Third Misconceptions Seminar Proceedings (1993)

Paper Title: CHILDREN'S CONSTRUCTION OF EXPLANATIONS IN SCIENCE

Author: Tytler, Russell

Abstract: A considerable amount of work has focussed on children's 'alternative conceptions' in science and their resistance to change. The nature of conceptual change is still, however, the subject of debate. The related question of the stability of children's conceptions across contexts has not been satisfactorily answered. In this study, small groups of children, ranging in age from 5 to 13, experimented with a range of activities illustrative of 'air pressure'. Transcripts of their discussions and resulting explanations, together with interview data, indicate the fluidity and context-dependence of children's ideas. Analysis of these and a sequence of written probes indicates a developmental factor in children's knowledge transactions within small groups, in their explanatory styles and conceptions, and in the consistency of their explanations across contexts. The impression this data gives is one of incremental growth in explanatory conceptions, and in the range of contexts to which they are applied.

Keywords: concept formation,educational methods,,cognitive restructuring,developmental stages,scientific concepts,classrooom techniques,language processing,

General School Subject: physics

Specific School Subject: fluid mechanics

Students: Elemantary school

Macintosh File Name: Tytler - Explanations

Release Date: 12-16-1993 C, 11-7-1994 I

Publisher: Misconceptions Trust

Publisher Location: Ithaca, NY

Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics

Publication Year: 1993

Conference Date: August 1-4, 1993

Contact Information (correct as of 12-23-2010):

Web: www.mlrg.org

Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

----- -----

Children's construction of Explanations in Science

Russell Tytler, Deakin University

ABSTRACT

A considerable amount of work has focussed on children's 'alternative conceptions' in science and their resistance to change. The nature of conceptual change is still, however, the subject of debate. The related question of the stability of children's conceptions across contexts has not been satisfactorily answered. In this study, small groups of children, ranging in age from 5 to 13, experimented with a range of activities illustrative of 'air pressure'. Transcripts of their discussions and resulting explanations, together with interview data, indicate the fluidity and context-dependence of children's ideas. Analysis of these and a sequence of written probes indicates a developmental factor in children's knowledge transactions within small groups, in their explanatory styles and conceptions, and in the consistency of their explanations across contexts. The impression this data gives is one of incremental growth in explanatory conceptions, and in the range of contexts to which they are applied.

INTRODUCTION

Much work has been done in recent years in the description and theoretical consideration of the many 'alternative conceptions' that children hold in relation to natural phenomena. Conceptions that children bring to the classroom are found to be not only rich and varied (Osborne and Freyberg, 1985; Driver, Guesne & Tiberghien, 1985), but are surprisingly resistant to change through instruction (Champagne, Gunstone & Klopfer, 1982). This stability contrasts with findings that children can adopt a range of often contradictory conceptions to explain different phenomena (Biddulph, 1983). Other studies (Engel Clough, Driver & Wood-Robinson, 1987; Gauld, 1986) have demonstrated the stability of conceptions over time. Engel Clough and Driver (1986), in a study of the stability of alternative conceptions across contexts, found the evidence equivocal. Their results are consistent with earlier studies (eg. Donaldson, 1978) that emphasize the context-dependence of children's responses to phenomena. In a more recent study Bloom (1990,1992) has shown children's thinking to be extremely fluid, progressing via a rich selection of episodic knowledge, metaphors, interpretive frameworks and emotions/values/aesthetics. The extent to which children hold and use consistent 'alternative conceptions' over a range of contexts (see, for example, Driver, 1989) has implications for the extent to which we view conceptual change as 'radical restructuring' (Vosniadou & Brewer, 1987; Carey, 1985a, 1986; West & Pines, 1984), and how we conceptualize the conditions that will favour such conceptual change (Posner, Strike, Hewson & Gertzog, 1982; Mitchell & Baird, 1986)

White (1987) argues the need for a 'theory of content' that would differentiate between different science topics and ideas in the way conceptual change occurs. He calls for more research on the formation and change of young children's conceptions, and for the development of a representation of cognitive structure that captures its fluidity. Most of the alternative conceptions research has sought to probe children's conceptions at fixed points in time. There is a need for a greater focus on the dynamics of children's ideas; the explanatory strategies they use, and the genesis of these strategies over the early school years. There is also a need to refocus attention on small group discussion as a strategy for encouraging conceptual change, rather that viewing the process as a private affair between teacher and individual student (see, for example, Borghi et.al.,1988). This paper describes an attempt to chart the dynamics of young children's construction of explanations of phenomena involving air pressure, working in small groups under the guidance of the researcher and classroom teacher.

The research was undertaken with the following questions in mind :

* What strategies do children use in constructing explanations of natural phenomena ?
* How stable are children's ideas when they engage in group based discourse on phenomena encountered in a classroom setting?
* Do children use explanatory conceptions in a consistent way, across contexts that scientists recognize as illustrating the same principles ?

A PRELIMINARY STUDY

A preliminary study involved the analysis of transcripts of a class of year 2/3 children's discussions of a range of activities focussing on the concept of 'air pressure'. The transcripts arose from a sequence of two two-hour sessions with grade 2/3 (aged 7 & 8) in a UK school. The sessions were taken jointly by the researcher and classroom teacher. The sequence of events in the sessions used in the more complete study, described below, was followed in the preliminary trial, except that the range of tasks was slightly narrower.

In session 1, after an introductory discussion to focus attention on the topic of 'Air', the class was organized into groups of 3 or 4 children, who undertook a sequence of tasks intended to reinforce the idea that air has a tangible presence. Each task involved an element of surprise. Groups were asked to work towards an explanation of each task, that they all agreed on. The discussions in each of the groups was recorded, and analyzed, and the children were asked for a written explanation of each of the tasks.

In session 2, the same procedure was followed for three different sets of four tasks intended to illustrate the principle of differential air pressure. The groups were then reconstituted so that each child was responsible for presenting their tasks within the new group, which then came to an agreed explanation of each of the twelve tasks. The group discussions in both phases were recorded.

The tasks for Session 1 included :

- B3 Children insert a tissue into a glass and plunge it, upside down, into a bucket of water, observing whether the tissue became wet.
- B4 Children float a small wooden boat in a bucket, and plunge the upturned glass over it to see if it would sink or float.

The 12 tasks used in Session 2 were arranged as 3 groups (Red, Yellow & Green) of 4. These included :

- R1 <u>'Tricky straw'</u> : A straw is pricked in a number of places with a pin, so that it cannot be successfully used to drink through.
- R2 <u>'Upturned glass'</u> : A glass full of water with a piece of paper across the rim is upturned. The water does not spill out.

R3 'Blocked funnel' : Water is poured into a funnel tightly sealed into a jar. It does not pour through because of the pressure of air trapped inside. If the finger is taken off a hole in the lid the water pours through unimpeded.

R4 'Bird feeder' : A commercial bird feeder is filled and upended. The tray fills but no more water comes out.

Y1 'Magic finger' : A can full of water has three holes punched in the bottom and one in the top. Flow of water through the bottom holes is controlled by closing and opening the top hole with a finger.

Y2 'Sucking up a balloon' : An airtight jar has two tubes inserted in the lid, one with a balloon attached inside. Sucking on the other tube causes that balloon to inflate.

Y3 'Sucker' : A glass of cordial has an airtight lid with a straw inserted. It is difficult to get a drink through the straw.

Y4 'Cup and saucer' : A full beaker of water with a saucer on the top is turned upside down. The water does not come out, unless the water round the bottom of the saucer is sucked with a straw.

G1 'The sticky dart' : A rubber suction cap is pressed onto a tile. It is difficult to remove.

G2 'Fountain' : A straw is attached through the lid of a sealed jar which contains water to above the level of the straw. When air is blown through the straw, water spurts up once the mouth is removed.

G3 'Tricky cup' : A transparent cup with a tiny hole in the base is immersed in water and withdrawn, upside-down.

G4 'Linked syringes' : Two syringes are joined by a plastic tube. Pushing one in causes the other to be pushed out. Pulling has the opposite effect.

The role of the researcher and teachers in each of the sessions was to circulate amongst the groups, clarifying tasks, encouraging discussion and focussing the children's attention on the questions.

The transcripts from Session 1 showed the children to be quite capable of maintaining a consistent focus in their conversations, recasting and refining their explanations as they reported to the tape or to an adult. In the class reporting session, it seemed that the groups in general had come to a ready understanding of the idea of conservation of amount and volume of air. The explanations for the 'dry tissue' and 'sinking boat' activities were relatively consistent across groups, except that, in the case of the tissue, attention seemed to focus on ideas like 'water will not mix with the air', or 'the air is trapped', whereas in the case of the boat, ideas like 'the air is strong and pushed the surface of the water down' predominated. In order for an explanation to provide satisfaction, it is framed in such a way as to focus attention on the critical elements perceived in the situation; in the case of the tissue, the non-invasion of the water into the glass, and in the case of the boat, its depression by the air.

There were a number of instances of children, in reporting to the whole class, tending to focus on personal insights and experiments they had contributed to group understandings, rather than reporting on generalized understandings the transcripts showed they had achieved.

The transcripts from Session 2 were analysed in greater detail for the insight they gave into the way children used different ideas to explain essentially the same phenomena, and for the way these ideas were negotiated within and between groups.

The notion of differential pressure was quite difficult for these children, and their response to the activities tended to focus on other interpretations. Often they were content with simply describing the sequence of events. Even with further encouragement from teachers to explain, the explanations were sometimes very cursory, dealing with a descriptions of the apparatus and method, and elements of the result that were not at all central. Many children seemed preoccupied with the 'trick' aspects of the activities and the explication of the trick in many cases was viewed as sufficient explanation. There were, however, many examples of groups focussing usefully on generating explanations of these 'discrepant events', and it was possible with these groups to chart the development of ideas within the group, and across groups in the explication of ideas thus generated.

Explanation of events in terms of human action was not uncommon. The 'fountain' was explained as water being 'blown out', as was the 'cup and saucer' when a straw was used to blow air under the rim. Quite often the construction of explanations based on causal sequences, instead of superficial observations based on human action, or simple descriptions of how to make the event 'work', required close involvement of adults. This had not been true of the activities in the first session, where the explanatory concepts were much simpler. These are examples of 'premature closure' (Baird & White, 1982). The details of the interaction between the air and water were ignored, particularly the time lag between blowing and the spurt of water in the case of the fountain. One group explained the 'blocked funnel' in terms of the squeezing of the stopper by the flask rim, physically closing off the funnel. The explanation is consistent, but implausible if the properties of plastic (its rigidity) are considered. The question arises as to whether this inferior cognitive strategy is due to a lack of wider domain knowledge, or to an unwillingness to put inferences to a wider set of tests.

In more successful attempts at an explanation, the idea of the water being 'trapped' was used, just as the idea of air being 'trapped' appeared quite often. In the following exchange related to the 'cup and saucer', Dean shifts his focus substantially, with no apparent antecedents to his idea of the outside air exerting a force at the bottom.

D	The water didn't come out because... the top of the beaker there was air, and the bottom there was a plate.. and the water was trapped.	Presumably the water was squeezed between the air and the plate.... a superficial analogy based perhaps on the previous exercise where air is trapped in an upturned glass.
	... and later ...	
D	I think... I think water is trapped. 'Cos the air was at the top there, it was forcing it.	
RT	What was forcing what ?	
D	The air was forcing the water not to come out.	

Ten minutes later, RT returns and asks 'why didn't the water come out ?

C Because the air was all in it, 'cos we didn't take the plate off.

RT Right... so what difference does that make ? .... Dean, what do you think ?

D I think because the air was forcing it back in and the air was forcing it out and the plate was full of water.

RT So when you say the air was forcing it back in... which air do you mean ?

D Air all outside.

Clara considers the existence of the plate sufficient to explain why the water doesn't come out. Dean, however, has been widening his perspective in the meantime to include the air outside.

It proved very difficult for children to widen their perspectives on possible causative agents, beyond the immediately obvious elements of a situation. The outside air was rarely mentioned as a factor. Sucking was commonly held to explain why the card does not fall off the upturned glass, and this tends to be associated with the air trapped in the glass. One group held this view, but in order to test their hypothesis tried to run the trick through with no air by putting the card on underwater. They still found a bubble, and took this as confirmation of their hypothesis, associating the upward motion of the bubble with an upward suction force on the card.

K ... the air was at the bottom and when you tipped it upside down the air sucked up the card. It was like a magnet to it....

N ... the air goes the air bubble goes up to the top and we tried with one... we put the glass under water so we put the green plastic card on .....(? .. and it worked) .. we tried it full up to the top....

J ... the air always goes up, so when it's upside-down it sucks it up.

The magnet analogy was a persistent feature of Karen's explanation.

They associate the upward motion of the bubble with an upward force on the card

Children were quite capable of accomodating parallel views of events. In one of few explanations of the card trick in which the outside air was mentioned as a factor, some clinging to the 'sucking' theory is still evident.

E We think it's because the air is pushing up and keeping the card on and also the water is sort of sucking it.

The 'tricky straw' activity gave rise to an interesting pheonomenon. A few groups, observing spray coming from the holes in the straw, embellished this and incorporated it into their suction theory of drinking. Lindy explains the effect:

L The liquid kept on falling out the hole and .. um.. so she couldn't drink it very well. That's what I think.

Some time later, she is asked why the holes in the straw make a difference.

L	Is it when you suck in, all the air's going out.... When you can suck up all the air goes outside so the the air can't ... can't catch hold of the drink...	Confuses the direction of air in relation to the holes.
	.....when we try and suck up all the air goes out the holes.... I think	

This confusion about direction of air, evident above, is also a feature in explanations of the 'magic finger' and other tasks.

There were a number of instances of children maintaining an original explanation of a task despite appearing to have agreed with a contradictory view within the group. Clara, for instance, had acquiesced in an incorrect account of the 'magic finger', but in running through an explanation for her home group reverts to her original explanation, but adds an insight that didn't appear in the previous group; that of air at the bottom stopping the water coming through the holes. We can, perhaps, trace this back to Dean's explanation of the 'cup and saucer' task, to which she was a party.

N	What I think happens is that when you hold the top no water comes down because the air is trapped..Because of the water by that. But when you take your finger off there's air coming out so that's why the water falls through. Is that right Clara ?	Narelle associates the escape of air from the top hole with the idea of the water being trapped.
C	I'm going to say. In the top there's a hole. In the water there's three holes.. and ... the air is at the bottom stopping it ... the water.. when .. you put your finger on it.... like that. And when you take it off..... um... it allows the water to go through.	Clara does not take up Dean's explanation, although she appeared to agree with it at the time.

In this sequence Clara and Narelle give differing, if not contradictory views, yet do not acknowledge the difference and do not attempt a reconciliation.

Not only were inconsistencies between different children's explanations often ignored, but children applied their insights inconsistently across contexts. When Narelle demonstrates the 'fountain' and asks if anyone knows what is happening, Clara offers a very coherent explanation that nevertheless ignores her insight into the pressure of outside air :

C	I do... I do....When you blow air into the .... water there's lots of bubbles and when you get .... and the air in the water.....(interruption on another point, but Clara persists) ... when you blow air into it the air's trapped inside... and when it .... because your mouth sits there ... and when your mouth lets go it forces its way up....that's what I think and I'm brilliant.	Clara clearly acknowledges the idea of air trapped under pressure and released when the mouth is removed.

On the other hand, she is very quick to say 'The air's sucking it on', as the explanation for the upturned glass and card trick. Children seemed to craft their explanations according to their mental images of the salient features of the phenomena, and insights gained in one context were readily abandoned in another.

Many children, while giving explanations of the same phenomenon on different occasions, developed successive embellishments, some of which showed the ability to generalize the ideas very quickly to incorporate either a wider set of ideas, or a more complete explanatory sequence; 'filling in the gaps', as it were.

Children displayed a consistency in explanation from group to group. They tended to stick to an explanation, particularly if they had arrived at it and argued for it. If it was contradicted later, they tended to subtly accommodate new ideas rather than switch over immediately. Parallel explanations were sometimes resorted to, as in describing the water in the 'magic finger' being kept up by both the air outside and the air inside.

There were many cases of flashes of insight that had no obvious antecedents; they did not seem to come from anywhere in particular. At times, insights shown in one situation were not matched by comparable insights by the same child in related situations. This issue has been explored more fully in the current study.

THE CURRENT STUDY

The preliminary study uncovered a range of interpretive frameworks, but also clear differences in approach between year 2/3 and and a class of year 7 children from the same primary school with whom the tasks were also run. The year 7 children were both more efficient at doing and explaining the tasks, and more confident in assigning properties to air. To explore these developmental issues the study has been extended in Australia to run with children over a range of year levels (Prep (Age 5/6), Years 3/4, 5/6, and adult). Children were asked for written explanations of their first four tasks from the second session, as well as the first, .and several further written probes were used. The current report is based mainly on this written material. Selected children were interviewed after the second session, and again six months later to investigate the stability of their conceptions over time. Each of the schools used had a predominantly middle-class clientele, and in the case of the Australian primary classes, the children were accustomed to working in science in small groups. In a sense, then, the results can be expected to represent optimum performance levels for children at each age. The Australian and UK schools were from areas judged to be similar in socio-economic terms. The adults were primary school teachers taking a science unit as part of a post-initial qualification. This group was included later, to put into perspective some of the developmental trends discovered with the children.

THE LANGUAGE OF CHILDREN'S EXPLANATIONS

The SOLO taxonomy (Collis & Biggs, 1991, Biggs & Collis,1982), which offers a model for characterizing levels of sophistication of children's developing conceptions, and hence explanations, was used as the basis for an analysis of the children's written explanations. The principles on which explanations were assigned to the various levels, within the 'concrete-symbolic' mode of functioning, mainly hinge around the sophistication of causal notions :

1. Prestructural Non-acceptance of the problem. There is no sense of a causal relationship, and 'explanations' essentially amount to statements of the outcome of the task. In 'transitional' responses, a causal statement is attempted but is misconstrued :
   'The card stuck on'
   'It was hard to suck'.
   '... because we didn't push it down far enough'
2. Unistructural One reason only is given, without any mediating description of a sequence of causally linked events. This level of explanation indicates 'premature closure', and often a jumping to conclusions without sufficient attention to the details of the implied explanation. A transitional response would involve an attempt at a causal sequence :
   'It squashes the air and that makes it stick'
   'Our lungs are sucking the drink up'.
   'There is so much pressure that the lemonade can't help coming up the straw'
3. Multistructural A causal chain is given in the explanation, linking two ideas in a sequence. There is no attempt,

however, to raise the explanation to the level of a generalization:
'She sucks up the air and the water comes up after it'
'Water came out of the bottom of the container because air coming through the top allowed water to escape'.

4. Relational — Relational explanations extend relevant points to a general principle, or interrelationship between factors. The relations here would refer to general principles of the action of air on water, or that of the competition for space.
'When we blew through the straw we made the air pressure very high because there was nowhere for it to escape from. When we stopped blowing and took our mouth away, it was able to escape so the water spurted out the straw to get the air pressure back to normal'
'Air takes up space. By lowering the cup into the water, the trapped air, being a space taker, prevented water from entering the cup and wetting the tissue'

SOLO LEVELS OF CHILDREN'S WRITTEN EXPLANATIONS

Using the schema described above, the children's explanations were categorized for the 'dry tissue' and 'sinking boat' tasks (B3 and B4), and the four tasks (R, Y or G series) done by the group in the first part of session 2. The explanations of the preps were dictated to adults using a 'conferencing' procedure. The results are shown below. The numbers are presented as percentages of the total number of n responses at each year level.

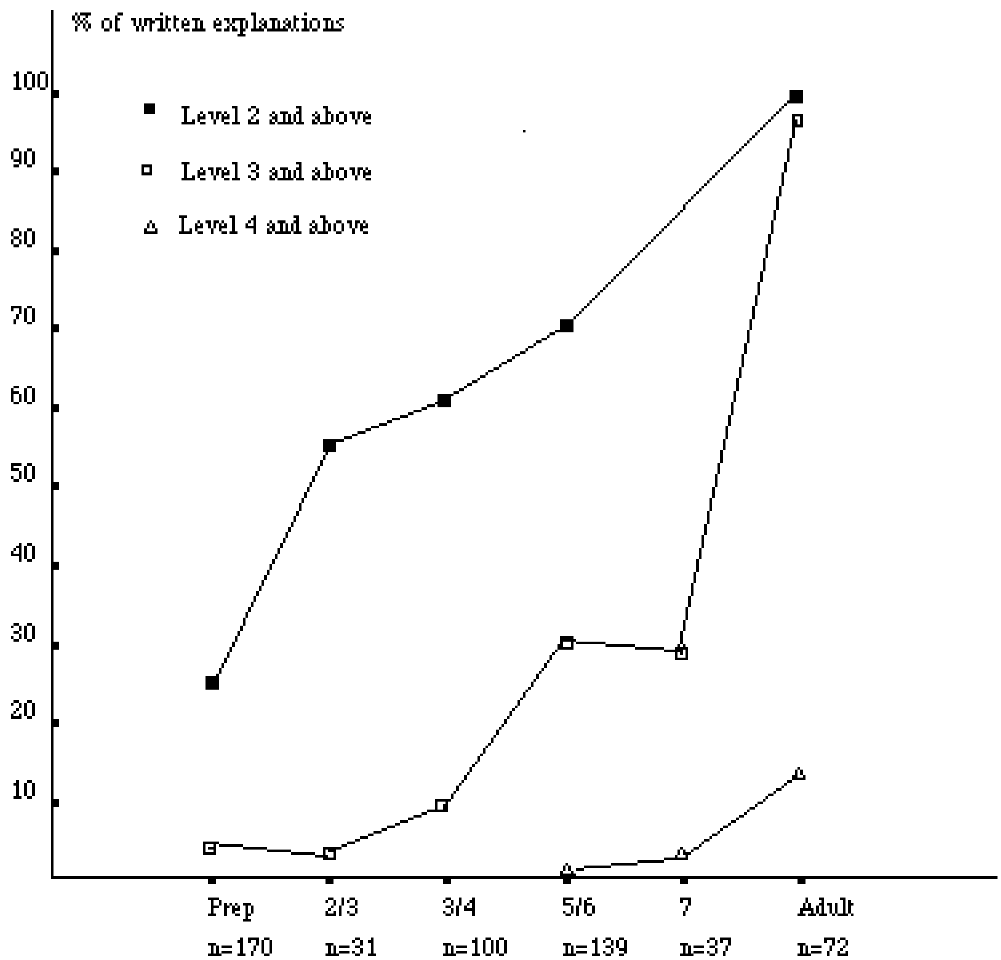

Figure 1. Percentage of children at each age using unistructural +, multistructural +, and relational SOLO levels of explanation

The table shows a marked developmental trend in level of explanation. This involves rather more than simply an increase in fluency of explanation; in 'getting better' at explaining. The taxonomy describes qualitative shifts in style of explanation. The older children, and especially the adults, are successfully using explanatory paradigms that the younger children are not attempting to use at all. The results support the contention (Biggs and Collis, 1991, Jones, Collis & Watson, 1993) that young children operate predominantly in the sensorimotor (associated with performance of activities) and ikonic (involving intuitive knowledge perceived as images) modes, and that these are used to support concrete-symbolic thinking in the earlier SOLO levels. Notions of 'trapping' or 'squashing', or 'sucking' are essentially ikonic, but could be seen as precursors to more abstract ideas of pressure and competition for space. The notion of cycles within the taxonomy, with higher order generalizations giving rise to further multistructural and relational levels (Levins & Pegg, 1993, Levins, 1992) has not been explored in this study, but if the study was extended into secondary school where children had been recently exposed to ideas of atmospheric pressure, and gas theory, one could well see that such a layered analysis may become necessary.

One of the problems in interpreting such a taxonomy is that the written explanation will be determined by a number of factors:

1. Knowledge/ understanding of science principles and ideas that impinge on the explanation, such as the nature of air, or force, or pressure.
2. Appreciation of explanatory forms in science (ie. the closeness of causal connections that constitute an acceptable explanation).
3. Judgment as to what is the appropriate level of explanation in the context.
4. Contextual factors such as time available, level of interest, writing skills etc.

The significance of the first factor, knowledge of science ideas, can be seen in the fact that level 1 explanations, for instance, persisted across all age levels, and individual children, while conforming to the developmental trend, often operated over a range of levels. It would seem that level 1 is used by even older children if they do not feel they have the relevant conceptual knowledge to offer a satisfactory explanation.

The distinction between factors 1 and 2 is a difficult one to make, and at a deeper level is bound up with the relationship between language and thought. An appreciation of notions like 'force' and 'pressure' would presuppose, for instance, familiarity with causal connections, and would make further causal connections possible. It is not clear, from this context, how much the trend identified above represents a developmental change in ‘domain-general’ factors such as notions of causality, or in ‘domain-specific’ knowledge such as of air and its behaviour (Carey, 1985). The trend in sophistication of explanatory form, identified here, is accompanied by increasing sophistication in conceptions, involving notions of force, pressure, and the competition for space.

Socio-cultural factors would also come into play. Children, as they participate in the schooling process, become increasingly familiar with acceptable forms of explanation. It could be that exposure with age to an increasing presumption of having to justify one's ideas leads to greater facility with and acceptance of explanatory principles. This occurs, for a child, both in the context of interaction with adults, and also with peers. It was noticeable, for instance, that prep. children did not interact conceptually with each other to any extent, but tended to talk along 'parallel tracks'. The notion of workshopping explanations to come up with a group consensus appeared alien to them. The adults, on the other hand, workshopped ideas seriously and did not reach agreement until a range of ideas had been explored. They seemed much more willing to withhold satisfaction with an explanation until they had reached a coherent causal link utilizing higher order principles.

A number of studies have explored 'misconceptions' held by primary teachers. This group of adults also displayed 'misconceptions' about the behaviour of air, but they had a very different approach to generating new conceptions compared to primary school children, operating at a much higher level of linking principles and reflecting on implications, with a much greater knowledge base. The result is, of course, by no means translatable to adults in general. These adults are self-selected in terms of educational attainment and entry to the unit, and also have a wealth of experience in learning that primary school children do not have access to. With regard to conceptual change in science, however, the difference with adults highlights the fact that 'alternative conceptions' younger children hold should not be seen in isolation from understandings about and experience with the nature of science explanations, and of the way scientists make sense of the world.

With regard to the issue of contextual factors, there is some evidence that the SOLO level is to some extent an artefact of the writing process. For the grade 3/4 children, for whom an analysis of transcripts has begun, the level of the written explanation tends to be below that of their verbal explanations. (There are also cases where the written explanation is more sophisticated than anything said within the group.) There were a number of cases where children had offered a number of complementary perspectives on the same task during the group negotiation of an explanation, yet in their written explanation offered only one of these, not necessarily the most sophisticated one. This richness of verbal compared to written explanations would support Barnes' (1976) contention that exploratory talk in the classroom is a powerful encouragement for idea generation. It could be that the act of formal commitment to an explanation has the effect of reducing the conceptual range. Physical problems associated with writing are probably not significant, since these were removed for the prep. children by the conferencing process, yet their explanations remain at a low SOLO level.

THE ‘LINK’ PROBE : PERCEIVED SIMILARITIES BETWEEN TASKS

The ‘link’ probe consisted of a worksheet displaying series of ikons, each representing one of the twelve tasks. Children were asked to join with a line, or branching lines, tasks in which ‘something similar is happening’. They were asked to write a brief reason for each link. Again, a conferencing procedure was used with the preps. There was a difference in the number of links children identified, and in the style of the reasoning they used to justify these links. The justifications were categorized using a four-point scale :

Level A : Based on physical similarity of equipment. (‘They both have straws’)

Level B : Based on the nature of personal action. (‘We used a finger to block a hole in these’)

Level C : Based on situational similarity with respect to equipment or matter. (‘Air is trapped inside’, ‘they stick’, ‘water comes out’)

Level D : Based on the identification of an underlying principle. (‘Air pushes’, ‘air is used to lift water’, ‘hard to pull because air wasn’t getting in’)

Using this scale, the children’s responses were analyzed and expressed as a percentage of the total recorded responses. In the graph below, L is the number of links described.

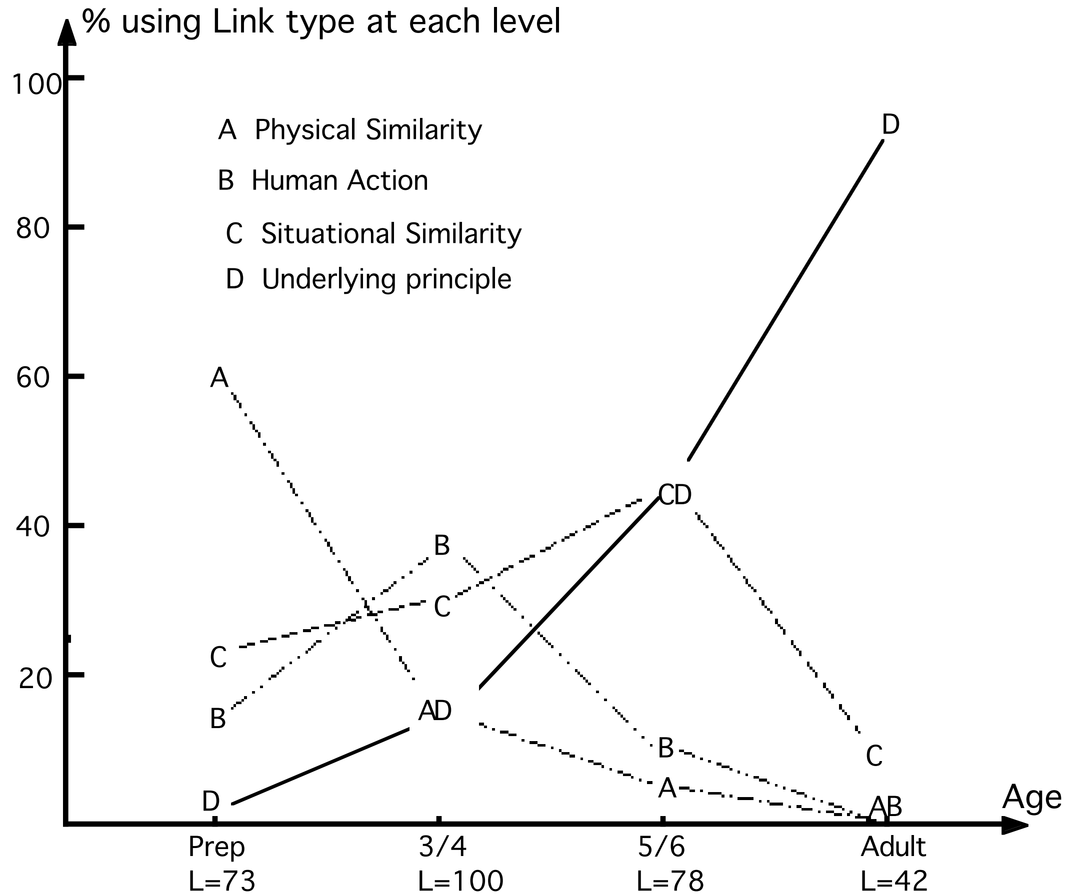

Figure 2 : Percentage at each age level linking tasks at different levels

Quite clearly, none of the preps are looking for links based on principle, while this is becoming a significant aspect of the links made by the 5/6s. Conversely, by 5/6, children do not see physical similarity or human action as being an appropriate basis for linking the tasks. It could be

- they have access to knowledge schemata (properties of air, pressure) that younger children do not, which enables them to see relationships.
- they have a greater awareness of fruitful ways to look at phenomena, and of the limited usefulness of A and B levels of operating
- they are more able, or prefer, to operate at an abstract, ‘relational’ level. We see this as related to Gentner's (1988) work showing

adults' preference for relational metaphors, compared to children's preference for 'attributional' (based on mere appearanced) metaphors.

It seems likely that all these factors would be operating interdependently.

EXPLANATORY CONCEPTIONS USED BY CHILDREN OF DIFFERENT AGES

Nine explanatory conceptions ('interpretive frameworks') were identified in the preliminary study, and these were extended and refined following analysis of children's written explanations in the current study. The following list places these conceptions in a rough order of increasing sophistication :

1. Description of observations (the water spurted out)
2. Human agent (because we blew hard)
3. Intentionality attributed to objects (the air wanted to escape)
4. Unfocussed references : to 'air' (the air made it happen)

4A. to water as a causal agent (the water blocked it)

5. 'Trapped' image (the air and water were trapped in the can)
6. Movement of air (the air couldn't circulate and so couldn't push)
7. Action of enclosed air : force (the air in the jar forced the water out)

7A. suction effect (the air under the dart sucks it onto the surface)

7B. pressure reduction/creation (by blowing we increased the pressure)

8. Action of outside air : force (the air pushed against the dart)

8A. pressure (the pressure from the outside air held the card in place)

9. Competition for space (the water can't get out unless air can get in to take its place)
10. Differential pressure (the outside air presses harder than the air and water inside)

This list is more complex than, but is not inconsistent with, the 'alternative frameworks' identified by Sere (1982), Engel, Clough & Driver (1986) and Brook & Driver (1988).

By examining the written explanations for session 2 it was possible to analyze the extent to which different age levels favoured particular conceptions. While a listing of the use of individual conceptions indicated a complex interaction between tasks, groups and year levels, a banding of conceptions according to whether they are

Pre-explanatory (conceptions 1, 2 and 3 which are not explanations in any real sense)

Intermediate (conceptions 4, 5 and 6 which represent images and generalized statements that do not really address any real causal notion that would be scientifically acceptable)

Advanced (conceptions 7 - 10, which involve conceptual entities such as force, pressure or notions of competition for space, and would be acceptable in some form as explanations)

showed a clear developmental trend.

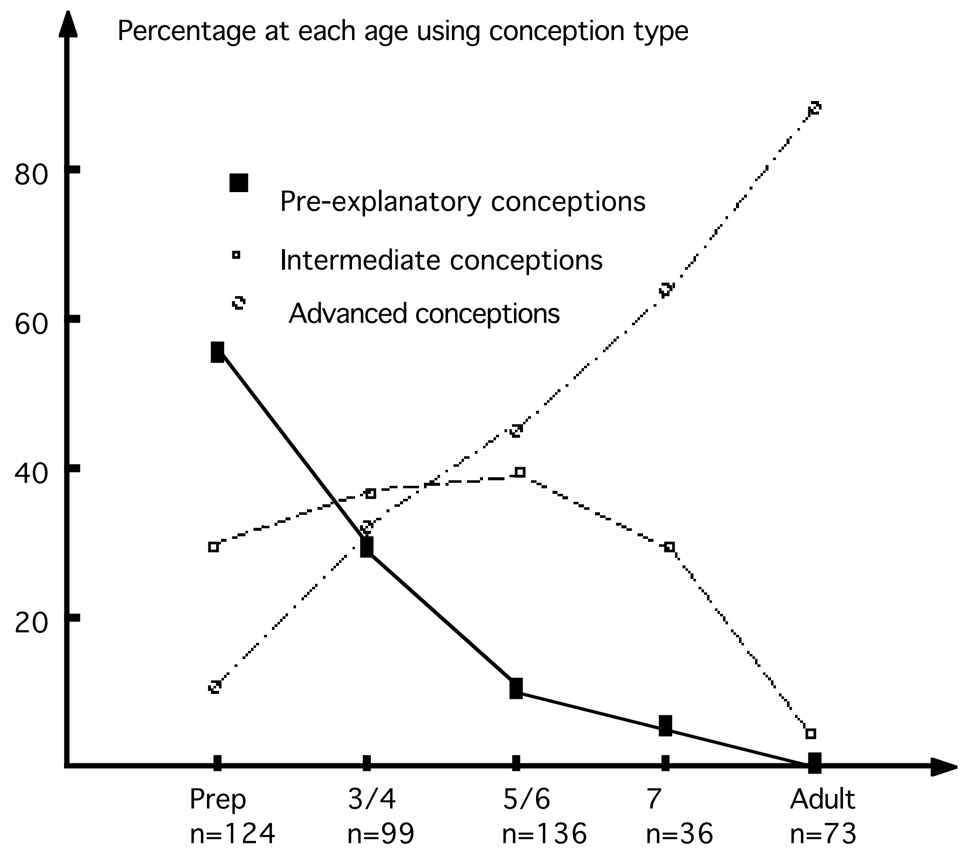

Figure 3 : Prevalence of different levels of conception with age

There is a clear reversal of preference between the prep and 5/6/7 and adult cohorts, as children move toward higher level conceptions that involve more sophisticated ideas (force, space) and are more generalizable across a range of tasks.

CONSISTENCY OF USE OF CONCEPTIONS

Theories in science are judged according to the principle of parsimony, whereby a preferred theory contains no redundant ideas, and operates across a wide range of contexts. Children's science, on the other hand, is held to be opportunistic and redundant, with different conceptions generated for each context without regard to consistency. Children's written explanations were analysed for consistency, across the five or six tasks for which they were generated. Individual children were scored according to how many times a conception was used more than once. A conception being used for three tasks, for instance, scored a consistency rating of 2, as did a case where two conceptions were each used twice. Only conceptions 5 - 10 were counted in this way, since it was felt the more primitive conceptions are not specific enough to warrant a fair comparison. Conceptions 7, 7A and 7B, and, separately, 8 and 8A, were counted as equivalent, since they involve a similar way of looking at the phenomena. The result is shown in Table 4. The numbers are small, because in many cases children (and adults) failed to generate explanations for more than four tasks..

Cons.rating Yr. level	0	1	2	3	4	5	Average consistency
Prep	7	1	0	0	0	0	0.1
3/4	9	3	1	1	1	0	0.8
5/6	6	3	5	6	0	0	1.5
Adult	0	0	0	2	2	2	4.0

Figure 4: consistency with which conceptions are used, with age

The reason for a general trend towards greater consistency with age seems to be twofold. Clearly, since the younger children did not have access to the more advanced, generalizable conceptions, they could not display consistency of use. With age, children gain access through greater knowledge and experience to more powerful ways of looking at the way air behaves. At the same time, they are actively looking to apply their explanations more widely across contexts. This was apparent during interviews with the children, when the 5/6 interviewees were clearly more interested than the 3/4, and certainly the prep children, to use their conceptions more consistently. This is also born out by the result on the 'link' probe, where older children looked for links between tasks based on explanatory principle rather than physical equipment or human factors. Observations of the way children were discussing their explanations in groups also highlighted the fact that the grade 5/6 children explicitly looked to use conception 9, the 'competition for space', across a variety of tasks. Conceptions 7B and 9 were, in fact, used with the greatest overall consistency.

The low consistency score for all these classes is due to children generating a range of interpretive conceptions that are quite fluid in the way they apply these across contexts. While the older children are looking to apply their ideas more consistently, they do not do so completely. Even after mastering a generalizable conception as it applies to a subset of the tasks, children hung on to more primitive conceptions to explain others. In the interviews, children who had mastered the notion of atmospheric pressure in some contexts failed to respond to specific prompts to apply the idea more generally. These tasks are all linked by the scientific idea of differential pressure, yet the children do not see them as linked in any consistent way. The linking they do occurs at a variety of levels, with interrelated conceptions being called upon to deal with the different contexts. These children do not operate with a set of beliefs ('alternative frameworks') about the behaviour of air that are applied consistently across a wide range of contexts. The relationship between conceptions, and contexts, could be represented by Figure 5 below. Each conception may be used in one or two contexts, but as children develop, the number of contexts to which the more advanced conceptions apply increases.

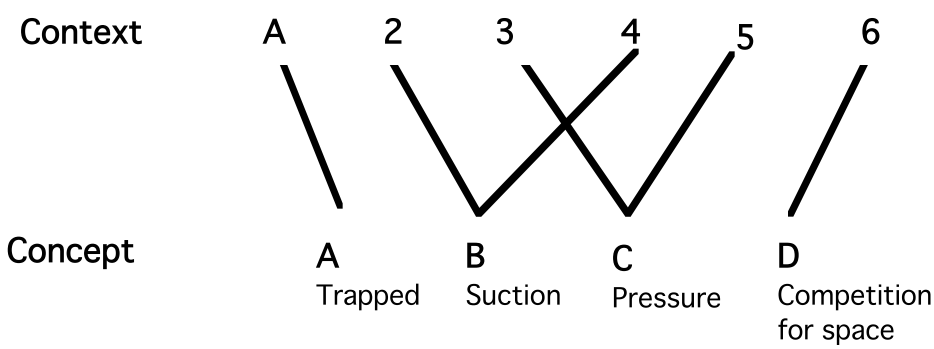

Figure 5 : Model of the application of explanatory conceptions across a range of contexts

THE ROLE OF DOMAIN-SPECIFIC KNOWLEDGE IN CHILDREN'S CONCEPTUAL DEVELOPMENT

Carey (1985a, 1985b) characterizes children's conceptual development as being determined by a growth in domain-specific knowledge, and it is clear that the dimensions along which children develop, identified in this study, all have as a large contributing factor knowledge of the way air behaves. Prep and grade 3/4 children, for instance, were given a probe in which they were asked to identify where, in a room, air would be found. The prep children tended to be unsure of the status of air in open, and closed jars, and in cupboards and other enclosed spaces. The 3/4 children had no such problems. The prep children had much greater difficulty, therefore, in framing explanations in terms of enclosed air. Grade 2/3 children were not so hampered in ascribing the existence of air to containers and enclosed spaces, but frequently made errors in explaining the direction of air flow in and out of holes. Such errors were rare with the 3/4s, and never occurred with the older children.

Brook & Driver (1988) identify a sequence in which knowledge of the properties of air develops over the ages from 5 to 16, and these correspond closely to the nature of explanations used by children in this study. They found that the idea of air exerting a force was prevalent even in young children, but the idea of air taking up space was held by the majority only from 8 years on. The idea of a vacuum, which is a more difficult concept than that of air taking space, is achieved by one-third of 12 year old children, and this would coincide with the increased use of conception 9, competition for space, by the 5/6 children. That conception is equivalent to the idea that 'nature abhors a vacuum'. The infrequent use of the idea of outside air pressure, markedly more common in the adult group, coincides with Brook and Driver's contention that the idea of an external atmosphere does not begin to take hold until the age of 12. There would seem to be a direct link, then, between domain-specific knowledge of air and the type of explanations that these children construct. Increase in knowledge in other domains, such as recognition of the idea of force, would also impinge directly on children's ability to construct explanations, and indirectly in that it would go hand in hand with greater sophistication in applying causal reasoning and in identifying the types of links and ideas that will prove powerful in constructing explanations. This parallel development in a range of aspects of children's explanations is explored in Figure 6.

Age/ grade	Knowledge	Conceptions	Explanations	Links	Consistency
5 Prep	Unsure recog. of air	Pre-explan. & intermed.	Sensorimotor /ikonic	Physical similarity	Opportunistic
7/8 2/3	Air recognized, not direction		Ikonic/ uni-structural		
8/9 3/4	Air takes up space. Pushes/sucks	Spread equal pre-expl.-conceptual	Uni-structural concrete-symbolic	Human action/ situation	More sophistic. but inconsistent
10/11 5/6	Force, pressure, suction, vacuum	Intermediate/ Conceptual entities established	Uni/multi-structural	Situation/ principle	Generalizable ideas increasingly used.
Adult	Ideas more established, wider ranging	Conceptual entities used consistently	Multi-structural/ relational	Principle uniformly sought	Parsimony an important issue.

Figure 6: Parallel growth in a range of factors contributing to the construction of explanations

CONCEPTIONS GENERATED DURING GROUP DISCUSSIONS

A preliminary analysis of the year 3/4 transcripts supports the findings of the preliminary study. There were many instances of children experimenting to test hypotheses, citing incidental observations to support preconceived ideas, refining their explanations over the course of a short discussion, and making unexpected leaps of understanding. Often ideas were generated so fast, and were sufficiently loosely expressed, that children who had appeared to agree carried away quite different interpretations to the second group. The dominant impression from the transcripts was one of the social nature of the learning. Focussed exchanges of ideas seemed to occur in a pattern, being often preceded by long periods of discussion of how to set up the task, of what they were looking for, of who should go next or play fast and loose with the water etc. The exchange of ideas was to varying degrees cut short by premature closure, where the group agreed on a low level explanation without challenge ('it's because of the air'), or simply failed to recognize the problem ('the water does come out of the bird feeder, into the tray'). Premature closure has been codified in the lower levels of the SOLO taxonomy as a pre-concrete-symbolic mode of operating. The generation of a high level explanation seemed to depend on one or two members being willing to keep asking the relevant question (Why does it do that ?). In this respect, the presence of the teacher was instrumental with a number of groups in pushing their ideas further, by simply focussing their attention on the relevant question, and requesting clarification of responses. The way the teacher acted in this study was similar to Viennot's (1992) idea of a teacher 'parachuting in' to group discussion to clarify and challenge. This has implication for the size of science classes in which activity based groups can effectively operate.

Some groups were particularly effective at generating explanations, with at least two or three of the group actively contributing ideas. Some individual children seemed particularly creative in generating ideas, and would develop multiple conceptions for the same task over the period of a discussion. Noel, in a discussion of the magic finger, developed the following ideas during the session :

- ..no air can get in because the water's there and ... covering the three holes down the bottom so no air can come up by bubbles
- the air is kind of trying to push the water ... up.
- I don't know exactly why but I know it does that because I've done it with straws

For his written explanation :

- the air couldn't get in. So the water didn't come out.

and in explaining this task to the second group :

- no air could get in from the bottom because the water is trying to go down

and in response to the teacher probing whether air has to get in for the water to go down, he sharpens his explanation to make explicit the principle for competition of space.

- because with the air in here the water is at a certain level.... if the water goes down... it needs more air to fill up that space

and when challenged to explain why it works with straws

- the air is at a certain level, and so is the water, and so, in other words, the air can't get bigger.

In a written probe, Noel selected as the best explanation, ahead of any notion involving force, or competition for space :

- With the hole at the top closed, the air and water are trapped in the can.

In another group, Greta is discussing R2, the upturned glass :

- it sticks to it. It holds the water in.. why does it do that ?
- do you think the air is holding it up ?
- it's holding it in with the air sort of stuck to it
- the air's suctioning it up ... so why is it staying there and holding all the water ?

and in response to the teacher arriving and asking how the air does that :

- .. well... there's water in there... yeah and there's air and so the air kind of must be making a cushion sort of between them both.

and when challenged to explain why the card falls off if no water is used:

- water and the air sort of trapping.. the water and the plastic are sort of trapping the air when it has water there sort of... so like no water the air can just press it down

The idea of a cushion was used again in other tasks. In her written explanation :

- with the air and the water together the air formed a cushion between the water and the card.

These children are developing a number of parallel conceptions; of the competition of air and water for space, of force, of suction, of air being trapped or acting as a cushion. Their ideas are not fully resolved at the end of these exchanges. Noel in fact uses the idea of air and water exchange to explain a range of the other tasks. Perhaps the generation of such 'multiple perspectives' is a necessary part of the solution of any problem, and a sophisticated understanding of a phenomena lies in the ability to recognize there are a range of ways of looking at it. The relationship between conceptions and contexts may therefore be better represented as :

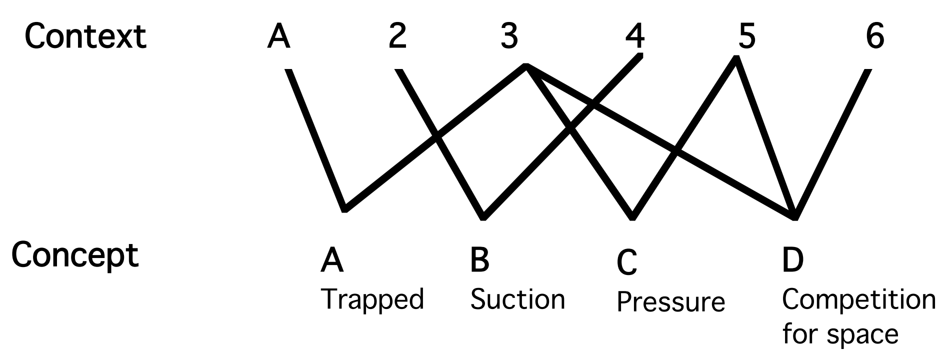

Figure 7: Multiple perspectives applied to a single context

Brook & Driver (1988) found that older children in particular were likely to generate and consider a range of alternative explanations for observed phenomena. This was true also of the adults in this study. Practising scientists would recognize many of these ideas (competition for space, trapping of air, pressure, force, even suction) as legitimate and useful in explaining these phenomena. They tend to be subsumed under the most powerful ideas once these are mastered, but they have their use as alternative ways of looking at things. The term 'situated cognition' has been used to refer to the fact that we all have alternative ways of seeing in different contexts. Learning science, in this view, is not so much a matter of changing conceptions as learning to distinguish contexts in which particular conceptions are valid (Solomon, 1983). These 'multiple perspectives' are a powerful problem-solving tool, but they may act as impediments to the understanding of new situations unless their limitations are recognized. Could it not be, however, that an important focus of science education should be the support of the generation of such multiple views about the world, just as much as the promulgation of exclusive and internally consistent theoretical structures ?

DISCUSSION

This study has identified a number of dimensions on which children develop in their ability to construct explanations of scientific phenomena, over the primary school years. With age, children display:

- increased tendency toward more complex and reasoned explanatory forms (as measured on a SOLO scale)
- increased use of higher order, 'generalizable' conceptions
- increased tendency to apply conceptions consistently across contexts
- a preference for higher order links, based on underlying principles

These dimensions operate interdependently in determining children's ability to generate science understandings. Though the results reinforce the notion that children are very opportunistic in the way they use conceptions in a variety of contexts, an underlying trend has been identified in which children move from the utilitarian and opportunistic mode of 'children's science' toward the more generalizable, parsimonious notions characterizing 'scientists' science'.

In terms of conceptual change, the picture that seems to emerge for individuals is one of gradual conceptual advance, with increasing use of higher order, generalizable conceptions and the gathering of an increasing number of contexts under these conceptions as they learn to use them more generally. Even after children have achieved a shift to a 'scientific' conception, they do not automatically apply it to the full range of relevant contexts, but need to learn to use it to replace earlier ideas used successfully in particular contexts. The study does not contradict the notion of conceptual change involving 'radical restructuring', and Carey's notion of domain specific factors being the key to such conceptual change is in fact supported by this analysis. What is called into question is the view that such conceptual revolutions involve a shift from a theory-like 'alternative', to a 'scientific' framework, and that this shift is applied simultaneously across a range of contexts.

REFERENCES

Baird, J.R. & White,R.T.(1982). Improving self-control of learning, Instructional Science, 11, 227-247

Barnes, D.(1976), From Communication to Curriculum, Middlesex, Penguin Books

Biddulph, F. (1983). Students' views on floating and sinking, Working paper No. 116 of the Learning in Science Project (Primary), University of Waikato: Centre for Research in Science Education.

Biggs, J. & Collis, K. (1982) Evaluating the quality of learning: The SOLO taxonomy, New York: Academic Press

Bloom, J.(1992). The development of scientific knowledge in elementary school children: A context of meaning perspective, Science Education, 76(4), 399-413

Bloom, J. (1990). Contexts of meaning: young children's understanding of biological phenomena, International Journal of Science Education, 12(5), 549-561

Borghi, A., De Ambrosis, C., Grossi, M. & Zoppi, D. (1988). Knowledge of air: A study of children aged between 6 and 8 years, International Journal of Science Education, 10(2), 179-188

Brook, A. & Driver, R. (1988) Progression in science: the development of pupils' understanding of physical characteristics of air across the age range 5-16 years. University of Leeds: Children's Learning in Science Project

Carey, S.(1985a). Are children fundamentally different kinds of thinkers and learners than adults?, in Chipman, S, Segal, J. & Glaser, R., Thinking and learning skills Vol. 2, pp 485-514, New Jersey: Lawrence Erlbaum

Carey, S (1985b) Conceptual change in childhood, Cambridge, MA: MIT Press

Carey, S. (1986) Cognitive Science and Science Education, American Psychologist, 41, (10), 1123-1130

Champagne, A., Gunstone, R. & Klopfer, L. (1982). Cognitive research and the design of science instruction. Educational Psychologist, 17, 31-53

Collis, K. & Biggs, J. (1991) Developmental determinants of qualitative aspects of school learning. In G. Evans (ed.) Learning and teaching cognitive skills., Melbourne, ACER.

Donaldson, M. (1978). Children's minds, New York: Fontana/Collins

Driver, R.(1992). Progression in students' science conceptions: Research findings and their implications for curriculum planning. Paper presented at the conference of the Australasian Science Education Research Association, Hamilton, New Zealand

Driver, R. (1989) Students' conceptions and the learning of science. International Journal of Science Education, 11, 481-490

Driver, R., Guesne, E. & Tiberghien, A. (1985). Children's ideas in science, Milton Keynes: Oxford Univ. Press.

Engel Clough, E., Driver, R. & Wood-Robinson, C.(1987). How do children's scientific ideas change over time?, School Science Review, Dec., pp 255-267

Engel Clough, E. & Driver, R.(1986). A Study of consistency in the use of students' conceptual frameworks across different task contexts, Science Education, 70(4), 473-496.

Gauld, C. (1986). Models, meters and memory, Research in Science Education, 16, 49-54

Gentner, D. (1988) Metaphor as structure mapping: the relational shift. Child Development, 59, 47-59

Jones, B., Collis, K. & Watson, J. (1993) Towards a theoretical basis for students' alternative frameworks in science and for science teaching. Paper presented at the conference of the Australasian Science Education Research Association, Lismore, Australia

Levins, L. & Pegg, J. (1993) Students' understanding of concepts related to growth. Paper presented at the conference of the Australasian Science Education Research Association, Lismore, Australia

Levins, L. (1992) Students' understanding of concepts related to evaporation, Research in Science Education, 22, 263-272

Mitchell, I. & Baird, J. (1986). Teaching, learning and the curriculum-1: The influence of content of science, Research in Science Education, 16, 141-149

Osborne,J & Freyberg,P (1985). Learning in science: The implications of children's science, Auckland, Heinemann.

Posner, G., Strike, K., Hewson, P. & Gertzog, W.(1982) Accommodation of a scientific conception: Toward a theory of conceptual change, Science Education, 66(2), 211-227

Sere, M. (1982). A study of some frameworks used by pupils aged 11-13 years in the interpretation of air pressure, European Journal of Science Education, 4(3), 299-309

Solomon, J. (1983) Learning about energy: How pupils think in two domains, European Journal of Science Education, 14, 49-59

Tytler, R. (1992). Children's explanations of air pressure generated by small group activities, Research in Science Education, 22, 393-402

Viennot, L (1993), Pedagogical outcomes of research in Science Education: Examples in mechanics and thermodynamics, Monash University Centre for Science, Mathematics and Technology Education, Writing workshop (in press)

Vosniadou, S. & Brewer, W.F.(1987) Theories of knowledge restructuring in development, Review of Educational Research, 57, no.1, 51-67

West, L. & Pines,L. (1984). An interpretation of research in conceptual understanding within sources-of-knowledge frameworks, Research in Science Education, 14, 47-56

White,R.T. (1987). The future of research on cognitive structure and conceptual change, Paper given at a meeting of the AERA, Washington D.C.

TABLE OF RESULTS FOR 'LINKS' GRAPH

Year level Type of link	Prep.T n =27 L = 73	3/4L n =21 L= 100	5/6T n =25 L = 78	Adult n =15 L = 42
A . Physical similarity	59	16	5	0
B. Human action	16	37	8	0
C. Situational similarity	25	31	42	7
D. Underlying principle	0	16	45	93

SOLO LEVELS FOR EACH AGE GROUP, FOR FIGURE 1

Year level SOLO level	Prep. n=170	2/3M n = 31	3/4L n= 100	5/6T n= 139	7M n = 37	Adult n = 72
1. Prestructural	39	35	20	7	5	1
1A. Transitional	36	10	19	11	3	0
2. Unistructural	19	42	49	37	46	2
2A. Transitional	2	10	3	15	19	1
3. Multistructural	4	3	6	23	22	44
3A. Transitional	0	0	2	5	3	38
4. Relational	0	0	1	1	3	13
4A. Transitional	0	0	0	1	0	0
% at level 2 or above	25	55	61	82	92	99
% at level 3 or above	4	3	9	30	28	96

Age level Explanatory level	Prep T n=124	3/4 L n = 99	5/6 T n= 136	7 M n = 36	Adult n = 73
Pre-explanatory	56	30	10	6	1
Intermediate	29	37	40	30	5
Advanced	11	32	45	64	88
Uncodable	4	1	5	0	5

FIG 3: CONCEPTIONS USED AT DIFFERENT AGE LEVELS