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# The development of representations as children learn about balancing

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The proposal that there is a simple dichotomy between implicit and explicit knowledge fails to fully explain why children and adults can perform a task with increasing awareness and efficiency before they are able to completely understand and explain their success. Karmiloff-Smith (1992) in her Representational Redescription (RR) model claims that representations of implicit procedures can be redescribed into further levels, E1, E2 and E3, which gradually afford increasing conscious and linguistic access. This study examines how 25 children's representations about balancing a beam on a fulcrum changed over time, as they attempted a set of tasks each day for five consecutive days. Children's behaviour was classified into seven levels, rather than the four identified by Karmiloff-Smith, and the path through these levels is traced as children progressed over the 5-day period. This provided one form of validation about the developmental sequence of the levels. Additional tasks assessed the flexibility of the children's representations, operationalized either as an ability to predict which beams would balance, or to identify which picture showed a beam that would balance on a fulcrum. The findings from these assessments shed light on the conscious accessibility and transportability of the children's knowledge, independent of their overt behaviour. The data also reveal a complexity in cognitive functioning which could not be identified from observations of performance alone. This research thus provides a theoretical endorsement and extension of Karmiloff-Smith's multi-representational framework of cognitive development and empirical support for a hypothesized path of development through the representational levels.

Children's understanding about balance has provided a testing ground for theories of cognitive development for many years (Halford, 1993; Inhelder & Piaget, 1958; Karmiloff-Smith, 1992; Karmiloff-Smith & Inhelder, 1974; Siegler, 1976). It is an activity which children engage in spontaneously during play and exploration, and a task that

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provides opportunities to gain insight into how children learn to combine information about variables. In addition, balancing is one of those activities in which doing and knowing can be dissociated. Many children can successfully balance one object upon another, without being able to explain how this is achieved. Most adults have some understanding of the factors influencing balance, but few can articulate the correct quantitative rule.

Success on the balance task in an experimental context depends upon the child understanding the importance of the weight and distance variables, i.e. that more weight on one side of the fulcrum can be compensated for by more distance on the other. Piaget claimed that understanding of any quantitative law about balancing would not be achieved until children reach the formal operations stage, at age 12 onwards, when they also acquire the concept of proportionality and the ability to engage in systematic problem-solving (Inhelder & Piaget, 1958). Siegler (1976), adopting a more systematic rule-assessment approach, stated that development progresses through a series of increasingly complex task-specific strategies, but that these were less tied to age than Piaget thought. More recently, the relational complexity of tasks has been used to explain the observations that gave rise to developmental stage theory, with tasks passed by children at a certain stage tending to have the same degree of relational complexity (Halford, Wilson, & Phillips, 1998). Common to all these theories is the proposal that as children get older they will be able to take account of more task variables. For Piaget, this increasingly sophisticated ability was driven by age and cognitive maturity. For Siegler, encoding and strategy use were less constrained by age and more amenable to training, whereas Halford's theory predicts that processing capacity increases, enabling the child to deal with more complex relations, but that development is also experience-driven and not discontinuous.

Whatever the degree of consensus or dissent amongst these theorists, there is one tacit assumption underlying each approach. This is that understanding and behaviour are synchronous. Karmiloff-Smith alone has suggested that children's behaviour may be produced in the absence of any rule-based understanding or explicit conceptual knowledge. Her model stands out as the only one which addresses children's procedural or implicit knowledge, proposing this as the starting point for development. Also, in contrast to other cognitive developmentalists, her model claims that it is more informative to look at how children gain access to their own procedural knowledge and then go on to build an abstract knowledge system, and eventually explicit knowledge, out of successful behaviour. In short, it is about how information *in* the mind becomes knowledge available *to* the mind (Karmiloff-Smith, 1992). This process, she claims, can occur rapidly within specific domains and can be observed occurring in children at all stages of development (and also in adults for some kinds of new learning). Therefore, understanding, and the way in which a task is performed, may change radically over short periods and should be observable at frequent intervals and task assessments. Furthermore, with experience, children as young as 5 or 6 years may be able to understand both the weight and distance variables in a simple balance beam task although they may vary in the degree to which they are able to articulate their knowledge.

It is this process of change from procedural success to conceptual, verbalizable understanding which is the focus of the Representational Redescription (RR) model (Karmiloff-Smith, 1992). The RR model challenges traditional notions of two modes of knowledge representation, implicit and explicit (Berry & Broadbent, 1988; Reber, 1967). By proposing intermediate levels, Karmiloff-Smith presents cognitive develop-

ment as implicit information gradually emerging into consciousness until it can eventually be verbalized and used more flexibly. The RR model has important implications for child assessment and education because cognitive development is not conceptualized as a progression from failure to success, or from less complex to more sophisticated thinking, but from implicit to explicit levels of representation.

The RR model claims that children as young as 4 or 5 years can balance different types of beams upon a fulcrum without any conscious understanding of how this is done. Karmiloff-Smith claims this is because their representations are at the *Implicit* level. It is supposed that representational redescription (RR) then occurs, transforming the implicit information into increasingly accessible and flexible codes. These more explicit levels are referred to as *Levels E1* and *E2* in the model. Finally, knowledge undergoes further redescription into *Level E3* and full conceptual understanding can be said to have developed, with the child not only performing successfully, but also being able to talk about what they know.

According to the RR model, *Level E1* is an abstraction formed by detecting a common feature among the implicit representations. In the case of balance, this may take the form of a strategy or theory which states that 'all things balance in the middle', a useful heuristic which holds true for many, but not all, instances in the child's experience. Although Level El representations drive the child's behaviour (e.g. by resulting in beams being placed on the fulcrum at their mid-point, even if they are unevenly weighted and balance off-centre) the representations are not available to consciousness and cannot be verbalized.

Conscious access is gained when further redescription transforms knowledge into *Level E2*. Although Karmiloff-Smith (1992) provides scant empirical evidence for this level, she states that she does not wish to dismiss the possibility of knowledge being represented in a form which can be consciously accessed but not expressed verbally. Some endorsement of this proposal comes from the work of Alibali and Goldin-Meadow (1993). They found that children could often express knowledge in their gestures which they could not state verbally. Other studies have found that children may also be able to make predictions about balance outcomes without being able to verbally justify their predictions, and this may indicate Level E2 knowledge (Pine & Messer, 1999). Thus, in the present study the children are asked to make predictions about each of the beams before they balanced them, to identify knowledge which may be available to consciousness for predictive purposes, but not for verbalization.

One unique feature of the RR model is the notion that two distinctly different types of representation can underlie successful performance at a task, at the Implicit level or at Level E3. Because task success is often used to identify whether a particular ability is present or absent in a child, this model presents a significant challenge to developmental theories which rely on performance measures. According to the RR model, knowing whether a child has an ability only gives us part of the picture about development. Assessing whether the child understands and can talk about the skill reveals far more about the child's underlying representations of a task, and such abilities constitute *Level E3*.

One aim of this study is to validate and extend the classification of behaviour described in the RR model. An earlier study found that there was more variability in behaviour than might be expected from the levels of the RR model (Pine & Messer, 1999). When 168 children, aged 4–9 years, were assessed on the balance beam task almost one-third of them did not directly correspond to Karmiloff-Smith's levels and some of these may have been in transition between levels. Although a large number (80)

of the children were found to have a 'centre theory' about balance, corresponding to Level E1 in the model, almost half of these were able to verbalize their theory, an ability which is not predicted by the model. A more comprehensive scheme for classifying children was drawn up, to take account of these observations, and is employed in this study. It is assumed that the levels in this classification are the result of differences in children's cognitive representations. However, because these levels are more fine-grained than those identified in the RR model, different levels could share common features in terms of the way representations are accessed or influence behaviour. Part of the purpose of this investigation is to investigate this issue by using additional tasks involving balancing.

The RR model is based primarily on cross-sectional data and consequently the sequence of levels needs to be validated longitudinally. Karmiloff-Smith claims that children's representations about balance can change rapidly, even in the course of a single session. Accordingly, a short-term longitudinal design with repeated testing was employed, based on this view of dynamic development. If the hypothesized developmental sequence of levels is correct (i.e. starting at Implicit and culminating in Level E3) then observed changes should be to levels higher in the sequence. In examining these changes we pay special attention to progression from Implicit and progression to Level E3. This is because successful performance at balancing occurs at both these levels, the main difference between the levels being in the child's ability to discuss their knowledge.

Another way to validate the developmental sequence of the levels is to assess whether the children have some theoretical knowledge about balance, independent of the task and therefore represented at a more abstract level. Two tasks were employed to address these issues which did not rely on the children giving verbal responses and therefore could also tap into knowledge which may be consciously accessible but not explicit. In one of the tasks children predicted which beams they would be able to balance by sorting them into two piles designated 'yes' and 'no'. This prediction task was used because it provides a method to identify whether children who cannot provide verbal explanations can access other relevant forms of knowledge. The other task involved children having to identify which of three pictures showed a beam positioned so that it would balance on a fulcrum. Children at the Implicit level are not supposed to have access to their representations, consequently it was expected that they would guess and produce random responses, whereas children at the E3 level are expected to choose the correct picture. The aim of this work was to utilize other techniques, besides observations of behaviour and the recording of verbal explanations, to provide a fuller picture of the nature of children's representations at the different levels. By using several different assessments of children's knowledge of this micro-domain it will be possible to examine whether children are consistent in their behaviour and responses, or whether there are inconsistencies that might be due to a failure to integrate all the relevant representations.

In summary, the aims of our study are:

(1) To test, over five sessions, the developmental sequence of children's changing representations about balance from Implicit to Explicit knowledge, whilst employing a more comprehensive system of classification than the RR model provides.
(2) To use new measures to investigate children's procedural and theoretical knowledge of this micro-domain and thereby obtain a better understanding of

the way children can access and utilize knowledge at different points of cognitive development.

## Method

### *Participants*

Twenty-five children, from one class at a Bedfordshire school, took part. There were 12 girls and 13 boys, aged between 5,8 and 6,1 years with a mean age of 5,10 years.

### *Materials*

*Picture story task*

The two pictures used to introduce the story had a seal with a ball or a plank of wood balanced on its nose. The three stimulus pictures (14 cm × 17 cm wide), from which the child had to make a choice about the correct balance point when the seal was balancing a plank of wood with a paint pot on it, were:

Picture 1: The seal correctly balancing at an off-centre point a plank with a paint pot at one end.
Picture 2: The seal incorrectly balancing the plank off-centre with his nose supporting the end without the paint pot.
Picture 3: The seal's nose positioned incorrectly at the centre of the plank of wood.

*Prediction and pre- and post-test balance beam tasks*

A fulcrum 1 cm wide × 1.5 cm high × 30 cm long was mounted along the centre of a wooden base. The beams for balancing were all made of wood and painted white. There were six in total, consisting one of each of the following beams:

Beam A: symmetrical, 30 cm long × 2.5 cm wide × 0.5 cm thick.
Beam B: symmetrical, 30 cm long × 2.5 cm wide × 1.0 cm thick.
Beam C: symmetrical, as beam A but with a 2.5 cm square block glued to each end.
Beam D: asymmetrical, as beam A but with a 2 cm block glued to one end and two 2 cm blocks glued to the other end.
Beam E: asymmetrical, as beam A but with a 2.5 cm block glued to one end.
Beam F: asymmetrical, as beam A but with two 2.5 cm blocks glued to one end.

*Free play*

On Days 2, 3 and 4 the beams used for the free play periods were identical to those used in the prediction test but they were painted in a variety of bright colours. In addition, another type of symmetrical beam was introduced to make the task more interesting and varied. This involved two flat beams (type A) one glued to the other with 15 cm overlapping and 15 cm protruding either end (i.e. symmetrical). There were two of each type of beam, making 14 beams in total.

### Procedure

*Day 1 and 5*: The children were taken individually to a quiet corner of their classroom and seated opposite the experimenter who had already been introduced to the class. The children told the experimenter their name and how old they were and the experimenter explained that they would be spending some time together 'finding out about how things balance.'

#### *Picture story task*

The experimenter then said, 'Now I am going to tell you a story about someone who is learning to balance'. The child was shown the pictures of the seal with a ball on the end of his nose and told that Sammy, the circus seal, could balance a ball. The next picture was shown and the experimenter said, 'Sammy is very clever, he can even balance a plank of wood on the end of his nose!' She went on to explain that the circus owner wanted Sammy to learn a new trick to balance a plank *with a pot of paint on one end* on his nose. Pictures 1, 2 and 3 were then presented side-by-side on the table in front of the child. In two of these pictures, the child was told that the plank would tip and the paint would fall off, but in one Sammy was doing it the right way so that the plank would stay perfectly balanced. The order in which the pictures were placed before the child was randomized on each day and for each child. The experimenter asked the child to look at the pictures and try to decide in which picture Sammy was balancing it correctly. The child chose which picture they thought to be the correct one by pointing to it.

#### *Prediction task*

Next the child was shown the set of white beams and the wooden fulcrum and was told that in a moment he or she would be asked to try to balance the beams. The experimenter then said, 'I would like you to try and guess which of these beams (points to beams) you think will balance on here (points to fulcrum)'. Two cards were placed on the table. One card had the word *yes* clearly printed on it, together with a smiley face and a large tick. The other card had the word *no* clearly printed on it, together with an unhappy face and a cross. This ensured that even children who could not read would understand the task. 'Any beams which you think will balance,' the experimenter told the child, 'I want you to put in a pile by this card (*points to "yes" card*). If you think there are any which will not balance, put them over here by the "no" card.' The child then sorted the beams into two piles.

#### *Balance beam task*

The cards were then removed and the fulcrum placed before the child. The beams were placed in one pile to the child's left. The child was then asked to try to balance each of the six beams. The child selected a beam, and after balancing it or attempting to, replaced it on the table where it was removed by the experimenter.

At the end of the final session debriefing took place. The children were thanked for their cooperation and praised for their achievement and returned to class.

*Day 2, 3 and 4*: The following tests were carried out as Day 1, the picture story task and the prediction task, in addition a free play session was included.

#### *Free play*

The children were given 14 coloured balance beams and the fulcrum and told they could play with them for 10 minutes and see how many they could get to balance. A toy

character was sat at the end of the table and introduced to the child as 'Barnie'. The experimenter explained that Barnie wanted to learn all about balancing and asked the child to tell him what they learned as they went along. This was done in order to encourage the children to talk.

The children were coded on each day as being at one of the seven levels identified in our earlier work (Pine & Messer, 1998, 1999).

*Implicit (Level I)*

The ability to balance at least two of each type of beam (i.e. both symmetrical and asymmetrical) with no consistent initial positioning of the beam on the fulcrum. The child gives no explanation or mentions any relevant variables. (This corresponds directly to the Implicit level described by Karmiloff-Smith.)

*Implicit Transition*

Inability to balance more than one of the symmetrical or asymmetrical beams. Although most beams are placed onto the fulcrum near their mid-point the child does not succeed in balancing more than one of each type.

*Abstraction Non-Verbal*

The ability to balance at least two of the symmetrical beams, but no more than one of the asymmetrical beams. All beams are placed on the fulcrum at their geometric centre. No explanations are given and no relevant variables are mentioned. This is distinguished from the Implicit level by the inability to balance the asymmetrical beams. (This level corresponds to Level E1 in Karmiloff-Smith's model.)

*Abstraction Verbal*

Similar to Abstraction Non-Verbal except explanations are now given. These are in terms of a centre theory, e.g. 'You have to put it in the middle'. (Although the behaviour is similar to Karmiloff-Smith's Level E1 she did not identify a level where the child was able to talk about the centre theory.)

*Explicit Transition*

Involves the ability to balance at least two of each type of beam and explanations are given which mention the strategy that is employed, e.g. 'You make this side longer' or 'You put the blocks nearer'. Beams are still placed on the fulcrum at their centre and then adjustments are made. This level is distinguished from the Abstraction Verbal level by the ability to balance all the beams and to describe an appropriate strategy for balancing asymmetrical beams. (This level was not identified by Karmiloff-Smith.)

*Explicit E3*

This is similar to Explicit Transition, with success on all or most of the beams, except that explanations are in terms of the compensatory function of length *and* weight, e.g. 'This side's heavier, so you have to make this side longer to give it the same weight' and demonstrate a fuller understanding. (This corresponds to Karmiloff-Smith's Level E3.)

*Explicit E4*

Similar to previous level except that asymmetrical beams are placed on or near the correct off-centre balance point. (An extension of Level E3 ability referred to by Karmiloff-Smith.)

It should be noted that two transition levels have been incorporated into the categorization system. Implicit Transition appears to describe those children in transition from Implicit to Abstraction levels, and Explicit Transition describes those children in transition from Abstraction to Explicit E3 knowledge. They are termed transitions because, as discussed later, they are characterized by mismatches between behaviour and theory.

The tasks were presented to the children in the same order on each of the five days.

## Results

Although the balance beam task was not the first task given to the children, these results are presented first, as the levels at which the children are classified on the balance beam feature in the other analyses. Findings from the picture task are presented next, followed by the findings about the prediction task.

### *Balance beam task*

#### *Improvement in number of beams balanced*

The children were given the six balance beams to balance as a pre-test on Day 1 and an identical post-test on Day 5. The mean number of symmetrical and asymmetrical beams balanced on Day 1 was 2.5 ($SD$ = 1.0) and 1.6 ($SD$ = 1.2) respectively. The equivalent figures on Day 5 were 2.9 ($SD$ = 0.4) and 2.6 ($SD$ = 0.8). Pre- to post-test improvement was found for both types of beam. Significantly more symmetrical beams were balanced at post-test than at pre-test, $t(24) = -2.4$, $p = <.05$, and also significantly more asymmetrical beams were balanced at post-test than at pre-test, $t(24) = -4.33$, $p = <.01$, indicating pre- to post-test improvement on both types of beam.

#### *Balance beam task: Representational levels*

The children's behaviours and verbalizations were coded according to seven levels (as outlined above). Analysis of the daily sessions found that, apart from one child, all changed levels at least once, with a mean number of transitions per child of 1.92 ($SD$ = 1.1). All of the transitions, and non-movements were recorded and are shown in Table 1 where, for each child, it can be seen which level they were at on each of the five days.

Of all the transitions, 88% were to a higher level, with only 12% appearing to regress. By Day 5, 80% of the children had progressed to a higher level of representation, 8% had stayed at the same level and 12% appeared to slip back. A small number of regressions did occur around the Abstraction Non-Verbal and Abstraction Verbal levels and may reflect some instability at these levels, but the majority of transitions were to the same or higher level.

No child moved straight from the Implicit to Explicit (E3) level. This confirms Karmiloff-Smith's assertion that there is no direct route from implicit to explicit knowledge and supports the notion of there being intermediate levels of knowledge representation. By Day 5, 14 children (56%) were at either Explicit Transition, E3 or E4, compared with only 1 child (4%) on Day 1. This endorses the proposition that children can redescribe their own implicitly represented knowledge to make it explicit, as these children simply had exposure to the relevant materials and the minimum of intervention.

**Table 1.** Transition table. Numbers refer to day number (1–5) when each child was at a particular level.

| Level | Implicit | Implicit Transition | Abstraction Non-Verbal | Abstraction Verbal | Explicit Transition | E3 | E4 |
|---|---|---|---|---|---|---|---|
| Child No | | | | | | | |
| 1 | | 1 2 | 3 4 | | 5 | | |
| 2 | | | 1 | 2 | 3 4 5 | | |
| 3 | 1 2 3 | | | 4 5 | | | |
| 4 | | 1 2 3 4 5 | | | | | |
| 5 | | | 1 2 3 | 4 5 | | | |
| 6 | 1 | | | 2 | 3 | 4 | 5 |
| 7 | 1 | | | 2 | 3 4 5 | | |
| 8 | | | 1 | 2 | 3 4 5 | | |
| 9 | | | 1 2 | 3 4 5 | | | |
| 10 | 2 | | 1 3 4 5 | | | | |
| 11 | | | 1 2 3 4 | 5 | | | |
| 12 | 4 5 | 1 | 2 3 | | | | |
| 13 | 5 | | 1 2 3 4 | | | | |
| 14 | | | | | 1 | 3 4 | 5 |
| 15 | 4 5 | 1 2 | 3 | | | | |
| 16 | | | | 1 2 3 | 4 5 | | |
| 17 | 1 | | | 2 3 | 4 5 | | |
| 18 | | 1 | 2 | | 3 | 4 5 | |
| 19 | | | | 1 | 2 3 4 5 | | |
| 20 | 1 | | 2 | 3 | 4 5 | | |
| 21 | 1 | | 4 | 3 5 | | | |
| 22 | 1 | | 2 | 3 | 4 5 | | |
| 23 | | | | 1 2 | 3 4 5 | | |
| 24 | 1 | | | | 2 3 4 5 | | |
| 25 | | | 1 2 | 3 | 4 | 5 | |

There were two absentees on Day 2.

### *Picture story task*

All children were asked on each day to choose the picture in which the seal was successfully balancing a plank of wood with a pot of paint at one end. Chi-squared analyses of the frequency of picture choices on each day were conducted. On Day 1 the choices were fairly evenly spread and there was no significant difference among the three choices. By Day 5, Picture 1 (with the correct balance point) was chosen by 52% of the children and Picture 3 (the centre balance point) by 44%, with just one child choosing Picture 2, $\chi^2(2, N = 25) = 10.375$, $p = <.01$. Thus, by the end of the week, all but one of the children appear to have learnt about the unfeasibility of Picture 2, although many still saw Picture 3 as plausible. Many of these children stated that it was correct because it was 'in the middle', suggesting they were accessing a centre theory of balance for this task.

To assess the children's choices on the picture task in relation to their level of representation, the frequency of choosing each picture at each representational level are presented in Table 2. Statistical analysis of these data was not conducted as cells may contain data from the same child more than once.

As Table 2 shows, up until the Abstraction Non-Verbal level the choices of picture appear to be fairly randomly distributed. Random choices were expected from these

**Table 2.** The frequency of picture choice at each level

| | Picture choice level | | |
|---|---|---|---|
| | Picture 1 (correct) | Picture 2 (incorrect) | Picture 3 (centre) |
| Implicit | 4 | 4 | 6 |
| Implicit Transition | 7 | 1 | 3 |
| Abstraction Non-Verbal | 10 | 10 | 10 |
| Abstraction Verbal | 9 | 3 | 15 |
| Explicit Transition | 6 | 3 | 23 |
| E3 | 1 | 0 | 1 |
| E4 | 2 | 0 | 2 |

Two children were absent on Day 2 and one child's data was disregarded because he chose two Pictures on Days 2, 3 and 4.

children if they had no conscious access to their theory. However, this would not necessarily have been expected from children at the Abstraction Verbal level who, by definition, had access to their verbal representation. This is confirmed by the findings; at this level there was a shift in favour of Picture 3 (where the seal's nose is incorrectly positioned in the centre). This suggests that at the Abstraction Verbal level, where children have a verbalizable centre theory, representations are transferable to the picture task.

This issue becomes even more interesting at the Explicit Transition level. Recall that Explicit Transition level children can balance both symmetrical and asymmetrical beams, although they initially place the centre of all the beams on the fulcrum. Furthermore, they do not yet have full explicit knowledge of weight and distance when describing their strategy for balancing asymmetrical beams. Their picture choices suggests strongly that they still access their centre theory when given the picture task, with 72% of them choosing Picture 3 with the centre balance point. Thus, although the children are able to balance the asymmetrical beams off-centre, the theory available for transfer is the centre theory and this is evidence for a mismatch between behaviour and theory.

### *Prediction task*

The children were asked each day to predict which beams they thought they would be able to balance by sorting them into two piles. This was aimed at assessing abstract or theoretical knowledge (accessed for the purposes of predicting) which may not be verbalizable. These data, without the effect of Day, are shown in Fig. 1 which depicts the mean number of both symmetrical and asymmetrical beams which children at different levels predicted would balance. Again, statistical analyses were not conducted on these data, as they deal only with different levels which may contain data from the same child more than once. Nonetheless, it is interesting to note the different patterns of success with symmetrical and asymmetrical beams at each of the representational levels. The predictions for symmetrical beams are fairly high at all levels, and appear to increase in a fairly linear fashion. It is in the predictions for asymmetrical beams, however, that a U-shaped profile can be observed. Because, at each of the levels, there are differences in performance and the ability to give valid explanations, it is worth examining the children's predictions in relation to these behaviours.

Children with *Implicit* level representations did not appear to make different predictions for symmetrical and asymmetrical beams. The fact that the mean number of positive predictions made by children at the Implicit level was below the maximum may mean they were making random guesses in the prediction task.

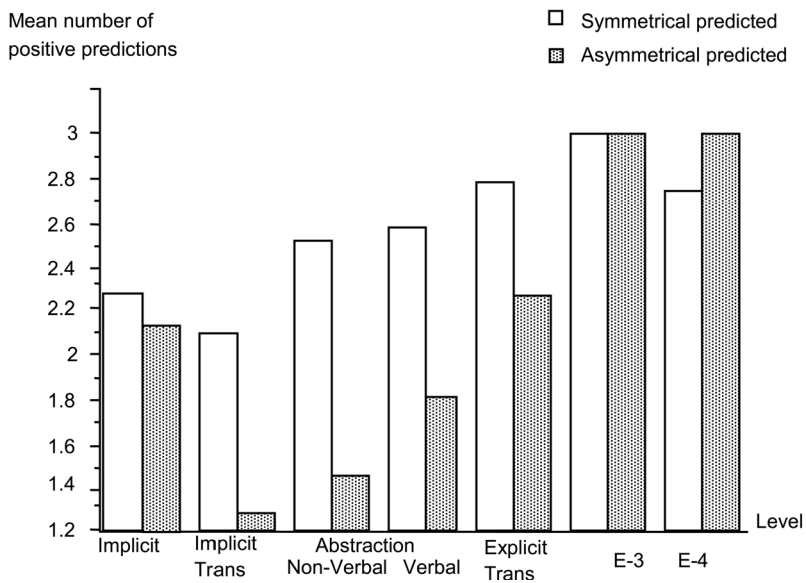


**Figure 1.** The mean number of symmetrical and asymmetrical beams which children at different levels predicted would balance.

Children at the four levels from Implicit Transition to Explicit Transition predicted that they would be able to balance more symmetrical than asymmetrical beams. At the *Implicit Transition* level there was a higher number of positive predictions for symmetrical than for asymmetrical beams. This suggests that the children were moving towards a centre theory, an interpretation supported by the fact that they placed all the beams onto the fulcrum at their mid-point. At this level there appears to be a mismatch between predictions and behaviour, as they failed to balance many beams, probably because of simple performance difficulties.

The children at the *Abstraction Non-Verbal* level, who were unable to verbalize their centre theory, also predicted that more symmetrical than asymmetrical beams would balance. This suggests that they had some access to their representations even though these could not be verbalized. Not surprisingly, children at the *Abstraction Verbal* level, who were able to express their centre theory, made more positive predictions about symmetrical beams than asymmetrical beams.

Interestingly, children at the *Explicit Transition* level appear to have made more positive predictions for symmetrical than for asymmetrical beams, even though they could balance both types. Again there is a mismatch here between behaviour (success on both types of beam) and representation (centre theory) which suggests they are at a transition with a mismatch between representations and behaviour.

Children at the E3 and E4 levels correctly predicted that both types of beam could be balanced. This is consistent with their having a consciously accessible representation which enables them to accurately predict as well as to verbalize.

Two features of these findings deserve to be highlighted. One is that children who were not expected to have access to their representations (those at the Implicit Transition and Abstraction Non-Verbal levels) consistently predicted that they could balance more symmetrical beams than asymmetrical beams. The other is that children at four of the levels appeared to predict that they could balance more symmetrical than asymmetrical beams. In some cases this appeared to correspond with their behaviour (Abstraction Non-Verbal, Abstraction Verbal) in others there appeared to be a mismatch between performance and prediction (Implicit Transition, Explicit Transition). The next set of analyses examines this issue about the accuracy of predictions in more detail.

### *Prediction and performance*

An accuracy score was calculated from the number of beams the child predicted they would balance, minus the number of beams they actually balanced (using the sample of three beams on Days 2, 3 and 4). Negative scores were converted to positives, as the direction of the difference was not important for this analysis. A higher score represented lower accuracy, and perfect accuracy was of course represented by a score of 0.

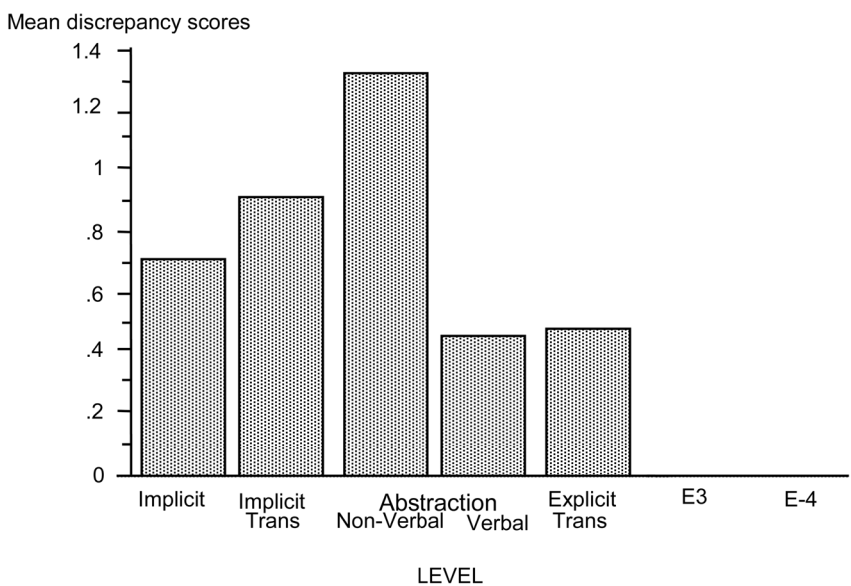


**Figure 2.** The mean prediction–performance discrepancy scores for asymmetrical beams at each level (lower scores denote greater accuracy).

Figure 2 shows the mean accuracy scores at each level. The lower scores, which denote greater accuracy, appear at the Abstraction Verbal level and those levels which succeed it, with E3 and E4 achieving perfect accuracy (mean scores of 0). There appears to have been an increase in accuracy when Abstraction Verbal level was achieved. This demonstrates an important difference between the Abstraction Non-Verbal and Abstraction Verbal levels, and confirms the distinctions made in the previous analysis of the children's predictions. The previous findings (see Fig. 1) suggested that

at the Abstraction Non-Verbal and Abstraction Verbal level children made similar predictions that symmetrical, but not asymmetrical, beams would balance. It was at the Abstraction Verbal level, however, that the children's predictions more closely matched their performance and their accuracy scores improved. Therefore, when the children had verbal access to their centre theory this appears to increase the accuracy of their predictions, suggesting that there is better access to representations about balancing.

These findings enable us to counter any argument that the two abstraction levels (non-verbal or verbal) are simply caused by some children being better at verbalizing or at giving *post hoc* explanations. It would appear that at the Abstraction Non-Verbal level the centre theory is becoming accessible and may give rise to some theory-based predictions which cannot be verbalized. A further level then is formed where the representation of the centre theory is accessed to make predictions about performance and to give explanations (Abstraction Verbal). The direction of progress from Abstraction Non-Verbal to Abstraction Verbal level is supported by the evidence that many children moved from Abstraction Non-Verbal to Abstraction Verbal representations, but very few moved in the opposite direction (see Table 1).

## Discussion

This study set out to follow the progress of 25 children as they learned about balance over a period of 5 days. Karmiloff-Smith's RR model stresses the notion of domain-specific development and thus allows for development in some micro-domains to occur very rapidly, whereas in other domains, such as language, this change takes place over a number of years. Although speed of change varies considerably across domains, the underlying process of representational redescription is said by Karmiloff-Smith to be common to all. The aim of this study was to track the relatively rapid development of children's understanding of balance to see if it corresponded with the hypothesized path of the RR model. The model posits that representations change from Implicit to Level E3, via Levels E1 and E2, but other studies (e.g. Pine & Messer, 1999) have revealed that as well as the original four levels, another three forms of behaviour could be identified. Hence a new classification system was implemented which accommodated all the children in this study.

The children's progression during the five sessions provides validation of the developmental sequence of the levels. Very few children regressed to a lower level. A notable feature of the description of the levels is that children at the Implicit level are as successful at balancing as those at the Explicit Transition, E3 and E4 levels. Consequently, it is reassuring that 92% of the children classified as being at the Implicit level passed through intermediate levels involving the abstraction of a centre theory before reaching the three highest levels.

The use of other tasks relating to balance, the prediction task and the picture story task, also provided important information about cognitive representations which helps to support our proposals about the ordering of the levels but also highlights the complexity of the children's cognitive development. We now examine the pattern of findings at each level to provide a basis from which to discuss the wider implications.

The children who were classified as being at the first three levels (Implicit, Implicit Transition and Abstraction Non-Verbal) were not able to give any coherent explanations of the strategy that they used on the balance beam task. These children also appeared to make random choices in their preference for the correct or incorrect pictures in the

picture story task, which suggests that because they were unable to access representations about balancing they were simply guessing. Taken together, these findings suggest that the absence of explanations about the balance beam task was not a simple product of shyness or lack of verbal ability. Rather, the lack of explanations appears to be caused by a genuine difficulty in accessing their knowledge and in the RR model it is suggested there is no conscious access to representations at Implicit and E1 levels.

For the first three levels there is also an interesting set of findings concerning whether there was a consistent or inconsistent relation between behaviour and predictions. The children's predictions at both the Implicit and Abstraction Non-Verbal levels generally corresponded to their performance with symmetrical and asymmetrical beams. However, children at the Implicit Transition level failed to balance most of the beams (note they initially placed beams on the fulcrum at their mid-point), but predicted that they would be successful with symmetrical beams. Thus, children at the Implicit Transition level seemed to be accessing some form of centre theory in both their behaviour and predictions, but they were not yet able to achieve success when given the physical task. Such a mismatch between knowledge accessed and performance suggests that this may be a transitional level between Implicit representations and the first abstraction of a centre theory. The notion that mismatches may reveal transitional states in learning is based on work by Alibali and Goldin-Meadow (1993) who found that children who were 'discordant', demonstrating mismatches between procedures described in speech and those shown in gesture, were in a transitional state when acquiring a concept.

There are further issues to discuss about the prediction task because it indicated that children had some access to their representations about balancing. According to the RR model, children at the Implicit level are not supposed to have access to their representations, yet they were reasonably accurate in predicting that they could balance most of the symmetrical and most of the asymmetrical beams. These predictions may have been based on probabilistic guesses, which would not present difficulties for the RR model. However, it is also possible that the predictions were based on some form of non-procedural representation and this is not predicted by the RR model. Clarifying why these children were able to make predictions is an important issue for further research.

In the case of children at Level E1, the RR model states that this knowledge is available as data to the cognitive system (Karmiloff-Smith, 1992) although the children are not supposed to have conscious access to such representations. The fact that most children at both the Implicit Transition and Abstraction Non-Verbal levels predicted that more symmetrical than asymmetrical beams would balance is consistent with the idea of using information in the cognitive system to make guesses about whether a beam could be balanced. Furthermore, it is interesting to note that this access appears to be to representations about balancing that guide behaviour not to knowledge about performance. The evidence for this is clearest with the children at the Implicit Transition level who predicted that they would balance more symmetrical than asymmetrical beams, attempted to balance most of the beams at the geometric centre, yet were unsuccessful at their attempts at balancing.

Children at the Abstraction Verbal level were able to talk about their centre strategy and this form of behaviour has not been described in previous versions of the RR model. Children at this level appeared to be better at accessing their representations than children at the previous levels who could not explain the way they balanced the

beams. Children at the Abstraction Verbal level were more accurate in their predictions about asymmetrical beams than were children at the Abstraction Non-Verbal level. Furthermore, when given the three pictures of the seal to choose from, these children showed a preference for the picture which corresponded to their theory. Together these findings point to children at this level having a coherent set of accessible representations which differ from those at earlier levels.

What these data do not tell us, however, is whether the children's predictions on the second and subsequent days may have been influenced by the feedback from the task on the preceding day(s). This issue is being addressed in a current study wherein one group of children makes repeated predictions without actually balancing the beams and receiving feedback. It is also acknowledged that prediction ability need not necessarily imply that the children have access to their representations but that, as is the case with the children at the Implicit level, they have some knowledge about how to approach the task.

A further level, termed Explicit Transition, was identified in this study. This level, like some of the others, involved inconsistencies in performance across the different tasks. Children at this level could balance both symmetrical and asymmetrical beams, and were able to give an explanation of their success in terms of either weight or distance. Consequently, it is surprising that these children predicted that they would be more successful with the symmetrical than the asymmetrical beams, and showed a preference for the picture of a seal which was congruent with a centre theory. One explanation for this is that the children's representations were not as well consolidated as might appear from their performance on the physical balance beam task. Consequently, when the children were confronted with a different and possibly more difficult task they tended to access an earlier, more stable, representation of the problem. This is evidence of a further mismatch between behaviour and the accessible representation, and suggests that these children were at a transitional level between the Abstraction Verbal and E3 levels.

All the children who progressed from the Explicit Transition level advanced to Level E3, and all the children who progressed from E3 advanced to E4. These children could balance all the beams and explain their behaviour in terms of the relationship between weight and distance. We did not detect any difference in the performance of children at Levels E3 and E4 other than the ability to correctly initially place the beam on the fulcrum at its balance point. Such findings suggest that there are more similarities than differences between these levels, and they are likely to involve similar forms of representation.

To summarize our findings, in relation to Karmiloff-Smith's RR model, there is evidence for the *Implicit* Level as the starting point for development. One third of our sample began with Implicit level representations and went on to redescribe them into more explicit levels. *Level E1* is also confirmed by the large number of children with a centre theory, but is recategorized as two Abstraction levels, Non-Verbal and Verbal. *Level E2*, the RR model implies, would give rise to the ability to balance both types of beam with conscious, but not verbal, access. No behaviour corresponding to Level E2 was found in this study. However, the Abstraction Non-Verbal level is characterized by conscious access without explanation (as E2) but this is accompanied by the ability to balance symmetrical beams *only*. The child then goes on to verbalize that knowledge at the Abstraction Verbal level. Lastly, full explicit knowledge in the form of *Level E3/E4* representations is found, extending to both beam types. These findings could be taken to indicate that the child acquires explicit knowledge of one dimension of the balance

problem first, as the centre theory indicates they are attending to only one variable. They may then go on to develop explicit knowledge of a more complex rule that acknowledges both the weight and distance variables, as predicted by Halford *et al.* (1998). Importantly, most of the 5-year-olds in this study demonstrated that they were not restricted to processing a single dimension of the problem but, with repeated exposure to the problem and minimal intervention, could take account of both weight and distance. This, too, accords with Halford (1998) when he predicts 'Hence, the ability to consider both weight and distance in a single judgment should develop at a median age of 5 years' (p. 827).

The system of classification proposed in this paper incorporates more levels than outlined in the RR model to capture the complexities of children's behaviour, particularly to incorporate transition levels. The findings endorse the proposed developmental sequence of the levels, and the multi-task data also validate the structure of the levels in terms of their accessibility and transportability. Approaches to studying cognitive development which rely purely on performance measures can reveal whether a particular skill is present in a child, or the age at which it emerges. However, when assessment relies purely on recording success or failure, the measurements obtained tell us very little about the structure of the representations sustaining an ability or the way they change in the course of acquisition. Success can be implicit, without any understanding, or explicit with understanding, and these two representations are distinctly different despite producing identical overt behaviour. Failure too, may not indicate lack of knowledge but that the child is in the first stages of theory building, as in the case of a child whose centre theory produces overt failure on unevenly weighted beams. In relation to this, the identification of transitional levels, where there are mismatches between different forms of representation, is particularly interesting. The presence of these levels suggests that, at certain periods during cognitive development, related forms of knowledge can co-exist but may be isolated from one another. During such periods it may be easier to facilitate cognitive change (Alibali & Goldin-Meadow, 1993; Pine & Messer, 2000), and the subtle measures introduced here promise to advance our ability to detect the level at which intervention is likely to be most effective.

Thus, we would argue that there are a number of messages from these findings. Although limited to one micro-domain they serve to illustrate how traditional notions of a dichotomy between implicit and explicit knowledge cannot fully explain the complexity of children's developing representations, and also where Karmiloff-Smith's model may be improved upon. A note of caution is also sounded for assessment procedures which rely on success or failure measures, as both can be sustained by different levels of knowledge not immediately apparent in the overt behaviours. These findings therefore highlight the importance of using different assessment procedures in order that we may gain a much deeper understanding of the complexities of cognitive development and the coherence or lack of it in children's representations.

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