PSYCHOLOGY 210

MENTAL MODELLING IN CHILDREN : Some Discussion, Empirical Investigations and Hypotheses.

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Preamble

In seeking out possible areas of research and study for my doctoral dissertation, I have become interested in the developing field of "mental modelling", particularly as it relates to the domain of Science. There are three questions in particular that I am focussing my attention on at present :

1. How do people - novices and experts - acquire and represent scientific knowledge ?

2. How do changes occur in the shift from being a novice to being an expert in adults (secondary school or undergraduate students) ?

3. What changes take place in mental representation as a child novice grows and develops into an adult expert or novice ?

This paper discusses aspects of these questions based on reading "Mental Models" (Johnson-Laird, 1983) and also the research reports brought together in the other "Mental Models" book (Gentner and Stevens (Eds.), 1983). In addition, I have endeavoured to carry out a few simple empirical investigations with my daughter (Leonie, aged 5:7 years). These are often repetitions of investigations carried out by others.

In my discussion, I raise questions, give interpretations of investigations, and make hypotheses in attempting to master the topic more fully. Hence any comments, criticisms and pointers for possible future study or research would be appreciated.

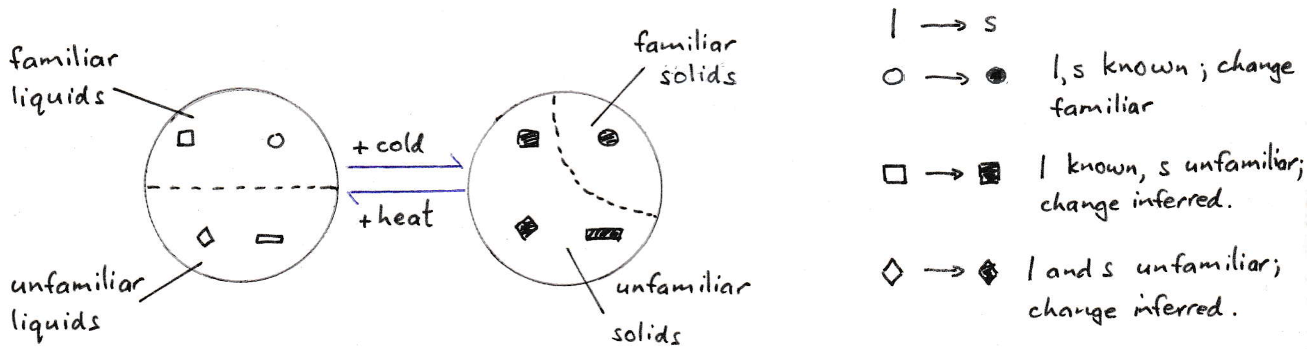
Investigating a change of state

The purpose of this investigation was two-fold : (1) Using familiar situations, what knowledge did Leonie (and her younger brother aged 3:9) have regarding the change of a solid into a liquid and vice versa?, and (2) what model might be proposed to account for such knowledge?

Two situations were used. In the first, a block of ice was placed into a glass of water, and at another time just placed on a plate. In response to questioning, both children were able to state that the ice would eventually change into water. When asked if we could get the ice back again, both replied that we could put the water into the refrigerator. At first the word "melt" was not used but with later questions, both children spontaneously used this word. "Freeze" was not used, nor were the terms "liquid" or "solid". In the second situation, a popsicle was used instead of an ice block. Both children were able to state that the popsicle would change into juice when taken out of the freezer; putting juice into the freezer would reverse the process.

When asked for a causal explanation for melting and freezing, Leonie was able to talk about heat (from the air/sun) to melt the ice and "adding cold" to reverse the process. She did not give any hint of an animistic explanation nor a psychological explanation (in terms of beliefs or wants). When asked about other liquids, even ones she had not seen in the frozen state, she was able to make correct inferences. Gavin however did not seem able to give any causal explanation.

A possible mental model representing the phenomena investigated is as follows:-



This is a simple causal, physical model in which the mental entities are concrete and match directly observable entities in the world. Such a model is probably at a functional level adequate for the world of a 5-year old. A more abstract model with entities related to chemical concepts of matter and energy would not be needed (for most adults too as well as a 5-year old!). It is interesting to note that Larkin (1982), in her studies of novice undergraduate Physics students, found that the entities in their models of force and movement were concrete and tied to specific real-world objects.

According to Piaget, a 5-year old is in a pre-causal state. Not until the child has developed a Boolean-logic system of representation is reasoning /logical inference possible. In reaching such a conclusion however, many of Piaget's problem tasks were related to unfamiliar events, eg. operation of steam engines, with which children had had no direct contact. Also Piaget's

Agreed. But there's a lot lurking in the notion of cause, i.e. it should support counterfactual conditionals such as "If the ice hadn't been heated, it wouldn't have melted" -- a stronger form of assertion than a mere a[illegible]e correlation, and certainly not a relation that can be captured in the propositional calculus!

In what sense of "abstract"?

criteria for causality were too stringent - he wanted explanations that were essentially correct. But with the Mental Model paradigm, formal logical inference is not necessary. Based on her observations of the world alone, Leonie, with the help of her physical mental model, was able to give an adequate causal explanation for changes of state.

Did you check for a grasp of causality supporting counterfactual relations?

A suggestion for future change of state investigations with children is to look at the liquid to gas change. How would children cope with the generally invisible gaseous state ? Conventional experiments involving heating water and using a cold glass surface to condense the steam could be used. In addition, demonstrations involving "real" condensation - such as breath on a window in winter - might be useful in order to compare the kinds of models generated from experiential knowledge with those formed by observing laboratory - type demonstrations. Such findings would have implications for teaching.

<u>Biological knowledge and representation</u>

Various researchers (eg. Gellert, 1962; Carey, 1985) have investigated the kind of biological knowledge developing children possess. Thus Gellert attempted to find out children's knowledge of the internal parts of the body and of bodily processes such as digestion, respiration, and reproduction. Carey has repeated these investigations and tried to give an account of how the knowledge acquired before age 10 is restructured in the evolving domain of biology.

These investigations show that a 5-year old can name, on the average, only three internal parts of the body while the typical 9-10-year old can name eight. Preschoolers think of the body in terms of what goes in and comes out. e.g. food, blood, bones(because these can be felt). Until about the age of 8, children know little about physiological processes - they do not have any model of what mediates the input and output in, say, digestion.

How does Leonie compare? In repeating the methods used by Gellert and Carey, she was asked to name internal parts of the body and to draw a picture showing where these parts might be located.(See attached drawing.) Apart from knowing more parts than children in other studies there are several important differences. She said blood but did <u>not</u> say 'food' which many 5-year olds give as something found inside them; she was apparently able to generate a model not just in terms of what goes in or comes out. The heart was not put in some out-of-the-way place as is done by many others. The stomach was named as a specific organ and not as an ambiguous term referring to the abdomen as well. Young children seem to know stomach only in the ambiguous sense and do not list it or draw it as one of the things found <u>inside</u> a person.

In contrast to changes of state involving say ice and water, the internal organs cannot be observed directly and so are abstract concepts to the young child. If it is correct that a 5-year old can only build physical models with entities relating to concrete objects, then such a child would not be able to generate an adequate model to provide a framework for inferential processes. Could 5-year olds with appropriate experiences with internal organs - say a child who lived on a chicken farm and regularly saw the birds being gutted - have a more adequate representation of the inside of the body? This could be checked empirically but two aspects rather than one would need to be investigated, viz. whether or not the child has a mental model for the inside of a chicken, and if, by analogy, the child would attribute similar organs to a human.

Gellert and Carey have found that the 5-year old's understanding of physiological processes such as digestion are limited. Explanations are usually couched in psychological terms such as wants or beliefs rather than in biological terms. Comments such as "I eat because I am hungry" or "If I don't eat, I will die" are typical. Leonie gave similar responses to questions about why we eat and what happens to food when eaten, though in addition she did know that the food went into the stomach. It is interesting to note that for the process of reproduction, children in Sweden had an understanding of the process that is 2-3 years ahead of their American counterparts. Clearly the conceptual world in which children are immersed and grow up in is an important factor in the acquisition of mental representations.

Agreed. It has to be so. Before Harvey no-one knew that blood circulated, and if you live in a 'culture' that does not know, you won't know.

Knowledge of projectile motion

McCloskey (1983) has investigated the kinds of knowledge undergraduates (some with and some without previous Physics) have acquired through experience with moving objects. He was interested in the solutions given by the subjects to a series of simple non-quantitative problems. In one problem the subjects were shown a diagram of an aircraft flying horizontally. A metal ball is dropped and the subjects were asked to draw the path the ball would follow from the time it is dropped until it hits the ground. Sixty percent of the subjects got it wrong (the percentage of physics students with incorrect responses was not reported)! The results suggest that many people have little accurate understanding of projectile motion. When asked to draw the path of a ball after it goes off the side of a cliff, 74% were correctly able to give a parabolic (or approximately parabolic) path. Subjects were then interviewed individually and asked to explain their answers. The majority relied heavily on a well-developed naive theory of motion, a theory remarkably consistent across subjects.

Based on this study I tested Leonie's knowledge of projectile motion. In the first investigation, she observed a ball being pushed off the edge of a table. This was repeated several times. She was then asked to draw the path of the ball. This she did without hesitation (see second attachment) though I was somewhat suspicious of the lack of thought/reflection. Part of the trajectory is curved, and part appears straight. On asking if this latter part was in fact straight, she replied "No, it's turning." Based on her observation of the moving ball, it seems as though she had a reasonably accurate mental representation(image?) of the path. She could offer no (theoretical) explanation as to what might cause this motion.

The second investigation involved the path a ball takes when thrown from one person to another. I firstly tried to get her to predict the path the ball would take if I threw it (and I pretended to throw it). Her answer was that it should move in a straight line from me to her. When this approach didn't seem to get anywhere, I threw the ball to her - once only - by throwing it up in the air. When asked to draw the path of the ball, she correctly drew the parabolic curve (see attachment).

Why was she able to draw the paths of the moving balls correctly when clearly many adults (including physics students) get it wrong? I make an attempt below to posit a tentative explanation for this.

Building a model of physical phenomena. An hypothesis.

Model building is not a static process. Over time, from birth to adulthood, the concepts/entities making up a model will continually be restructured and new relations between concepts established. The model will be a causal model, the sophistication of which will vary according to the need of the user - this is the functional level of the model. Thus the simple change of state model generated by Leonie may also be perfectly adquate for an adult who has no concern for Science. But it would not be at a suitable level for a high school chemistry student or a physical chemist. For such people the simpler model will undergo different levels of transformation with concepts becoming increasing abstract and seemingly unconnected to real-world phenomena.

I believe the notion of causality in inherent in all mental models, is present from an early age, and possibly innate. (Work by Bullock, I'm slightly sceptical of their claims. Do they have a rich enough concept of causality for their analysis?

Gelman and others provides evidence of causality in children as young as 3 years of age). However, causality is constrained by the availability of knowledge.

What factors might be necessary for the building of mental models in the domain of Science? There could be three factors as follows:

1. An environment that provides a sufficient number of entities and relations between the entities for a person to perceive. This could be a world of real objects, experiences, language, books and other media.

2. The degree of concreteness of the entities in this environment. Initial models will be physical in nature with concrete mental images mapping real world objects. For a child or an adult in a new learning situation, a high degree of concreteness is necessary. Further exposure to the environment may lead to a restructuring of earlier models.

3. Observability and the reinforcement of observations over time is necessary. If a child is able to make observations, or if things are pointed out in order to focus attention, more efficient models will be made.

If all three of these conditions are 'strong', then a richer model will be generated. If any of the conditions is 'weaker', a correspondingly weaker model with fewer concepts and relations will be acquired. Note that in either case the model formed may be right or wrong (as an expert would interpret this). Over time the model will evolve but a mental trace of earlier models still exists. In cases of cognitive overload or where a more sophisticated model does not seem to lead to satisfactory inferences or explanations, regression to a simpler model will take place. Also, the stronger a model is, the more resistant it will be to artificial change such as occurs in teaching a new or alternative conceptual framework. Teaching must overcome, not only the entrenched model but an accompanying belief in it.

To illustrate the above, consider first the change of state example. A child in an environment where solid-liquid changes can be observed will readily acquire a model of the process. As the objects are concrete, with repeated observations a strong model develops. While the causal mechanism exists, this will not be apparent in the model until a more abstract reality underlying the surface phenomena can be perceived by the child. Thus Gavin was unable to provide any reason for the change of state whereas Leonie was able to use the concepts of heat and cold. When Leonie was presented a series of quick questions requiring explanations or inferences, she regressed under the cognitive overload. Her response was "I don't know." Presumably if she had been older and had say an atomic model, the regression would have

When Ss regress, do they know it? Do they resume their reasoning at a meta-level?

Mechanism?

richer than if the conditions are lacking? Yes. [illegible] a truly scientific model? No. Galileo made many observations yet he did not formulate Newton's laws. It is also necessary to see beyond the observable i.e. to ignore those variables such as friction that obscure the simple relation between mass, force, and acceleration. It would be an interesting task to discover what circumstances, [illegible] and guidance, would enable intelligent students to discover Newton's laws.

been to one involving heat and cold. A model for the liquid-gas changes is not acquired as readily because of the difficulty of observing gases. I would speculate that a child would be well into the primary school years before this model is acquired and that experiences such as condensation of breath on a cold day would not be readily assimilated into the liquid-gas model, or useful in developing it.

The solid-liquid mental model is an example of a 'strong' model whose surface/concrete structure would not readily be changed (not that anybody would want to change it as the ideas are essentially correct). However the deeper abstract explanatory component of the model is weaker and would easily accommodate to teaching that involved say an atomic theory interpretation. The mental models of the internal body organs at both the surface/concrete level and the deeper/abstract explanatory level is an example of a weak model readily capable of development and/or restructuring due to teaching.

A similar pattern of model acquisition, change, or resistance to change would occur in adults. Consider the acquisition/development of models in the domain of mechanics, and specifically the relation between force and motion. At the surface level, we have many experiences that a object will move only if a force is applied. When that force is removed, movement will stop. Together with the large variety of similar experiences available in the modern world, and a lot of physics terminology "floating around in the air", children will have a very strong 'force-as-motion' model by the time they complete secondary school. This model would be consistent over many people (because of standardized experiences) and highly resistant to change. This incorrect pre-Newtonian conception of motion would not readily be restructured in line with Newtonian physics, which is exactly what McCloskey (1983) and Clement (1983) observed, even in university undergraduates who had completed courses in mechanics. Even amongst students who had accommodated to the Newtonian notion, I hypothesize that regression to the naive model would readily occur, especially under say examination conditions, where there is an urgency to get an answer to a problem.

An excellent paper: A (with charming illustrations!)
A key difficulty in the area is to separate out the effects of education from those of (naive) observation. My guess is that observation alone does not yield the sort of models observed by McCloskey -- his results may well show the effects of a half-remembered education.

A further difficulty is to discern children's grasp of causality & its essentially stronger relation than correlation.

Phil J-L March 10 1985

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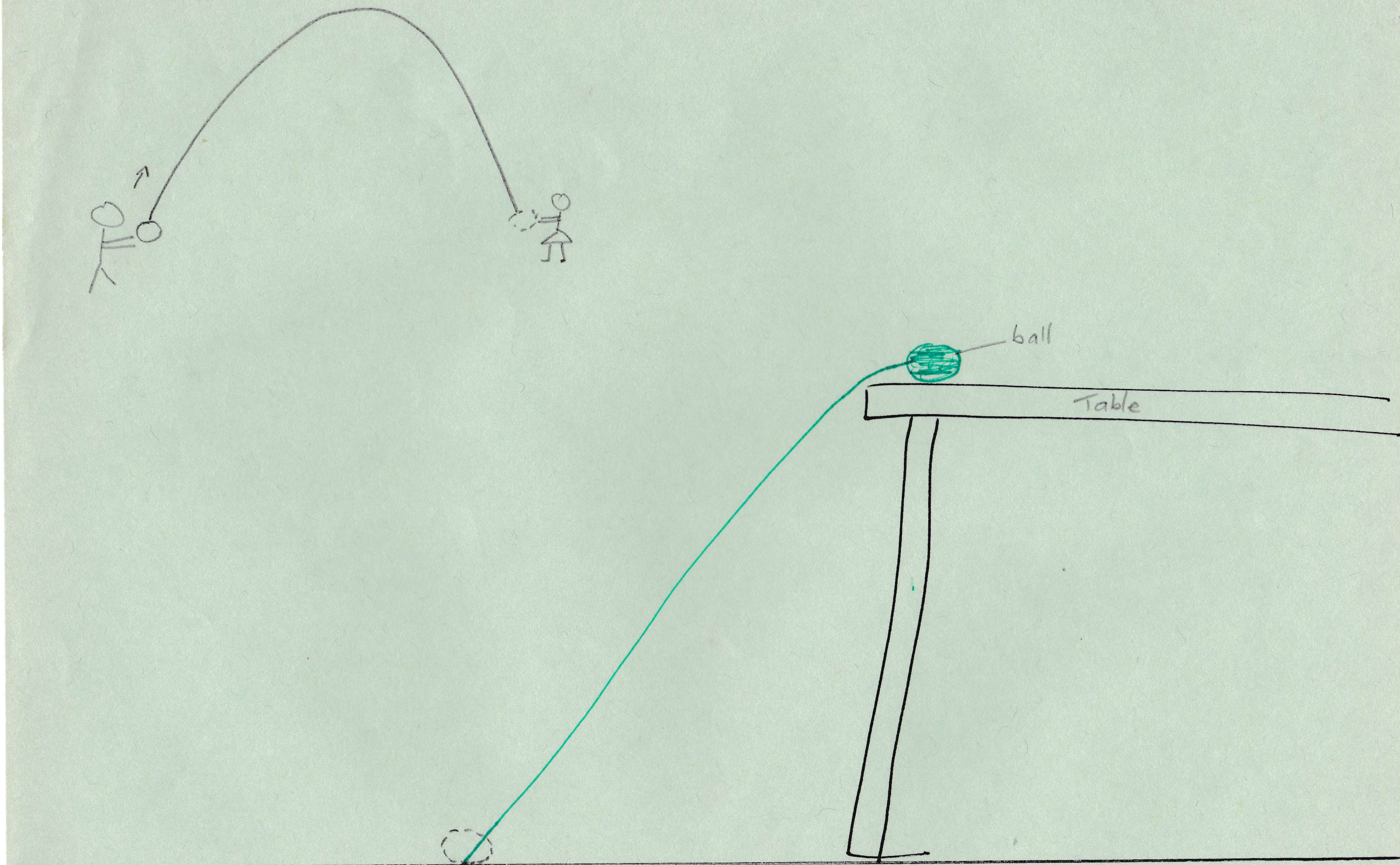
→ Causation & Counterfactuals.

Phil


brain (inside the head, not just under the hair)
bones in the head
heart
[shoulder - this term not actually used]
stomach
blood (all the red part)
bones in the body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