

Start Socratic dialogue.
R.: Do you know where Australia is?
C.: Yes.
R.: Many people think that Australia is on the other side of the Earth from where we live (in China).
R.: (I ask child to imagine that they have a new friend in Australia). Drawing 'friend'
R.: Just as you have drawn yourself where you thought you would be on the Earth, so I would like you to draw your friend where you think they would be in Australia on the other side of the Earth, as far away from you as they could possibly be.
R.: Draw your friend on your drawing.
R.: Label your friend as 'My friend'.
R.: Where have you drawn your friend?
C.: In Australia.
R.: Why have you drawn your friend there?
C.: They live there.
End Socratic dialogue.

Modelling 'friend'
R. (I introduce a model person representing their friend).
R. This is a model of your friend. You will see that your friend is also playing ball. Place the model of your friend on your play-dough model of the Earth where you think that your friend should be.
R. Where have you put the model of your friend?
C. In Australia.
R. Why have you put the model of your friend there?
C. They live there.
[Child uses imagination to visualise someone on the other side of the Earth].

Example in support of Strategy (d): encouraging children to use their imagination to probe dynamic memory of Earth Shape and Gravity through thought-experiments such as dropping and throwing balls on this and the other side of Earth

Child: Tian Xiao Xi (China, Han, female, age 9 years 6 months).
Setting: School interview room.

Questions about dropping and throwing balls

R. As you can see (from the model people) you and your friend have a ball each.

R. If you throw your ball up, where will it go?

C. On the ground.

[Child uses imagination to visualise trajectory of ball based on knowledge and experience cf. Edelman et al.'s (2001) argument that memory is an act of imagination.]

Start Socratic dialogue.
R.: Why will it go there?
C.: Because of gravity.
R.: If your friend throws their ball up, where will it go?
C.: On the Earth.
[Child uses imagination to visualise trajectory of ball based on teaching and experience.]
R.: Why will it go there?
C.: Because of gravity.
R.: What is gravity?
C.: Like a magnet.
End Socratic dialogue.

Protocol discussion. Child uses analogy to explain a concept that is too difficult for her to understand. She is not alone: even Einstein did not fully understand gravity.

Children who had an understanding of gravity in a Newtonian sense as a force attracting objects to the ground were able to respond scientifically to each situation. 'Why' questions afforded an entry into Socratic dialogue exploring the child's ideas in depth.

Example in support of Strategy (e): Inviting children to use their imagination to decentre when responding to questions about novel situations such as viewing the Earth from the Moon

Child: Amy (NZ European, female, age 5 years 4 months).

Setting: School interview room.

Questions about viewing the Earth from the Moon

R. Have people been to the Moon?

C. Yes—Mr Armstrong has—he was the first one to go to the Moon.

R. You mean Neil Armstrong, the astronaut?

C. Yes.

R. Imagine that you went in a spacecraft to the Moon.

R. Tell me what you could see from the Moon?

[Child imagines travelling to Moon].

C. I could see Mars, the Sun, the Earth, because the Earth is a planet and the Earth is what we are on now.

[Child imagined Mars, the Sun and the Earth as a planet in space.]

R. (Later—when asked where she lived—Amy said that she lived on the Ground, not on the Earth).

Start Socratic dialogue.
R.: What would the Earth look like from the Moon?
C.: Oh—down here you mean—from up on the Moon to down right here?
R.: That's right.
C.: It would look like a tiny wee ball—as small as that dot (points to a dot on my field note-pad about 2 mm dia.).

R.: Why would the Earth look like that?
C.: Because we'd be right up in space—far, far away from the Earth—like—I'll show you—see that bar there (points to a climbing bar in the play-ground)—we look much more bigger than it because we're quite far away from it.
End Socratic dialogue.

Protocol discussion. Child alludes to distance perspective from a vanishing point—and shows the ability to 'decentre' in Margaret Donaldson's terms: see Donaldson (1978), pp. 19–20.

R. What shape would the Earth be?

C. Tiny as my sister's baby rat's eye (talks about pet rats).

R. What shape is that?

C. Just a little black dot.

R. Imagine that you were on the Moon and were looking at the Earth very carefully.

R. What could you see on the Earth from the Moon?

R. Could you see Land?

C. Yes.

[Child uses imagination to visualise features on Earth from Moon.]

R. Oceans? Seas?

C. They'll only be tiny little blue squishes (indicates marks about 2–3 mm long on her drawing).

R. Sky? Atmosphere?

C. Yes.

R. Clouds?

C. Yes.

R. Could you see countries like New Zealand?

C. No.

R. Could you see large cities like Wellington?

C. No—it's far away from Masterton (changing point of perspective from the Moon to Masterton—the town where we are conducting the interview).

R. Could you see towns like Masterton?

C. Yes.

R. Could you see schools like this school?

C. Yes—it would be tiny.

R. Could you see people, like children in the playground?

C. Yes.

[Through audition utilising interview guide[5] questions and Socratic dialogue child switches perceptions of Earth.]

Protocol discussion. Amy's responses indicate that she has no difficulty imagining what the Earth would look like from the Moon.

MAIN DISCUSSION

These protocols make apparent several of the points raised in our introduction. It is now clear that understanding perception as integral with cognition has important implications for how pupils should be engaged in dialogue concerning their prior learning and any new, yet-to-be-acquired, knowledge. Individual pupils vary of course in the details they are considering in reaction to what is being investigated. At best, a learner's attention will converge on features intended to bring about *meaningful learning* (see Ausubel et al., 1978; Bryce & Blown, 2023). Short of that, a pupil's prior knowledge may not encompass the required ideas and he/she may not 'see' what is meant. It is therefore important for thoughtfully exercised

Socratic dialogue to be conducted in order to ascertain in depth what children are thinking. Drawing on these examples of the interview strategies.

Summary

Perception research questions raised and addressed

In our introduction we asked what children are attending to in a *perceptual* sense when they are responding to questions and *what* should teachers take from pupils when they say (or imply) that they 'see' what is meant (such as understanding the concept of planet Earth). We further asked whether perception and cognition were separate processes or whether they were two faces of the same coin. And why it mattered. Our literature review revealed that findings from neuroscience challenge the independence of perception and cognition as separate neurological processes. And our psychological findings from selected protocols of interviews with children aged 3–18 in the domain of science education and children's cosmologies support this conclusion.

The extensive research which has guided teaching practice for several decades is heavily tilted in favour of cognition rather than perception as the primary focus of teacher-pupil attention predominantly in whole class teaching environments (particularly in developing countries such as China where class sizes tended to limit one-to-one interactions). Socratic dialogue utilising scaffolding within the ZPD seems a fruitful strategy to shift the psychological and neurological focus towards perception–cognition as a single learning construct. However, and whether we like it or not, AI has become (or will become) a major source of children's information about the world. Above all, children need to be taught how to discern truth from falsehood, fact from fiction, science from pseudo-science. The new construct of *Perception–Cognition* based on the traditional sources of teachers, parents and librarians should help children to navigate the way forward.

Perception–cognition as a creative process

The selected protocols contain instances where children pause to think about what they are looking at or observing, as if they were comparing new *information* from what they are seeing with some form of existing mental model of the ESM system in memory. Or, thinking deeply about the meaning of phenomena such as why the Sun appears to move (based on observation of shadows); why the Earth appears to be flat (based on observations of Ground and Sky); and visualising the shape of the Earth (by drawing and modelling self and friend in relation to Habitation of the Earth and Identity with Earth). In settings utilising Socratic dialogue, the researcher contributes to the creative interaction by encouraging children to use their imagination and, when opportune, directs children to seek further knowledge from teachers and librarians. It is evident that the dynamic process has no clear boundary between perception and cognition; rather the two merge to build new knowledge.

In reflecting on thought-experiments, Albert Einstein is reported to have said (and obviously from a physical science perspective): 'Imagination is more important than knowledge'. This was *not* to belittle what has been learned and understood; rather it was to draw attention to the importance of trying to advance one's thinking. He went on to say: 'For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand'. These remarks interestingly align with the quotations we cited earlier from the cognitive and neuroscience perspectives where Clark (2015) and Edelman et al. (2001) emphasise the key role of imagination in thinking and remembering.

As we reported in Bryce and Blown (2021), working from a developmental perspective, imagery and imagination play an important role for the individual in interpreting novel situations and solving problems mentally that are impossible to perform in real life. Examples from our studies included imagining a friend on the other side of the Earth; imagining flying to another country; imagining going to the Moon and viewing the Earth from the Moon; and imagining balls falling. These activities and their associated dialogue supported the argument that perception–cognition is a dynamic creative process involving multiple modalities.

Mental models in perception

If, as posited by Millidge et al. (2022), 'the core function of the brain is to minimize prediction errors with respect to a generative model of the world' (Abstract p. 3), then perception and cognition may be taken to be complementary processes designed to facilitate this objective. We see the cosmological categories, earth notions and mental models of the Earth and other astronomical phenomena featuring in our own and others studies of children's cosmologies as subsets of children's science concepts (Bryce & Blown, 2006; Nussbaum & Novak, 1976; Vosniadou & Brewer, 1992, 1994). As such, children's responses provide insights into predictive coding and the critical roles of memory and imagery in maintaining a coherent worldview—one that makes sense of the world, whether intuitive, cultural or scientific. With the advantage of hindsight resulting from recent advances in neuroscience, the interview may be described as a process minimising prediction error between knowledge or mental model *before* instruction or questioning or Socratic dialogue, and prediction error *after* cognition of information gleaned from perception. For example, when a child observing shadows with a shadow stick realises that the apparent motion of the Sun is caused by the rotation of the Earth. Their cosmological concept (mental model) of Earth motion becomes more scientific changing from Earth stationary (or moving in an indefinite way) to Earth moving (spinning). Before interview the child's prediction error would have been maximal in that they may not have thought much about Earth or Sun motion. Whereas during and after the interview the prediction error would become minimal because the perceptions of the observations of shadows and cognition of same would be in memory with an updated cosmological concept (mental model). Multi-modal triangulation utilising drawing and play-dough modelling in addition to verbal language reinforces the mental model and further reduces prediction error because of multiple pathways in memory.

The value of the spoken word in response to open-ended questions and Socratic dialogue

The spoken word has proved particularly helpful during Piagetian interviews in clarifying complex ideas; or explaining cultural interpretations of phenomena; or capturing switching between cultural and scientific repertoires; particularly when responding to Socratic dialogue. Where verbal language needs support is when interviewing young children aged 3–6 at kindergarten or pre-school; or when interviewing children in another culture using another language through interpreters. In these situations, a multi-modal methodology with drawing and modelling affords triangulation with verbal language (limited owing to age, or subject to interpreter mediation with technical terms having to be simplified in real time during three-way researcher–interpreter–child dialogue). A fourth modality employed with success by the current authors to complement the spoken word was gesture. Hand movements when modelling the shape and motion of ESM being video recorded for later analysis (see Bryce & Blown, 2016). Using everyday and scientific language precisely yet economically is an essential skill required of researchers who use interviews. Knowing which everyday term translates to which scientific word and vice versa requires the type of ability that Barsalou (2003) refers to when he associated concepts with skills.

Socratic dialogue as a research method and a pedagogical strategy in the AI era

Although we did not deliberately use it as a teaching tool the interview revealed the potential of Socratic dialogue as a teaching strategy particularly if combined with a multi-modal approach with supporting activities. Although, like the majority of workers in the field we relied heavily on the spoken word to share information our work employed a multi-modal approach with input from verbal language, drawing, gesture and play-dough modelling—activating the associated modalities.

Activities included:

- observing the apparent motion of the Sun using a shadow stick;
- observing the Moon in daytime;
- observing Ground and Sky;
- drawing the shape and motion of the ESM;
- modelling the shape and motion of the ESM with children's own play-dough models;
- drawing and modelling self on this side and friend on the other side of the Earth;
- throwing and dropping balls observing the trajectories;
- observing the influence of gravity on water in containers and free-flowing.

These activities utilising multiple modalities and media afforded opportunities for children aged 3 upwards in two cultures (some with special educational needs) to share their cosmologies based on perception–cognition. Thus we found that Socratic dialogue was an effective research tool when employed in Piagetian clinical interviews and we recommend its use as a teaching strategy when one-to-one teaching opportunities arise either face to face or in future facilitated by means of AI.

In the past utilising Socratic dialogue as a teaching method has been limited by the one-to-one nature of the endeavour. Applying the technique to whole class situations as reported by Reis (2003) is problematical in that in essence Socratic dialogue is about individual students interacting with scientifically literate teachers and other informed sources.

As used in the current study as a research method Socratic dialogue follows in the Piagetian tradition of one-to-one clinical interviews. Although Piaget did not apply Socratic dialogue as such his interview technique implicitly encouraged students to examine their ideas. Nor did Piaget apply Socratic dialogue as a teaching strategy although he must have encountered situations of researcher/teacher conflict in response to children's notions (see below).

Artificial intelligence, meaningful verbal learning and sources of information

If we take perception to be information based (see Gibson, 1966, 2002) rather than sensation based, then the question of sources of information arises. This is particularly relevant in the current electronic age where AI chatbots such as ChatGPT are taking over the roles that were traditionally those of teachers, librarians and parents (see Blown & Bryce, 2018), however, without the latent 'peer review' that traditional sources embodied as a result of cultural and scientific knowledge. Yet what if traditional sources of knowledge are replaced by machines? How would an AI 'know' how and when to conduct Socratic dialogue? Would such interviews have any meaning in the sense that Ausubel et al. (1978) described as meaningful verbal learning?

Realistically it is unlikely that educational researchers will be able to halt the growth of AI systems personalising knowledge through chatbots but we should be able to encourage teachers and parents to teach children to discriminate between scientific and non-scientific sources. If perception is a merging of current and past knowledge through bottom-up information and top-down past knowledge processes as Clark (2013) argued, then the sources of the information and the scientific accuracy of the knowledge need to be monitored to achieve meaningful learning with individuals.

In our research we predominantly used Piagetian one-to-one clinical interviews triangulated with children's drawings and play-dough modelling. Because we were conducting a longitudinal study measuring 'conceptual change' over time we were acting as researchers rather than teachers. However, when children's responses invited further investigation, we utilised Socratic dialogue. Applying these techniques to a teaching situation, we were guided by Ausubel's meaningful verbal learning with its emphasis on individualised teaching (Ausubel et al., 1978). By engaging teacher's ideas as the primary form of scientific knowledge in classroom dialogue, fewer scientific sources are minimised. Albeit one-to-one teaching is teacher intensive, with appropriate application of AI to non-teaching aspects of teacher workloads more time could be allocated to meaningful as opposed to rote learning. Essentially the spoken word expressing human creativity through teacher–pupil dialogue would become the dominant process of knowledge interchange rather than interactions with electronic media. Stefania Giannini, UNESCO Assistant Director General for Education, in a 2024 think-piece expressed her concern 'that the checks and balances applied to teaching materials are not being used to the implementation of generative AI'. The traditional checks and balances are those provided by teachers, librarians and parents. In our cross-cultural research we found that although our participants came from diverse cultures, their cosmologies were remarkably similar, a key factor being mediation by scientifically minded teachers. Our studies were conducted before the age of ChatGPT but the Internet was identified as a source of knowledge in both cultures. However the main sources of astronomy knowledge were teachers, librarians and parents. Whatever the future of AI in education the role of teachers as mediators of scientific knowledge should remain paramount (see Blown & Bryce, 2006, 2018, 2022; Dempsey, 2023; Department for Education, 2023; Education Scotland, 2024; Giannini, 2024a, 2024b, 2024c; Lieberman, 2020).

The blurred boundary between perception and cognition

Although by their very nature, Piagetian interviews and supporting Socratic dialogue are predominately associated with verbal interchange utilising audition, and observational astronomy is in the main dependent on the visual modality, our multi-modal methodology afforded the opportunity for children to express their ideas through drawing utilising dexterous modalities, and modelling with play-dough utilising sensory-motor modalities. In some cases there was evidence of verbal language being ignored or inhibited as children concentrated on their observations, drawings or models (see Bryce & Blown, 2016). This suggests that the children were concentrating on what they could see and feel while making comparisons with some form of idea or notion or model in memory involving integration of perception and cognition.

Finding psychological evidence in the form of speech, drawing or modelling to infer what is going on neurologically is challenging but it seems that *temporal spontaneity* of response may be a factor. If children respond immediately to questions about what they are observing then there is little ground for a ‘fuzzy’ interface between what is seen and what is thought (although they may simply be fast thinkers and talkers), but if the child takes time to answer questions about their observations (as several children did in our research), it suggests that they are thinking about what they are seeing in conjunction with what they already know. ‘Fuzziness’ or ‘blurring’ may result as the child considers alternative repertoires from everyday and scientific sources in memory or through Socratic dialogue, prioritising some and inhibiting others from making the most plausible selection by inference. Current neuroscience research is in its infancy with respect to answering some of the questions raised but research by Clark (2013), Ahissar and Assa (2016), Nee and D'Esposito (2018) and Tacca (2011) appears to indicate a fruitful way ahead.

The fuzzy boundary between perception and cognition was particularly evident from the hands-on experiments such as observing the apparent motion of the Sun with a shadow stick, viewing Ground and Sky, and throwing and dropping balls. These dynamic activities involved interactions of perception and cognition in real time. They afforded the ‘direct experience with phenomena’ that facilitates meaningful learning as identified by Nussbaum & Novak (1976). Being based on observational astronomy they provide fertile ground for study of the perception–cognition interface and the foundation for future learning.

Researcher/teacher conflict: Researcher as teacher

Despite our best efforts to avoid it, we experienced researcher/teacher conflict in conducting our *longitudinal* research. We wished to avoid enhancing the survey group children's knowledge over and above that resulting from teaching and development. Hence as a rule we only switched from researcher to teacher with control group children who were interviewed once only to control for (measure) the influence of the interview in enhancing astronomical knowledge (see Bryce & Blown, 2006). Longitudinal Piagetian studies with repeated measures are now few in number. However, teachers as teachers and researchers as researchers need to take note of the new paradigm. Essentially there needs to be more one-to-one or small-group interaction between teachers and children utilising Socratic dialogue as we have detailed in our findings. Only in this way can the pauses between questions about what children see, and answers about them, be explored to reveal the processes of cognition. Even then, given that some perception–cognition is unconscious, teachers and researchers may never gain the full picture of children's thoughts. We have encountered many early-learned ideas in children and have used them to direct attention to points worthy of comment.

We did not argue the case for Socratic dialogue as a pedagogy because we wished to avoid deliberate teaching since it would compromise our desire to minimise the impact of the interview and interviewer. In the event, as discussed, the children being unfamiliar with researchers looked upon the researcher as a teacher, which created a conflict for the researcher. We were engaged in a cross-age, cross-cultural, longitudinal study utilising repeated measures to track conceptual development over time. To counter mediation by the researcher as interviewer and the interview questions, Socratic dialogue was utilised as objectively as possible. However children tended to see the researcher as a teacher and frequently asked questions which the researcher attempted to answer honestly while maintaining the Socratic tradition. Where applicable the researcher referred children to their teachers and librarians. Our rationale was to measure conceptual change resulting from education and development independently of the interview as a source of information. Nevertheless an after-the-study questionnaire revealed that many children saw the researcher and the interview as sources of astronomy knowledge. [At one NZ kindergarten the researcher was greeted with ‘Here comes the Sun man’.] Later statistical analysis showed that survey group who were interviewed twice 2–3 years apart had significantly enhanced cosmological concepts over the control group who were interviewed only once. This suggested that the interview questions of the first interview had created neural pathways which enhanced recall at second interview (see Edelman, 1987). A similar result was reported by Cromer (1987) who compared a longitudinal group, which he surveyed at quarterly intervals over a 1 year period, with a cross-sectional group which he surveyed only once. He found that the experience of being asked questions which focus on a particular linguistic construction increased the rate of children's language development in that specific area.

IMPLICATIONS

Integration of perception and cognition for teachers and researchers

Teachers, parents and librarians have been confirmed by research to be important sources of knowledge in the eyes of young people (see Blown & Bryce, 2018). The evolution of the Internet and associated electronic sources has altered the picture but traditional sources continue to be the mediators of everyday and scientific knowledge. The difficulty is discerning truth from fiction and science from pseudo-science (see Matthews, 2023). Not only children but also adults are bombarded with information from a variety of sources. Teachers and researchers learn to be selective and take care to apply ‘peer reviewed’ in ‘respectable journals’ to their criteria. Parents may also apply cultural restraints on what they teach their children intending to ‘keep their feet on the ground’, so that they learn to avoid conspiracy theories and the like. The climate change debate (see Bryce & Day, 2014) and controversies over Covid-19 vaccination are examples of major issues that children seek answers about from both traditional and modern (electronic) sources. Viewing perception and cognition as one should enable teachers to teach children not only to discern more critically what they see, hear and feel, but also to think about what they are hearing, reading and discussing, in class and home. Just as researchers read broadly to select pertinent knowledge for and against their arguments, so children need to be taught to select the wheat from the chaff in the avalanche of information available to them from all sources. Collaborative learning is an example of strategies whereby children can interact with their peers and teachers evaluating information at the perception–cognition interface (Day & Bryce, 2013).

Utilising Socratic dialogue with AI to scaffold within the ZPD

A more fruitful pedagogical application of Socratic dialogue (rather than in whole class situations) may be to use it to build on Bruner's concept of scaffolding within Vygotsky's ZPD to take children from where they are with science and social skills to where they need to be developmentally. The Covid-19 pandemic accelerated educational digital technology and a move from whole class to individual teaching. Thinking positively, AI has the potential to afford individual teaching with elementary forms of Socratic dialogue. Designing appropriate software to mimic teacher questions in response to student questions in real time would be challenging beyond the means of current AI developments such as the ChatGPT series. Replicating the kind of knowledge that scientifically minded teachers have would require artificial general intelligence akin to machine consciousness as envisaged by Turing (1950). However, current AI is enabling teachers to spend more time with students in one-to-one dialogue by reducing administrative and assessment tasks, such as setting and marking homework, freeing teachers to teach individual children (Education Scotland, 2024; Garnett & Humphries, 2024; Giannini, 2024a, 2024b, 2024c).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interests.

DATA AVAILABILITY STATEMENT

None.

ETHICS STATEMENT

None.

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Endnotes

[1] The Greek philosopher Socrates claimed to 'know nothing'; thereby avoiding an expectation to teach, and thus persuade his students that they knew more than they were aware of. In doing so he was considered by the oracle of Delphi in Greece to be wise.

[2] According to Rensink (2013), the first is sampling, involving the pickup of information by the eye. The second is filtering (or gating), the control of information considered relevant. The third is binding, involving the formation of more integrated structure over space. Fourth is holding, which creates the coherent structure necessary to perceive continuity over time. Fifth is indexing, which enables individuation of selected items.

[3] Barsalou (1999) in *perceptual symbol systems* took cognitive representations to be non-perceptual or amodal. Later, in 2008 in his *grounded cognition* theory he revised his view and argued that cognition was based on modal simulations. Kaup et al. (2024) argued that perception has both modal and amodal representational formats. Spence & Di Stefano (2024) reviewed various interpretations of amodal and reported: 'Many developmental scientists conceive of the term as referring to those perceptual qualities, such as, for example, the size and shape of an object, that can be picked up by multiple senses (e.g. vision and touch potentially providing information relevant to the same physical stimulus/property) … Cognitive neuroscientists, in contrast, tend to use the term amodal to refer to those central cognitive processes and brain areas that do not appear to be preferentially responsive to a particular sensory modality or to those symbolic or formal representations that essentially lack any modality and that are assumed to play a role in the higher processing of sensory information.'

[4] The apparatus and materials consisted of: (i) a shadow stick composed of a wooden metre ruler screwed to a block of wood to observe the apparent motion of the Sun; (ii) A4 paper and coloured felt-tip pens to draw the shape and motion of ESM; (iii) play-dough in three colours to model the shape and motion of ESM: (iv) model people to explore concepts of 'self' and 'friend' living on 'this side' and 'the other side of the Earth'; (v) tennis balls and drink bottles with water to demonstrate effect of gravity on thrown and dropped balls and free-flowing liquids; (vi) marbles to represent balls for placement by 'self' and 'friend' on play-dough model Earth; and (vii) crayon model bottles to represent drink bottles for placement by 'self' and 'friend' on play-dough model Earth.

[5] An interview guide containing an extensive range of questions covering children's concepts of Earth science and elementary astronomy was used to guide the interview through the various stages reported in protocols. This was complemented by questions utilising Socratic dialogue when opportunities arose (see Blown & Bryce, 2013).

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