The Problem of Metaconceptual Awareness in Theory Revision

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Abstract

In this paper we report an experiment that investigated the question of whether elementary school children have metaconceptual awareness of theory revision processes. Fifty-two elementary school children (grades, 1, 3 and 5) were asked to select between phenomenological and scientific depictions of different astronomical phenomena and indicate which of these depictions were closer to “Reality” and which were closer to “Appearance”. The results showed an increase with age in the number of scientific depictions selected. They also showed that the children who selected both phenomenological and scientific representations of the astronomical phenomena were not capable of deciding which depictions best represented “Reality” and which “Appearance”. It is argued that the task requires the ability to understand that the same world situation can be represented in different ways and that children have difficulty understanding the theoretical nature of representations and thus of flexibly manipulating multiple representations of the same physical phenomenon.

Introduction

As children are exposed to science instruction, they gradually revise their naive physics in ways that make it more consistent with currently accepted scientific explanations. The question we investigated in this paper is the following: Are children aware of this revision process? Or more generally, are conceptual change processes in the learning of science under the full metaconceptual control of the learner?

At least two alternative hypotheses can be formulated. The first is that children are like scientists who are aware of their theories and test them in an explicit fashion during the process of theory building and revising. In this case they should have full metaconceptual awareness of their theoretical views and the difference between their views and the scientific explanations to which they are exposed. The other hypothesis is that children are not like scientists in this respect. Although they are capable of interpreting new evidence to revise theories, they are neither aware of their theories nor do they explicitly evaluate them.

We are not the first to claim that children can revise their theories without full metaconceptual control. Karmiloff-Smith & Inhelder (1974) argued that young children are capable of forming and revising theories without necessarily being aware of these theories. According to Kuhn, Amsel & O’Loughlin (1988) young children revise their theories as their experience increases, but lack the skillful coordination between theory and evidence of adults. According to them, the ability to think about a theory, that means to represent it as an object of cognition, is weak among young children.

Klahr (Klahr, 2000. Klahr, Dunbar & Fay, 2000) investigated developmental differences in search heuristics used in scientific reasoning. They found that children are capable of distinguishing between theory (hypotheses) and evidence. However, children’s performance was inferior to that of adults when they had to distinguish between a given implausible hypothesis and a plausible hypothesis of their own creation. In contrast to adults, children did not simultaneously consider the two alternative hypotheses, but they focused on their own plausible hypothesis and tried to find evidence to support it. Possible inconsistencies were interpreted either as errors or failures to support the desired outcome.

In later work, Karmiloff-Smith (1991, 1992) argued that the changes in children’s theories are connected with changes in representations. A way to revise theories is through an internal process, which Karmiloff-Smith calls “representational rediscription”. The end result of representational rediscription is the existence in the mind of multiple representations of similar knowledge at different levels of detail and explicitness, which enable the learner to appropriate this knowledge.

Vosniadou (Vosniadou, 2003. Vosniadou, Skopeliti, & Ikospentaki, 2004, 2005) argued that the presence of misconceptions can be used as evidence that the process of conceptual change is not under the full metaconceptual control of the children. Many misconceptions regarding, for example, the shape of the earth are synthetic models that reveal children’s attempts to assimilate scientific information to their naïve physics. The model of the “dual earth” is a clear example of a synthetic model, according to which there is a spherical earth in the sky (a planet) and a flat earth where people actually live. We believe that the formation of synthetic models is possible precisely because children are not metaconceptually aware of their own beliefs or presuppositions and of the fact that these beliefs are inconsistent with the new, scientific information to which they are exposed at school. Metaconceptual awareness in this case requires the ability to form two representations (the one based on phenomenal appearance and the other based on the scientific model-the globe) in order to compare them. DeLoache and her colleagues (DeLoache, 1989, 2000. Marzolf, DeLoache & Kolstad, 1999) have shown that there is a developmental trend in representational ability. In a series of experiments in which young children were asked to find objects hidden in a full-sized room based on information provided to the children through their exposure to a realistic scale model of the room, DeLoache et al. (1999) found that 2.5 year old children cannot utilize the information given in the scale model in order to find the objects in the real room, but by the age of 3, they can. DeLoache argues that children under the age of 3 may not be able to maintain a dual orientation to a model (a dual representation) treating it only as an object rather as a symbol.

Our situation is of course a more complex one. As mentioned earlier, metaconceptual awareness in our tasks would require children to be able to simultaneously compare two alternative representations of the same astronomical phenomenon, a representation based on phenomenal appearance and another based on the scientific model.

In order to investigate this question, we designed an experiment in which we presented the children with phenomenological and scientific depictions of six different astronomical phenomena and asked them to select from them the one that was closer to "Appearance" and the one that was closer to "Reality".

We hypothesized that the younger children would provide mostly phenomenological responses both for the Appearance and the Reality questions because they had not been exposed or had not yet understood the scientific explanations of the astronomical phenomena. In the case of the older children we expected an increase in scientific depictions, resulting from their greater exposure to the scientific models.

Our second hypothesis was that, lacking metaconceptual awareness, the children who had understood the scientific explanations would still find it difficult to make the distinction between "Appearance" and "Reality", because this distinction requires the ability to entertain dual representations for the same world situation. We thus expected that the children will either select only scientific depictions for both "Appearance" and "Reality" or that they would mix the two.

Method

Participants

Fifty-two children from two middle-class elementary schools in Athens participated in this study. Eighteen children attended Grade 1 (mean age 6 years and 4 months), 17 children attended Grade 3 (mean age 8 years and 9 months), and 17 children attended Grade 5 (mean age 11 years and 2 months).

Materials

The materials consisted of a *Reality-Appearance Pretest* and an *Astronomy Test*. The *Reality-Appearance Pretest* was used to ensure that all the children could make the distinction between *Reality* and *Appearance* and was similar to the tests developed by Flavell and his colleagues (Flavell, Green & Flavell, 1986). Each child was presented with a sheet of white paper (Reality), which was placed under a red transparent plastic filter (Appearance) and had to name the Real and the Apparent color of the paper under these circumstances. In the process the child was explicitly told: "As you know, the things around us are sometimes different in reality from what they appear to be, and sometimes they are the same".

The *Astronomy Test* consisted of four different depictions of each of the following six astronomical phenomena: *Shape of Earth, Shape of Earth and Gravity, Sun and Earth Relative Size, Sun and Moon Relative Size, Day/Night Cycle, and Solar System*. For each astronomical phenomenon, two of the four depictions were more consistent with scientific representations to which students are exposed in instruction, while the other two were closer to young children's own phenomenological representations, as they have been revealed in previous studies (Vosniadou & Brewer, 1992, 1994. Vosniadou, Archontidou, Kalogiannidou, & Ioannides, 1996).The experimenter showed the child one of the six sets of the four cards that depicted an astronomical phenomenon (e.g. the Shape of the Earth) at a time asking him/her to choose the one that he/she thought was closer to "Reality" and place it underneath a card that wrote "As it is in Reality" and then to choose the one closer to "Appearance" and place it underneath a card that wrote "As it appears to our eyes". Children's responses were audio-recorded and were later transcribed for scoring. The materials used in the *Astronomy Test* are shown in Figure 1.

Procedure

The children were tested individually in their school by one of the experimenters. Testing time was between 20 to 30 minutes. All the children in the sample passed the *Reality-Appearance Pretest* and proceeded to take the *Astronomy Test*.

Results

According to our first hypothesis there should be an increase in scientific depictions as a function of grade. In order to test this hypothesis we scored children's depiction selections for Appearance and Reality as follows: children were given the score of (1) if the depiction selected represented an initial phenomenological model, the score of (2) if the depiction selected represented an advanced phenomenological model, the score of (3) if the depiction selected represented an initial scientific model, and the score of (4) if the depiction selected represented an advanced scientific model. Given our scoring system we should expect lower means for the Appearance question

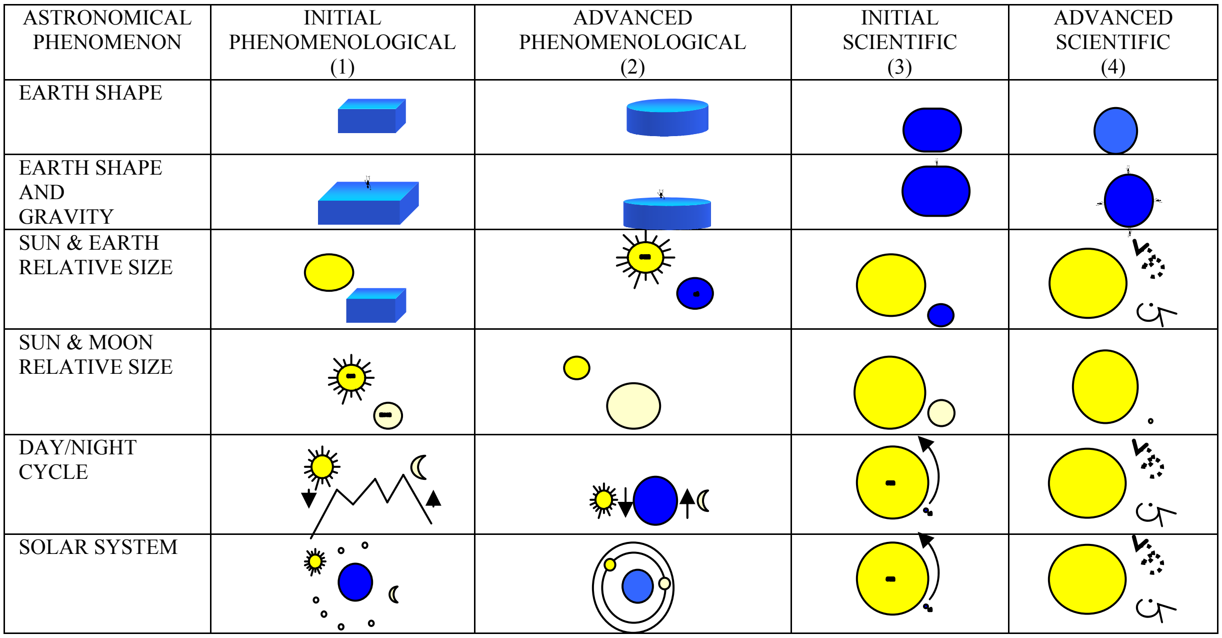

Figure 1: Scientific & Phenomenological Depictions of Astronomical Phenomena used in the Astronomy Test

(Phenomenological Depictions) and higher means for the Reality question (Scientific Depictions).

A 3 way ANOVA was conducted on these scores, with the following factors: Question Type (with two levels: Reality and Appearance question), Grade (with three levels: 1st, 3rd and 5th grade) and Astronomical Phenomenon (with six levels: the six astronomical phenomena which are shown in Figure 1).

Table 1: Mean Scores for Reality and Appearance Questions by Grade.

Grade	Reality	Appearance	Difference
1st	14.00	13.83	0.16
3rd	17.17	13.23	3.94
5th	18.29	12.05	6.23

The results showed that, as expected, there was a statistically significant interaction between Question Type and Grade ($F(2, 49)=7.619; p<0.01$). More specifically, we obtained an increase by grade of the mean score for the questions that refer to Reality (scientific) and conversely a decrease of the mean score for the questions that refer to Appearance (phenomenological). As shown in Table 1, the difference between the Reality and Appearance scores is low for the 1st grade, indicating that the younger children selected mostly phenomenological depictions both for Reality and Appearance. The increase in Reality and Appearance scores with age is in accordance with our hypothesis that there will be an increase of the scientific depictions by age.

The results of the ANOVA also showed a main effect for Astronomical Phenomenon ($F(5, 245)=45.979; p<0.01$), which was due to the fact that the Shape of Earth and Shape of Earth and Gravity questions had higher mean scores than the other astronomical phenomena. The results also showed a statistically significant interaction between Astronomical Phenomenon and Grade ($F(10, 245)=3.624; p<0.01$). As shown in Table 2, the mean score increased by grade for all astronomical phenomena except for the Shape of Earth and Shape of Earth and Gravity. This finding shows that children selected the scientific depiction more often in the case of the Shape of Earth and Shape of Earth and Gravity questions than in the other cases.

Table 2: Mean Scores for Astronomical Phenomenon as a Function of Grade.

Astronomical Phenomenon	1st Grade	3rd Grade	5th Grade
Shape of Earth	6.61	6.64	6.23
Shape of Earth and Gravity	6.27	5.94	5.41
Sun and Earth Relative Size	4.11	5.17	5.64
Sun and Moon Relative Size	3.44	4.94	4.88
Day /Night Cycle	3.61	3.76	4.23
Solar System	3.77	4.05	3.94

The above results are consistent with our hypothesis that there will be an increase in the selection of scientific depictions as a function of age. Thus we have evidence that children, as they develop, solve the ontological problem. However, these results do not provide information regarding the solution of the epistemological problem. Our hypothesis was that the students who understood the scientific representations would not necessarily have metaconceptual awareness of the shift that they had made from an original phenomenological representation (Appearance) to a scientific one (Reality). Our prediction was that these children were likely to commit the error of selecting only scientific depictions for both Reality and Appearance, or that they would mix up the two representations, often selecting the scientific depictions for Appearance and the phenomenological depictions for Reality.

In order to better test these two alternative hypotheses, each child's selection of the two depictions for Reality and Appearance for the six astronomical phenomena were placed in the following four categories:

1. Phenomenological Responses Only (P-P): when the cards chosen were the initial or advanced phenomenological depiction for both Reality and Appearance.
2. Reversal of Phenomenological-Scientific (P-S): when the cards chosen were the initial or advanced phenomenological depiction for Reality and the initial or advanced scientific depiction for Appearance.
3. Scientific Responses Only (S-S): when the cards chosen were the initial or advanced scientific depiction both for Reality and Appearance.
4. Correct: Scientific-Phenomenological (S-P): when the cards chosen were the initial or advanced scientific depiction for Reality and the initial or advanced phenomenological depiction for Appearance.

Table 3a: Distribution of Responses in the four Categories (1st Graders)

Astronomical Phenomenon	Categories of Response			
	P-P	*P-S*	*S-S*	*S-P*
Earth Shape	-	6%	61%	33%
Earth Shape & Gravity	17%	17%	28%	38%
Sun & Earth Relative Size	61%	33%	-	6%
Sun & Moon Relative Size	50%	44%	-	6%
Day/Night Cycle	55%	17%	-	28%
Solar System	66%	17%	11%	6%

In Tables 3a, b, c we can see the distribution of responses in the four categories described above for the 1st, 3rd and 5th graders respectively. In Table 3a, we can see that in most astronomical phenomena the 1st graders provided phenomenological responses only, indicating that they had little or no knowledge of the scientific explanations for these phenomena. Concerning the phenomena *Shape of Earth* and *Shape of Earth & Gravity*, the 1st grade children showed some evidence of understanding the scientific explanations, a finding supported by the *Astronomical Phenomenon x Grade* interaction, discussed earlier. However, even though we find evidence for the solution of the ontological problem, the 1st graders do not appear to have solved the epistemological problem. As can be seen, most of the 1st graders (61%) selected only the scientific depiction for both Reality and Appearance in the case of the *Earth Shape* and were split between selecting either only the scientific depictions or the correct responses in the case of the *Earth Shape & Gravity*.

Table 3b: Distribution of Responses in the four Categories (3rd Graders)

Astronomical Phenomenon	Categories of Response			
	P-P	*P-S*	*S-S*	*S-P*
Earth Shape	-	-	59%	41%
Earth Shape & Gravity	6%	23%	12%	59%
Sun & Earth Relative Size	18%	29%	18%	35%
Sun & Moon Relative Size	12%	35%	18%	35%
Day/Night Cycle	53%	6%	-	41%
Solar System	53%	12%	6%	29%

Table 3c: Distribution of Responses in the four Categories (5th Graders)

Astronomical Phenomenon	Categories of Response			
	P-P	*P-S*	*S-S*	*S-P*
Earth Shape	-	6%	41%	53%
Earth Shape & Gravity	18%	6%	6%	70%
Sun & Earth Relative Size	18%	6%	35%	41%
Sun & Moon Relative Size	6%	12%	18%	64%
Day/Night Cycle	29%	12%	-	59%
Solar System	64%	6%	6%	24%

Looking at the distribution of responses in the case of the 3rd and 5th graders (Tables 3b & 3c) we can see that an increasing number of children can sort out successfully the distinction between the scientific and the phenomenological depictions. For the phenomena *Earth Shape* and *Earth Shape & Gravity* over 50% of these children could form the correct distinction between the scientific and the phenomenological depictions. Only for the phenomenon Solar System most children continued to provide phenomenological responses (64%). However, even though most children seemed to be aware of the scientific model, they continued to mix up the scientific and the phenomenological, either selecting only scientific depictions or mixing up the scientific with the phenomenological. A chi square goodness-of-fit analysis was performed on the data displayed in Tables 3a, b, c. A statistical significance with regard to the frequency of the correct answers by grade, for the Astronomical Phenomena Relative Size of Sun and Moon ($\chi^2(6)=23.994; p<0.05$) and Relative Size of Sun and Earth ($\chi^2(6)=21.798; p<0.05$) was found.

Discussion

The results of the present study confirmed our first hypothesis, namely that a) the younger children would select mostly phenomenological depictions for both the 'Appearance' and 'Reality' questions, and b) there will be an increase in the number of scientific depictions selected by the older children.

The results also supported our second hypothesis according to which even the children who selected the scientific depictions would find it difficult to distinguish "Reality" from "Appearance". Indeed, for the majority of the astronomical phenomena investigated, many of the 1st and 3rd graders and even some of the 5th graders who selected scientific depictions gave erroneous responses. They either thought that scientific depictions represented both "Appearance" and "Reality" (the S-S category) or selected both scientific and phenomenological depictions but could not distinguish which depiction belonged to "Appearance" and which to "Reality" (the P-S category). Even in the case of the *Shape of Earth*, where children are exposed to the scientific model very early, some of the older children could not make the correct distinction between the scientific and phenomenological depictions.

The task of deciding which depictions are closer to "Appearance" and which are closer to "Reality" requires the ability to retain in mind and compare different representations that depict the same situation in the world. This task requires metacognitive abilities and more specifically the ability to understand that representations of situations in the world are theoretical entities, hypotheses that can be tested, found wrong and replaced by others. It appears that such metaconceptual abilities develop late and are not necessary for fundamental theory revision processes to take place.

More specifically, it seems that children start the knowledge acquisition process with the construction of naïve, phenomenological representations of the physical world without metaconceptual awareness. In other words, the children do not consider these phenomenological representations to be hypotheses which can be subjected to hypothesis testing and disconfirmation. At this 'absolutist level' of epistemological understanding, there seems to be only one 'correct' representation, and knowledge is only an accumulation of facts (see Kuhn, 2004).

Phenomenal representations are gradually replaced, usually in the context of school instruction, with representations closer to the culturally accepted scientific ones. However, it appears that even this process of theory revision can take place without metaconceptual awareness. The findings of the present study that many children select only the scientific depiction to refer to both "Reality" and "Appearance" or confuse the phenomenal and scientific depictions indicate that understanding the scientific representation does not necessarily entail the ability to understand that the same world situation can be interpreted in different ways.

The ability to understand which depiction refers to "Reality" and which to "Appearance" seems to be related metacognitive developments that make it possible for children to understand the theoretical nature of their representations and the ability to make them the very objects of critical examination.

According to Kuhn (in press), one of the important aspects of cognitive development and learning is the ability to use a meta-level executive function to monitor learning. This executive function allows learners to flexibly access dual representations, one of their own understanding and the other of the new information to be investigated. "In its absence, there exists only a singular experience – of 'the way things are' – as a framework for understanding the world" (p. 8).

This possible interpretation of the results is supported by similar findings in the domain of language development. A series of experiments by Karmiloff-Smith (1979, 1992) have shown that 3-5 years old children, form two independently stored representations of the same phonological form and map each of them to a specific functional context. Since children of this age exploit two independently stored representations, they make no mistakes and they can produce simple functions of the indefinite and definitive article. Around the age of 5-6 years old, children's representations seem to change, marking explicitly the relation between two identical forms. However, children start to make mistakes with respect to which of the two functions is intended in each case and they do not always understand when the same word is used as a numeral referent or as an indefinite one. Only later, around the age of 6-7 years old, children have a consciously accessible and verbally stated metalinguistic knowledge and the relation between the two representations has been stored in one explicit form.

According to Karmiloff-Smith's model, for the child to conceive the different alternative interpretations of a phonological form, a process of representational redescription must take place. Only then, the child is capable to produce multiple representations at different levels. The children, who do not have such metarepresentational capabilities, fail to recognize that the same situation may be seen and interpreted through multiple, different representations.

In our situation we do not have similar forms that take different functions, but similar world situations that can take different representations. The two situations are similar in that they break conventional relations between a representation and the situation to which it refers.

The ability to flexibly access two different representations reveals a developmental progress as children become capable of understanding the difference between "seeing" and "seeing as", as for example in "the earth is a sphere in reality, but it looks like a flat object". This ability also makes them capable of explaining the transition from one representation to another, as for example when they can explain that "very big spherical objects may seem flat to anyone who is on them".

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