Do Children have Epistemic Constructs about Explanatory Frameworks: Examples from Naive Ideas about the Origin of Species

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Abstract

This paper presents the results of a study which examined children's ideas about the origin and differentiation of species. The focus of this paper is on the epistemic constructs associated with children's explanatory frameworks. Two groups of elementary school students, 9-year-olds and 12-year-olds, were interviewed using a semi-structured questionnaire. The results indicate that most children explain the phenomena of speciation in terms of a conceptual framework that strongly resembles either early Greek or later renaissance variants of Essentialist theories in biology. Children also demonstrate a spontaneous understanding of important epistemic constructs associated with theoretical frameworks. For example, most children show an explicit awareness of the boundaries of their theoretical frameworks and have some idea of the phenomena that such a framework can and should explain. Many children treat questions about the origins of the first animal and plant species as "first questions," or questions which are in principle unanswerable. The children appear to distinguish between facts that they as individuals lack but that are probably known by experts, domain problems that are unsolved but could in principle be answered by biological theories, and problems that are beyond the explanatory scope of biological theories.

Introduction

Naive Theories and Conceptual Change

A key issue in recent research on "naive" mental representations has been the degree of metacognitive awareness and control that novices have over such representations. Researchers like Kuhn (1989) and diSessa, (1988) argue that children in particular lack metacognitive awareness of their theories as mental entities and think with rather than about theories. The above researchers claim that because children lack the epistemic constructs in terms of which experts think about and evaluate theories, children's theories are local, incoherent, and infinitely malleable over time and context. They suggest that elements of an expert or "scientific" epistemology can only be acquired through formal schooling in the institution of science.

There is research (Samarapungavan, 1992) showing that in theory choice contexts, where task demands focus children on the metaconceptual aspects of theories, children can evaluate theories on such dimensions as conceptual coherence, empirical consistency, and explanatory power, much like scientists are presumed to (Kuhn, 1977; Laudan et al., 1986). This paper presents the results of a study which examined children's ideas about the origin and differentiation of species. Our research shows that elementary school children demonstrate a spontaneous awareness of such epistemic constructs as theoretical boundaries and "first questions" in relation to their explanatory frameworks for this domain. Prior research (Carey, 1985; Keil, 1989) on young children's biological knowledge indicates that elementary school children appear to have the beginnings of a principled conceptual framework for biological phenomena. This conceptual framework which is radically different from the biological theories of adults in some respects, provides children with a way of distinguishing between animate and inanimate objects (Carey, 1985) and allows them to make deductive inferences about individual animals or plants based on knowledge of their membership in super ordinate biological (Gelman & Markman, 1986) or ontological (Keil 1989) categories.

The studies of Carey (1985), Gelman & Markman (1986), and Keil (1989) yield interesting information on the kinds of conceptual distinctions children use in constructing biological categories. However, these studies do not tell us whether and how children explain the origins of the biological categories and the reasons for the differentiation of these categories from each other. The present study was designed to explore children's ideas about the origin and differentiation of animal species. On the basis of the work of Carey (1985) and Keil (1989) discussed above, we hypothesized that young children might think about species in terms of an essentialist framework in which questions about "origins" simply do not arise and no evolutionary change is possible (a theory held by the early Greeks and by renaissance scientists, see Mayr, 1982).

Initially, our focus in this study was on the conceptual content and coherence of children's theories. One unanticipated finding of the current study was that in answering questions about speciation, children spontaneously invoke the epistemic construct of theoretical

boundaries. They respond by differentiating between the kinds of phenomena that a biological theory may or may not be expected to explain. As a result of this finding we initiated a qualitative analysis of the kinds of epistemic distinctions children make when they encounter questions that they are unable to answer. In the following sections, we will present a brief description of the content of children's explanatory frameworks and present data on the kinds of epistemic distinctions that children make.

Methods

Subjects

The subjects were 35 children who attended a public school in Hoofddorp, a city in the Netherlands. There were 2 age groups: Group 1 (N= 17, mean age 9,4 years, range 8,1-10,4 years) and Group 2 (N=18 children, mean age 12,3 years, range 11,4 -13,1 years). The children's scores on the Raven Progressive Matrices test of intelligence were in the normal range (Group 1: mean = 32 sd = 7.7; Group 2: mean = 43 sd = 4.6).

Materials and Procedure

A structured questionnaire containing 16 questions was developed to examine children's ideas about the origins and differentiation of species (See Samarapungavan & Wiers, 1992; Samarapungavan & Milikowski, 1992 for details of methodology). The concepts investigated included the initial conditions for life on earth, the geological and biological history of the earth, the explanations for the existence of species-specific characteristics, the mechanisms of biological inheritance, and the mechanisms for the origin and differentiation of species. Each conceptual area was tested with multiple questions to provide converging evidence for children's concepts and to enable us to examine the consistency of children's ideas. Some questions required only verbal responses. On other questions, children had to classify pictures of animals and order such pictures on time lines to demonstrate their taxonomic knowledge and their ideas about biological history. Other questions required children to construct family trees demonstrating the ancestry of some current species and the descendants of some initial species.

The children were asked factual questions (e.g., Q1 How old is the earth?), questions that required explanations of biological phenomena (e.g., Q9a How did people first appear on earth?) and questions that called for predictions or inferences to novel situations (e.g., Q12 If you teach a mother dog how to jump through a hoop and this mother dog has puppies, will these puppies be born knowing how to jump through a hoop?). Each child was interviewed individually and the average interview took about 50 minutes. All interviews were tape-recorded and transcribed. If a child's answer was unclear, follow-up questions were asked for clarification.

Scoring

The explanatory framework. The conceptual content of children's answers to each question were first scored independently of their answers to other questions. Then a qualitative analyses of children's combined responses on all questions was performed to determine their overall explanatory frameworks. The protocols were scored by two independent judges and 93% agreement was obtained. All disagreements were resolved through discussion (see Samarapungavan & Wiers, 1992; Samarapungavan & Milikowski, 1992 for details).

The epistemic constructs. Children's spontaneous comments about nature of the limits on their individual knowledge as well as on the kinds of answers a biological theory could generate were categorized as follows:

1. Personal ignorance. Facts that the child did not personally know but that were in the domain of public knowledge and that could be accessed by individuals. These facts could be obtained from reference sources (books, musea) or by asking experts (teachers, scientists).

2. Cutting edge problems. Important phenomena that were currently unexplained or important facts that were currently unknown but that could potentially be known / explained in the future.

3. First Questions or Unanswerable Questions. Problems that are beyond the explanatory power and scope of biological theory or philosophical first questions.

4. Unimportant phenomena. Phenomena that are trivial or unimportant and therefore do not require an explanation.

Results and Discussion

Children's Explanatory Frameworks for Speciation

As there were no differences in the types of explanatory frameworks constructed between the two age groups, the results presented are pooled accross groups. Of the 35 children examined in this study, 7 children (20%) had numerous inconsistencies in their pattern of responses and were classified as having mixed explanatory frameworks. For example, one child started out by saying that in the beginning there were only tiny sea creatures which subsequently evolved into larger land species. Later she said that people had always existed on earth. Twenty eight children used consistent explanatory frameworks.

Essentialist frameworks. Twenty two children (62%) were classified as having essentialist explanatory frameworks. All essentialist children explicitly ruled out creation by God as an explanation for the origins of species.

Pure essentialists with marginal micro changes within species. Nine children (26%) answered in a manner consistent with an essentialist explanatory framework that allows for little or no change in the phenotypic properties of species over time. These children believe that all current species have always existed although in some cases the ancestors looked somewhat different. For example, many of these children said that the ancestor of modern man was the "ape man" and that the "ape man" had always existed. Pure essentialists think that the only changes in the

distribution of biological species over time occur as a result of the extinction of entire species. These children understand the functional or adaptational value of various species-specific characteristics. For example, they say that the fur of the polar bear keeps it warm and functions as camouflage against the snow. However, they do not explain the emergence of these characteristics in terms of their adaptational value. Instead they appear to believe, as Aristotle did, that the essences of species reflect an inherent and immutable design which allows them to be adapted to their environment Children who are pure essentialists cannot explain intra-species variation and dismiss it as an unimportant phenomena. They also cannot specify a biological mechanism for the inheritance of characteristics.

Dinosaur essentialists. Eight children (23%) were placed in this category. The dinosaur essentialists differ from the pure essentialists in their belief that the first animal species on earth were "dinosaurs." They say that while some dinosaur species became extinct, others were gradually transformed as a result of adaptational pressure from the environment into their modern day descendants. Follow up questions reveal that these children believe that the dinosaur ancestors of current species were simply bigger versions of the current species with exaggerated phenotypic characteristics such as longer hair, and bigger teeth. These children think that scarcity of food and a warmer climate caused (by some unspecified mechanism) a gradual transformation in our dinosaur ancestors until they became smaller and less hairy or thinner-skinned depending on the species. We call these kinds of changes "micro changes" because the overall morphology, behavior, and habitat of the species is preserved from dinosaur ancestor to modern day descendant. For example, all five children referred to the mammoth as the "dinosaur elephant" and to the Neanderthal man as the "dinosaur ape man." Indeed the kind of change allowed for by these children strongly resembles that posited by renaissance scientists like Leibniz and Buffon (see Mayr, 1982). These children do not consider the possibility of "macro changes" or large qualitative changes in morphology, behavior etc., over time, and respond to questions about the emergence of species-specific characteristics in the same way as the pure essentialists. This is also true with regard to the questions about intra-species variation and biological inheritance.

Essentialists with Spontaneous Generation. Five children (14%) were placed in this category. They differ from the dinosaur essentialists and the pure essentialists only in their belief that the first species to appear on earth originated as a result of spontaneous generation. Three children said that species originated from inanimate matter which (by some unexplained mechanism) became transformed into tiny animate particles which contained the blueprint for the original ancestors of current species. The animate particles gradually grew bigger and took the form of the original species. Two children said that in the beginning there were tiny "seeds" or life particles strewn all over the earth. Each seed contained the blueprint for the original ancestors of current species. Again by some unspecified mechanism, these seeds grew and became transformed into the first species. The explanations of these children for the origins of species strongly resemble those of renaissance scientists like de Maillet (see Mayr, 1982).

Creationist frameworks. Three children (9%) were classified as creationists. These three children differ from the pure essentialists only in their belief that the various species have been created by God.

Evolutionary frameworks. Three children (9%) were placed in this category. Children with evolutionary frameworks say that neither plants nor animals always existed on earth. These children say that life began with tiny sea creatures which gradually became differentiated into fish, amphibians, and land animals. They clearly allow for macro changes between ancestor and descendant species. Their family trees reflect divergent evolution and true differentiation. Like the essentialists, these children know about extinction.

All 3 children explain the emergence of species-specific characteristics in terms of the Lamarckian mechanism of the inheritance of characteristics that are acquired through use and disuse. For example, all 3 children said that giraffes used to have short necks but that as a result of their straining to reach leaves in tall trees, the necks of the giraffes grew longer. The babies of these giraffes were then born with longer necks.

While these children clearly understand the role of biological adaptation in differentiation, they do not understand the role of intra-species variation in this process. Like the essentialists, these children regard intra-species variation as an unimportant phenomenon. These children do have a partial understanding of the mechanisms for biological inheritance. They say that individual phenotypes express the characteristics of one or both parents which are transmitted reproductively through "cells," "sperms," or "eggs."

The Epistemic Boundaries of Children's Explanatory Frameworks

Essentialist Frameworks. Because essentialist children believe that species always existed on earth and that the essences of species remain constant over time, questions about the origins of species or about the origins of species-specific properties make little sense to these children. This series of questions often elicited comments from children that revealed their ideas about the epistemic boundaries of their explanatory frameworks.

1. First questions or unanswerable questions. Essentialist children often indicated that the questions we put to them about the origins of species-specific characteristics were "strange" or incorrectly worded. Seventeen of the 22 essentialist children (77%) said that our questions about the origins of species or about the origins of species-specific characteristics were beyond the

scope of biological theory. Examples of these types of responses can be seen in the excerpts from the protocols of two essentialist children given below.

Example 1: Jasper (Age 11 years)

E: How do you think giraffes come to have their long necks?
C: It (i.e., the neck) did not come into being! It was always there. I don't understand what you mean by that.
E: How did people first appear on earth?
C: Its the same as with the animals. No can know that! That will always be a puzzle.

Example 2: Jan (Age 8 years)

E: How do you think giraffes come to have their long necks?
C: Oh! That is a rotten question!
E: Why do say that?
C: Because there is no answer for it. No one in the world could answer that.

Further evidence that essentialist children do understand the boundaries of their explanatory framework comes on their responses to Q5a-b in which they are asked what they think of the Creationist account in the Bible. While all the essentialist children repudiated creation by God as an explanation of the origin of species, 14 children also indicated that they understood the limitations of their own framework in dealing with the problem of origins. This is illustrated in the protocol excerpt given below.

Suzzane (Age 8 years)

E: Can you tell me how the animals and people originated according the Bible?
C: God made the animals and Adam and Eve and then they got children.
E: So what do you think of the Biblical explanation for how the animals and people came into being?
C: I don't know. I don't believe it at all but I also do not know how else the world came into being. I know it is strange that suddenly there is the earth with all these animals and all. I don't believe that God or someone just suddenly put them here but I don't really have a better explanation myself. I don't think anyone does.

2. Cutting edge problems. Essentialist children appear to distinguish between first questions that are beyond the scope of biological theory and unsolved problems that are within the scope of biological theory. Thirteen of the 22 essentialist children (59%) recognized an unsolved or difficult problem which was within the scope of an explanatory framework for biological phenomena. We call this type of response a recognition of "cutting edge" problems. An example is given below.

Mischa (Age 12 years)

E: Ostriches have wings but they cannot fly. Why can't they fly?
C: Because they are too heavy?
E: Good. Now why do they have wings?
C: Good question! I guess all birds have wings and they are birds. But then why is it, their wings don't work for them? That is a difficult question.
E: Yes. What do you think the answer might be?
C: I don't know. I doubt that it has been found out. Maybe if real experts study them, they will find that wings have some other use as well.

3. Personal ignorance. These are responses in which children indicate that they are personally ignorant of the facts but believe that the facts are known to experts. Eighteen of the 22 essentialist children (82%) gave these types of responses in the course of the interview. An example of this type of response is given below.

Ineke (Age 10 years)

E: Good, let us start with the giraffes. Can you tell me what the ancestors of the giraffes were?
C: Oh! I have forgotten what they are called. It is a dinosaur giraffe with a difficult name.
E: Can you try and remember the name?
C: No. But I would know if I went to the museum. They have dinosaur bones there with all the names.

4. Unimportant phenomena. Essentialist children treat certain phenomena as unimportant and "unworthy" of explanation. For example they regard intra-species variation as an unimportant phenomenon. This is illustrated in the protocol excerpt given below.

Roel (Age 12 years)

E: Why do people have different color of eyes? For example why do some people have blue eyes and others green or brown eyes?
C: Why? It doesn't make any difference! Besides, it would be pretty dull if everyone had the same eyes wouldn't it?
E: Is that why you think we have different colors of eyes, to make things more interesting?
C: No we just do. Color of eyes is not important.

Evolutionary frameworks

First questions. All three children with evolutionary frameworks also responded to questions about the beginnings of life as questions that were beyond the scope of biological theory. An example is given below.

Sabine (Age 10 years)

E: Remember you told me that the first animals to come into being were tiny sea creatures? Well how did these first tiny creatures come into existence?
C: Yes, that is a very good question. But I don't think anyone can answer it. We can't find out about the very beginning.
E: Why not?

C: Because there is nothing one can study before life begins, there are no fossils or anything.

In this context it is interesting to note that 91% of the children who knew of extinction justified this knowledge with reference to the fossil record. Thus, the children certainly understood the role of empirical evidence in supporting belief. An example of this can be seen from the protocol excerpt of an essentialist child below.

Marieke (Age 8 years)

E: How can we know that there used to be animals earlier that are not there today?
C: Through fossils and foot prints and tracks that have been found.
E: Suppose you had a friend that did not believe that there used to be animals that no longer exist. How would you win this friend over to your point of view?
C: I would show him the fossils of these animals and show him how old they were and explain it all.

Like the essentialist children, those with evolutionary frameworks also gave "cutting edge problem" responses on occasion. The following excerpt from the protocol of a boy discussing the origins of man illustrates this type of response.

Jacques (Age 10 years)

C: Our closest ancestor was a kind of ape but it was not a gorilla or something like that. Experts have found different bones in the Middle East and Africa. Some think we come from the Neanderthals but others think from a different kind of ape. It is difficult but experts are studying these things now to find out the entire line from the beginning.

Children with evolutionary frameworks also gave "personal ignorance" and "unimportant phenomena" responses that were very similar to those described for children with essentialist frameworks above.

The 3 children with creationist frameworks only gave "personal ignorance" responses which were very similar to those of essentialist and evolutionary children described above. It is possible that the mechanism of creation in accordance with a divine plan or purpose removes any limitations on the scope of the explanatory framework for creationists, thereby precluding other types of epistemic distinctions in this domain.

General Implications

Our results show that about two thirds of the children tested used complex epistemic constructs that allowed them to differentiate between their personal knowledge and public knowledge, and between biological phenomena and problems that were either within or beyond the explanatory bounds of biological theory. Embedded in the children's theories are notions about the relative importance of phenomena or observations and about questions that can be informed by empirical evidence. The epistemic constructs bias children towards interesting and away from uninteresting phenomena. They serve to direct children's mental efforts towards questions that are potentially solvable and away from those that offer no prospect of an empirical solution.

We believe these findings are significant in the light of recent questions raised by several researchers (diSessa, 1988; Keil, 1989; Kuhn, 1989) about the epistemic status of naive theories. Keil (1989) has proposed that a naive theory is an explanatory framework which provides at least partial explanations for phenomena that are recognized as important. By this definition, children in the current study certainly have naive theories of speciation. These theories function as explanatory frameworks for a variety of biological phenomena. Embedded in the explanatory frameworks are concepts about the nature of species, the function of species-specific properties, the competition among species for scarce environmental resources, factors that determine the survival and extinction of species, and the kinds of transformations that are biologically possible within or across species boundaries. However, children's explanatory frameworks are more than collections of mutually compatible biological concepts. The frameworks also contain epistemic constructs that provide children with a way of selecting important phenomena and problems for consideration and with a way of establishing the explanatory boundaries of the frameworks.

The results of this study support the position of researchers such as Carey (1985) and Brewer and Samarapungavan (1991) that the differences in the conceptual content and explanatory scope of children's theories and expert (adult) theories do not appear to be the result of differences in the underlying reasoning processes available to children and adults. They also support Carey's (1991) argument that children's naive explanatory frameworks are often incommensurate with those of adults and / or experts in much the same way as older theories in the history of science are thought to be incommensurate with their successor theories (Kuhn, 1977). Consequently, acquiring the expert framework requires more than the enrichment of naive concepts. It requires the conceptual restructuring of the naive framework. In order to accept current scientific accounts of evolution, children would have to change their epistemological commitments to the phenomena and problems that are to be explained as well as restructuring their biological concepts. In this context, it is interesting to note that children like scientists believe that the kinds of questions that theories should address are those that can at least potentially be empirically informed. The reason that most children in our study gave for treating questions about the origins of life as philosophical first questions was precisely that these questions could not (in their view) be empirically informed.

Chi (1992) suggests that the most difficult kinds of conceptual restructuring are those which require ontological shifts. The move from an essentialist biological framework to an evolutionary one requires just such a shift from a world in which ontological categories are static and eternal to one in which new categories may evolve. Our research provides a potential explanation for the known difficulty (Clough & Wood-Robinson, 1985;

Samarapungavan & Milikowski, 1992) that adolescents and lay adults have with understanding neo-Darwinian theories of evolution. We propose that two biases combine to create a predisposition towards Lamarckian rather than neo-Darwinian explanations of evolution as children begin to restructure their naive essentialist frameworks. The first is the essentialist bias towards treating natural variation as an unimportant phenomenon. The second is the essentialist bias towards identifying the functional value of known physical and behavioral characteristics of species in an attempt to explain the survival or extinction of species populations in a changing environment. Our research would suggest that in order to be acquire a neo-Darwinian point of view, children would need to be persuaded that questions about the origins of life on earth can be empirically addressed and the phenomenon of natural variation is central to modern evolutionary approaches.

Conclusions

Our results demonstrate that at least on some levels, elementary school children can think about as well as with theories even before they have any systematic schooling in the public institution of science. This research leaves important questions about how and when children begin to acquire epistemic constructs of the kind described here unanswered. However, the spontaneous use of such epistemic distinctions by elementary school children does indicate earlier competence with regard to the metacognitive regulation of explanatory frameworks than is generally supposed.

References

Brewer, W.F. & Samarapungavan, A. (1991). Child Theories versus Scientific Theories: Differences in Reasoning or Differences in Knowledge? In R. R. Hoffman & D. S. Palermo (Eds.), *Cognition and the Symbolic Processes: Vol. 3. Applied and Ecological Perspectives* (pp. 16-32). Hillsdale NJ: Erlbaum.

Carey, S. (1991). Knowledge acquisition: Enrichment or conceptual change. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 257-292).

Carey, S. (1985). *Conceptual Change in Childhood.* Cambridge Mass.: MIT Press.

Chi, M. T. H. (1992). Conceptual change within and across ontological categories. Examples from learning and discovery in science. In R. N. Giere (Ed.), *Minnesota studies in the philosophy of science: Cognitive models of science* (Vol. 15, pp. 129-186).

Clough, E., & Wood-Robinson, C. (1985). How secondary students interpret instances of biological adaptation. *Biological Education, 19,* 125-130.

diSessa, A. A. (1988). Knowledge in pieces. In: G. Forman & P. B. Pufall (Eds.) *Constructivism in the computer age.* Hillsdale, NJ. : Erlbaum.

Gelman, S. A. & Markman, E. M. (1986). Natural Kind Terms and Induction in Young Children. *Cognition, 23,* 183-208.

Keil, F C. (1989). *Concepts, Kinds and Cognitive Development.* Cambridge Mass.: MIT Press.

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review, 96,* 674-689.

Kuhn, T. S. (1977). *The Essential Tension.* Chicago: University of Chicago Press.

Laudan, L., et al. (1986). Scientific change: Philosophical models and historical research. *Synthese, 69,* 141-223.

Mayr, E. (1982). *The Growth of Biological Thought.* Cambridge, MA: Harvard University Press.

Samarapungavan, A. (1992). Children's judgments in theory choice tasks: Scientific rationality in childhood. *Cognition, 45,* 1-32.

Samarapungavan, A. & Milikowski, M. (1992, July). *Knowledge acquisition in evolutionary biology.* The 25th congress of International Congress of Psychology, Brussels.

Samarapungavan, A. & Wiers, R. (1992). Children's ideas about the origins and differentiation of species. Tech. Rep. V. F. Programma Kennisverving, Psychonomics. University of Amsterdam.