The Development of Cognitive Flexibility: Evidence from Children’s Drawings

Fiona Spensleya Josie Taylorb

aUniversity of Oxford, Oxford, and bThe Open University, Institute of Educational Technology, Milton Keynes, UK

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Abstract
Karmiloff-Smith [1990] has claimed that her ‘draw a strange man’ task indicates that young children’s first successful drawings are produced by inflexible procedural representations – consistent with her Representational Redescription (RR) model. In this paper, children’s drawings of a man with a beard, ‘a strange man’ and a normal man simply interrupted, indicated that young children are able to make modifications mid-procedure in a manner inconsistent with a procedural representation. Examination of the order of production of drawing elements indicated that the sequence is not as rigid as Karmiloff-Smith had predicted. A difference in types of spontaneous modifications with age in the ‘draw a strange man’ task was replicated. However, a further task explicitly requesting all the types of modifications observed in strange-man drawings (e.g., draw a man with something missing) demonstrated that young children have the ability to make all the types modifications, even if they do not do so spontaneously. Theoretical problems with the RR model in the drawing domain are discussed, and a new model, Recursive Re-Representation, is proposed which overcomes these theoretical problems and accounts more parsimoniously for the empirical data.

Human beings have the ability to behave flexibly, to go beyond simply carrying out a task, to reflecting on that knowledge and using that knowledge to approach new problems. This is in contrast to less advanced animals which can show remarkable inflexibility: Barends [1941, quoted in Eibl-Eibesfeldt, 1975] induced digger wasps to repeat their entire nest-checking routine 30–40 times simply by moving the caterpillar (food for her...
larvae) a small distance from the nest whilst the mother was inspecting the nest. Children would very quickly avoid this kind of repetition.

Whilst it is easy to distinguish flexible from inflexible performance, it is not clear what flexibility is in cognitive terms. Flexibility clearly improves with development, and children are relatively less flexible than adults. Piaget [e.g., 1970] identified inflexibility at various stages in children’s development with flexibility increasing during childhood through domain-general changes in thinking. Increased flexibility has been described as the development of metacognition and metacognitive skills, and these have been the focus of much interest particularly in the educational literature [e.g., Bruner, 1996]. The ability to reflect on knowledge is an important educational achievement, but the literature is descriptive rather than illuminating the underlying cognitive concept. Metacognition has been described by Flavell [1979] as ‘cognition about cognition’, although the relationship between the cognitive and metacognitive is still unclear. The term ‘metacognition’ has been used with widely differing meanings, applying to both explicit knowledge about cognition and to the processes of cognitive monitoring, and this imprecision undermines its usefulness as a concept [Forrest-Pressley, MacKinnon, and Waller, 1985]. Robinson [1983] has clearly identified the relevant questions in metacognitive development, but concludes that we have no answers about how children become capable of reflecting on their own performance. The explanation of metacognitive or reflective processes is an essential component of a complete account of cognitive development [Kuhn, 1992], but there is a dearth of attempts to address the issue directly in information processing terms. There is little work within cognitive or developmental psychology defining cognitive flexibility in representational terms, nor proposing a developmental mechanism.

Karmiloff-Smith [1979] importantly recognised that the progression towards flexibility was not simply a matter of learning to perform a specific task. The development of flexibility involved progression beyond behavioural success on a task, moving from unreflective to reflective performance. Karmiloff-Smith [1992] and Halford [1993] both view the development of flexibility as the move from implicit to explicit knowledge, with flexibility or understanding following the acquisition of skill on a task. Halford [1993] argued that children can perform tasks before they can be said to understand them. Where children have been trained to succeed on advanced Piagetian tasks, for example, this knowledge forms an isolated island of ability rather than the integrated and generalisable knowledge which is acquired through normal development. In the drawing domain, Phillips, Inall, and Lauder [1985] have trained 6- and 7-year-old children to produce a drawing of one particular three-dimensional geometric shape, and found that whilst they can acquire the skill for that specific shape, their knowledge does not transfer to other three-dimensional shapes.

Halford [1993] bemoans the paucity of models of the progression from implicit to explicit knowledge. Karmiloff-Smith’s [1986, 1992] Representational Redescription (RR) theory stands alone as a formal model of the endogenous development of cognitive flexibility. She describes RR as ‘a process by which implicit information in the mind, subsequently becomes explicit knowledge to the mind’ [Karmiloff-Smith, 1992, p. 18]. Karmiloff-Smith has outlined the RR model in most detail in her 1986 paper, and in 1990 she studied children’s drawings to try and support one particular aspect of the theory: The opaqueness of initial procedural representations associated with successful, but inflexible, performance. The present paper focuses on this aspect of her model, and presents data from the drawing domain which do not support the RR account. Theoret-
ical problems outlined in Spensley [1995, 1997] will be elaborated in this domain, and an alternative approach: Recursive Re-Representation (3Rs), will be proposed. It will be argued that the 3Rs model provides a more parsimonious explanation of the data, and attaches greater importance to cognitive flexibility within cognitive development.

**Representational Redescription**

The RR account developed from Karmiloff-Smith’s [1979] insight that development does not end with ‘behavioural success’ and that traditional learning models which require feedback from task failures cannot account for this period of ‘post-success’ development. The RR model [Karmiloff-Smith, e.g., 1984, 1986, 1992, 1994] was then proposed to explain this specific period of development beyond successful performance, rather than as a complete account of cognitive development. The RR model begins with successful but unreflective performance, and ends with flexible, reflective performance. It explains the emergence of cognitive flexibility in a domain as the redescription of knowledge into a series of four representational formats. The first level is the original representation associated with successful performance, and the other three levels reflect repeated redescriptions of the original [Karmiloff-Smith, 1986]. These formats increase in generality, and then in accessibility to awareness. Initial opaque procedures (Implicit level) are redescribed into more general procedures (Explicit 1) which can be related to other redescribed procedures and are available as data to the cognitive system, although not available to conscious access nor verbal report. Explicit 1 procedures are then redescribed into a more accessible format (Explicit 2) and finally into a ‘mentalese’, accessible to consciousness, and finally, in some cases, into a verbalisable representation (Explicit 3). According to the RR model, cognitive flexibility is possible when representations can be accessed by awareness. Awareness can only access knowledge in the two highest level representational formats. The earliest representations associated with successful performance are inflexible and opaque. Redescriptions between these formats are achieved by endogenous metaprocesses which operate on the representations and are stimulated by stable success at the previous level [Karmiloff-Smith, 1986].

The RR model has three behavioural phases associated with the underlying changes in representational formats. These are most apparent in, although not restricted to, U-shaped behaviours [Strauss, 1982]. In a domain which produced a U-shaped behaviour, these would be: phase 1 – initial success; phase 2 – performance decrement; phase 3 – new, flexible success. Spontaneous U-shaped behaviours are rare (but they are useful for expository purposes). In most domains these three hypothesised phases would not be accompanied by observable changes in behaviour. The RR model is a phase, as opposed to a stage model (e.g., Piaget’s). The RR model’s phases relate locally to specific tasks, and the phases are passed through in the fixed sequence for each task. However at any particular age, a child will be at different phases in different domains.

The example most frequently cited by Karmiloff-Smith [e.g., 1984, 1992] to illustrate the RR model is her block balancing task [Karmiloff-Smith, 1984]. This task, she claims, produces a U-shaped curve in performance in 4- to 9-year-old children. Children were asked to balance a number of blocks on a narrow bar. The blocks were of three types. Type A blocks were symmetrical and balanced in their centre. Type B blocks were obviously weighted at one end and therefore balanced off centre. Type C blocks were
inconspicuously weighted with lead implants, so that they were visually indistinguishable from type A (symmetrical) blocks, but actually balanced off centre.

Karmiloff-Smith [1984] reported that the youngest children could successfully balance all the blocks, whilst slightly older children failed on all but the type A blocks. The oldest children could again balance all the blocks [but see Spensley and Joiner, 1999, for an alternative view of this task]. According to the RR model, the behaviour in the first successful phase reflects data-driven processes. During this phase the child treats each block as an isolated problem and successfully balances the blocks through a process of positive and negative proprioceptive feedback. The child places the block in a random position on the bar, and then moves the block backwards and forwards along the bar until balance is achieved. The underlying knowledge is represented as isolated, compiled, procedures [Karmiloff-Smith, 1986]. Karmiloff-Smith is not concerned to account for the process by which the knowledge associated with initial success is acquired, she just claims that once acquired it is represented in this format.

The second phase reflects the redescription of the Implicit-level procedures by predominantly ‘top-down’ metaprocesses. This operation produces additional organisation-oriented procedures which reflect the common components present across all the individually successful motor procedures. Children’s behaviour in phase 2 of the balancing task is dominated by their (Explicit-1 level) ‘theory’ that things balance in the middle, and phase 2 children are only able to balance the type A blocks. They only try to balance blocks at their geometric centres and those blocks that do not balance are discarded as ‘impossible’ to balance. These new procedures may be over-general, as in this example. Where over-generalisations occur, a decrement in performance can be seen and the child’s behaviour exhibits a U-shaped growth curve. This behavioural evidence of redescription will not be directly available for the majority of tasks, where the redescribed phase 2 procedures will continue to produce correct performance.

In the third phase, children once again manage to balance all the blocks. Initially they try the geometric centre, but they have the flexibility to use proprioceptive feedback if this approach does not succeed. Phase 3 may produce similar (or even the same) outward performance as phase 1, but the underlying representations are different. The rigidity of the phase 2 redescription into generalised procedures is lost, as these procedures are modified by external data to cope with exceptional cases in a flexible way. The child’s behaviour in this phase is neither dominated by top-down control mechanisms, nor by environmental stimuli. There is a dynamic interaction between them. The phase 3 procedures have been redescribed to allow for conscious access, although they maintain the original code in which the skill was acquired. Procedures may be further redescribed from this original code into an abstract code or ‘mentalese’. This uniform code enables generalisations to be made across codes and allows easy translation into a linguistic code facilitating verbal report. This fourth level of representation will not occur in all domains, and there is no spontaneous behavioural evidence associated with this final redescription.

Karmiloff-Smith emphasises the distinction between behavioural change and representational change in cognitive development. Other accounts of development [e.g., Marshall and Morton, 1978] have taken behavioural success as evidence of underlying competence (in the Chomskian sense) and do not account for a child’s development beyond the achievement of successful performance. Karmiloff-Smith [1992] provides many examples of children developing beyond successful performance, and this is particularly clear in their linguistic behaviour. Children who successfully used words such
as 'went' later produce the incorrect forms 'go-ed' and 'went-ed' before they once again produce the correct word. She argues that successful performance does not necessarily indicate an adequate underlying representation (competence) and that, in general, representational development continues beyond the initial appearance of successful behaviour. This continuing development results in the ability to operate flexibly in a domain. However, the only evidence for the idea of representational development beyond behavioural success (in the form required by the model) is provided by examples of U-shaped behaviours. The claim that this three-phase process is general to all of cognition seems to be an, as yet, unsupported hypothesis. However, Karmiloff-Smith [1992] has related her model to a broad range of domains, and claims generality [Karmiloff-Smith, 1992]. Her examination of children’s drawings [Karmiloff-Smith, 1990] was one attempt to support her conception of the phase 1 inflexibility associated with initial success, without any suggestion of U-shaped behaviours.

A distinctive feature of the RR theory is the level of formality with which it has been specified [Karmiloff-Smith, 1986]. Karmiloff-Smith is one of the few developmental psychologists who have attempted to specify their theories at the algorithmic level [Marr, 1982]. For this reason, it is possible to test the theory, as it has the merit of being clear enough to be falsifiable.

Evidence from Children’s Drawing

The issue of flexibility has been addressed in the drawing literature. Goodnow [1978] and Sitton and Light [1992] have both described developmental sequences in the modifications of children’s drawings, indicating that flexibility increases in terms of the differentiation in the final drawing products. However, these accounts do not comment on the underlying cognitive restructuring associated with these changes. Freeman [1980] has described a rigidity in 4- to 7-year-olds, who will draw the canonical projections of, for example, a cup with the handle to one side, despite being encouraged to observe a model with the handle hidden. However, he claims, this rigidity can be overcome by instructions.

Karmiloff-Smith [1990] developed a drawing task to demonstrate developmental differences in flexibility. At this time, there were no reports of spontaneous U-shaped behaviours in children’s drawings, although Davis [1997] has since found one at the level of the aesthetic content of drawings. In Karmiloff-Smith’s study of children’s drawing she sought evidence for one part of her RR model, specifically, the issue of representational format. She argued that the representations associated with initial successful performance, i.e., phase 1, were isolated, compiled procedures. The task involved asking children to draw a man and then ‘a man that does not exist’ (also a house/‘house that does not exist’ and an animal/‘animal that does not exist’). The rationale was that the ability to draw ‘a man that does not exist’ requires children to operate on their representations to make alterations to their man-drawing procedure. In terms of the RR model, this kind of flexibility does not emerge before the initial procedural representation has been redescribed. There is evidence in the drawing literature for stereotyped productions in children’s drawings: Goodnow [1977] reports the importance of orderly sequences in drawing by children from 3 years old, and Freeman [1980] suggests that the major components of human figure drawing are subject to serial order effects. However, there is no suggestion of the absolute rigidity proposed by Karmiloff-Smith.
In keeping with her model, Karmiloff-Smith [1990] took ‘behavioural mastery’ as the starting point and looked at children between the ages of 4 and 10. In communities where children have access to drawing materials, most children can draw a simple house and man by the age of 4–5. She hypothesised that these early competent drawings are represented as ‘compiled and automatised’ procedures [Karmiloff-Smith, 1990, p. 63] that can be run easily and consistently by the young child. The child has no access to the constituents of the procedure and the procedure can only be run in its entirety (consistent with the notion that it is compiled).

At this level of representation it was claimed that children experienced difficulty with the task of drawing ‘a man that does not exist’, due to the fact that ‘they are forced into operating in some way on their internal representations’ [Karmiloff-Smith, 1990, p. 61]. Almost all the children she tested were able to complete the task, but the 4- to 6-year-old children fulfilled the task requirements in a significantly different way to the 8- to 10-year-olds. The younger children were only able to modify their drawings by altering the shape of elements, the overall shape of the outline, or by omitting elements. Karmiloff-Smith argued that at the first level of procedural success children could only execute a complete drawing procedure (composed of a number of elements) and then stop. Where omissions were made, Karmiloff-Smith ‘asserted with some assurance’ [Karmiloff-Smith, 1990, p. 66] that these must have been made at the end of the sequence, i.e., the procedure had just been prematurely terminated, omitting the final element. In contrast, the 8- to 10-year-olds produced all these types of modifications and, in addition, were able to produce variations that involved interrupting their procedures, such as deleting elements in mid-sequence, moving or transposing elements, and adding additional elements (either from the same category, e.g., adding extra arms or legs to a man, or cross-category, e.g., adding wings to a house).

In a subsidiary experiment, Karmiloff-Smith countered the possible claim that this age difference could have been caused simply by a lack of inventiveness on the part of the younger children. She asked eight 5-year-olds to draw ‘a man with two heads’ and ‘a house with wings’. Seven of these children were apparently unable to draw ‘a man with two heads’, and were only able to copy an example slowly and laboriously. This tortuous success was only achieved, Karmiloff-Smith claims, by creating a completely new procedure (although procedure-creation is a process outside the scope of the model). The ‘man with two heads’, it was claimed, involved interrupting the drawing procedure after the production of the first head to repeat the head drawing phase. By contrast, children were successful in drawing ‘a house with wings’ as this could be achieved by adding wings to a completed house procedure.

**Drawings Are Not Compiled Procedures**

Spensley [1990] has shown that by using the computational metaphor of ‘compiled procedures’ [Karmiloff-Smith, 1990, p. 62], Karmiloff-Smith is making very strong and specific claims. A procedure is a sequentially fixed series of operations. A compiled procedure is a procedure that has been re-coded (for speed of execution) in such a way that there is no access to the constituent parts of the original procedure. The compiled procedure forms a new unanalysable whole (in a lower level code) which can only run in its entirety. The constituents of the original procedure do not exist as units within the new compiled procedure.
The modifications that Karmiloff-Smith found in the 4- to 6-year-old children’s drawings are not consistent with the analogy of a compiled procedure. These children were able to change the shape of elements, which implies that the elements were accessible, at some level, to be modified. This would not be the case with a compiled procedure. Similarly, deletion of an element, even if it is only the last element in the sequence, presupposes the existence of identifiable elements. The uninsightful interruption of a compiled procedure would not necessarily leave the picture cleanly missing one complete element. The procedure could as easily be terminated halfway through drawing a leg, for instance, although this kind of modification was not reported.

It is not essential to the RR model that the procedures are compiled, and Karmiloff-Smith [1992] has accepted that this is not what she meant. However, the model still requires all elements within the procedure to be inaccessible and for the whole procedure to be opaque in some other way. This issue will be dropped in favour of testing the weaker claim that drawings are (uncompiled) procedures. This still leaves the predictions of strict ordering in the production of elements, and the non-interruptable nature of the execution of the procedure.

**Experiment 1: Drawings Are Not Procedures**

A simple test of the hypothesis that 4- to 6-year-old children execute procedures when they draw stereotyped objects is to discover whether children consistently produce all the components of all their drawings of a particular object in a strict order. For example, if a child draws a man in the sequence: head, face, hair, body, legs, arms, then for every man drawing that this child executes, these elements must be produced in that same order. If children do not produce exactly the same set of elements in each drawing, the procedural account could be taken to apply only to the ‘core’ aspects of the drawing. In this case any non-essential modifications, such as hats, must be made independently of the execution of the main procedure; that is, after (or before) all the core elements have been produced in their strict sequence. Children should be unable to add new constituents or non-core elements in the middle of their procedures.

Karmiloff-Smith [1990] did not record the order of production of elements within her children’s drawings, nor routinely note whether omissions were made at the end of the sequence. However, these predictions can be checked with a simple replication of her experimental task of ‘drawing a man’/‘drawing a man that does not exist’ and consistently noting the order of production of elements.

A further prediction of the procedural account is that the execution of a procedure should be uninterruptable. Karmiloff-Smith supported this aspect of the procedural account with the claim that young children did not produce any modifications of their drawings that involved interrupting their procedures. She argued that all their modifications could have been made at the end of a drawing (based on an analysis of the finished drawings). However, the ‘draw a man that does not exist’ task is a complex one and seems to involve more, cognitively, than the mere interruption of a drawing procedure. The uninterruptable nature of drawing procedures could be demonstrated more clearly by using much simpler interruptions.

If, as Karmiloff-Smith claims, 4- to 6-year-old children cannot interrupt their procedures, then any disruption to the execution of their drawing should force the child to start again. A simple interruption was created in this experiment by knocking a jar of
pens onto the floor and asking the child to help retrieve them. If young children have absolutely no access to their 'procedures', then this interruption should force them to restart their drawings.

For children to insert new elements into their drawings they have both to suspend their 'procedure' and to insert something new. It is conceivable that children might be able to restart an interrupted procedure before they could alter it to insert an additional element. That is, young children might succeed with the simple interruption task before they could succeed with Karmiloff-Smith's more complex 'man that does not exist' task.

An intermediate level of difficulty could be achieved with a conceptually simpler modification. If the modification did not have to be invented by the children, this would relieve the, perhaps confounding, cognitive load of the original task. Asking children to make a conceptually congruent modification should prove just as difficult as the 'man that does not exist' task if their representations are the opaque procedures suggested by the RR model. In this experiment, children were asked to draw 'a man with a beard', a conceptually congruent modification which is outside their normal stereotype. If 4- to 6-year-old children do not have the ability to modify their procedures, then they should only be able to succeed on the 'beard' task by adding a beard to a completed man drawing.

To summarise, the following experiment involved a replication of Karmiloff-Smith's 'draw a man'/'draw a man that does not exist' task with two additional conditions: draw a man (interrupted) and draw a man with a beard. This allowed the order of production of elements to be analysed across four man-drawing examples. If the drawings are produced by executing procedures, then all the elements common to all the pictures should be drawn together, and in precisely the same order. Further predictions, from the RR model, are that a simple interruption should disrupt young children's performance and that, in their drawings of bearded men, the beard should always be drawn last.

Participants

Twenty-eight children were tested, with ages ranging from 4 years 8 months (4:8) to 9 years 4 months (9:4). There were 16 children in the younger 4- to 6-year-old group (mean age: 5:8), and 12 in the older 7- to 9-year-old age group (mean age: 7:11).

Procedure

The children were tested individually in a private room. They were initially presented with a sheet of paper and asked to select a pen from a plastic jar containing 12 pens. The children were given three drawing tasks containing the four experimental conditions. In the first task, children were asked to draw a picture of two men. They were allowed to draw one man without distraction (simple) and were interrupted in the middle of executing the other drawing (interrupt). This interruption involved being asked to help pick up the jar and pens that the experimenter had 'accidentally' knocked onto the floor. This invariably involved them leaving their seat and crawling on the floor. The interruption was not specifically timed but occurred when the experimenter judged that a child was in the middle of her drawing. The task was not subdivided into two tasks of drawing a single man to avoid asking children to repeat a task that had already been completed satisfactorily. In the second task, children were asked to draw a man with a beard. In the third task the children were asked to draw a 'man that does not
Results and Discussion

The simple interruption caused no problems. None of the children showed any difficulty in recommencing their drawings. Without hesitation they picked up where they had left off. Two children (5:1 and 5:7) were not interrupted because they effectively interrupted their own procedures by drawing both heads before completing either man. The continuity in performance following a simple interruption was obviously maintained by the external record left by their partial drawing. However, being able to continue where one left off, even in this supportive context, seems to require some flexibility which is inconsistent with the rigid execution of a procedure.

None of the children had any problems drawing a man with a beard. All but 2 of the children drew the beard in conjunction with their drawing of the face (that is, either immediately before, immediately after or in the middle of drawing other facial features). The other 2 children did leave the beard until the end, but these were not the youngest children as Karmiloff-Smith would have predicted. One of them (5:11) paused for an extended period while drawing the face, asked ‘Shall I do a mouth?’ and then decided to postpone the problem. This involved quite high level anticipation of his drawing production, which does not resemble the unreflective execution of a procedure. The other (9:2) finished his drawing, turned to look at the experimenter, then, with a cry of ‘Oh!’ appeared to remember that the man should have had a beard.
Drawing a ‘man that does not exist’ did prove more problematic. Many of the younger children had difficulty understanding what was required of them, and 4 of them failed to modify their drawing in any way (age range 5:4–6:0). Some modifications were ‘funny’, e.g., funny hats and funny faces, and some changes were not obvious from the final drawing (fig. 1, 2) but were described verbally.

All the modifications were grouped using some of Karmiloff-Smith’s categories: (1) deletion of elements, (2) changing shape of elements, (3) changing position or orientation of elements, and (4) adding new elements from the same or cross-category. No drawings fell into the ‘changed shape of the whole’ category, and as there was only one cross-category addition, the addition categories were merged. The results are shown graphically in figure 3. The modification types made by the two age groups clearly replicate Karmiloff-Smith’s [1990] results. Changing the shape and size of elements was found right across the age range. However, all except 1 child (7:7) made their modifications ‘mid-procedure’. Deletion of elements was also found across the age range, but with all of these omissions being made mid-procedure. These mid-procedure modifications are inconsistent with the representational format proposed in the RR model. Only the older children inserted extra elements (n = 3), and only 1 child (9:1) introduced a ‘cross-category’ element (pig’s trotters for arms). Only 1 child (8:3) changed the position of elements by transposing the nose and mouth.

In the critical 4- to 6-year-old age group, all those who made modifications to their drawings made them in the middle of their ‘procedure’. This reinforces the results from the ‘beard’ condition, indicating that young children are able to interrupt their ‘procedures’. All the 4- to 6-year-old children produced at least one modification (either the beard or their ‘strange’ modification) ‘mid-procedure’.
The order of production of the core elements of the children’s drawings was analysed. Core elements were individually designated as those that appeared in all four of a child’s drawings. Non-core components were ignored. Although 21 of the 28 children consistently started by drawing the same component (usually the head) in each of their productions, only one 4- to 6-year-old and 2 older children went on to draw all the core components in the same order. Typically, a child would add the feet as the last element in their first drawing and then produce them in conjunction with drawing the legs in all subsequent productions. Here again, these results do not support a procedural account as there is no evidence to support the notion of a sequentially fixed production order.

To summarise, there was no evidence to support Karmiloff-Smith’s hypothesis that young children are executing a simple procedure when they are drawing a man. The difference in modification type with age replicates Karmiloff-Smith’s [1990] findings, but her explanation, in terms of procedural representations, cannot be supported. These results will be explored in experiment 3, and elaborated in the ‘General Discussion’ section.

**Experiment 2: ‘Behavioural Success’ in Drawing**

A possible criticism of the previous study would be that the children tested in this experiment were more advanced than those studied by Karmiloff-Smith, although they were the same chronological age. That is, they could already have progressed beyond phase 1 procedural representations. In experiment 2, experiment 1 was extended to a group of younger children.

The RR theory specifically explains representational development beyond ‘behavioural success’. However, it is not obvious what constitutes ‘success’ in the drawing
domain, unlike the block-balancing task where a child either could or could not balance a block. Karmiloff-Smith [1990] does not define ‘success’ or ‘behavioural mastery’ beyond the ‘capacity to draw familiar objects with automaticity’ (p. 60). If a ‘successful’ drawing of a person is taken to be a recognisable likeness of a specific individual, then ‘success’ is achieved by only a minority of adults. If ‘success’ is taken to be the point at which others (adults) spontaneously recognise that the marks on the paper represent a person, then this is achieved by children younger than those studied by Karmiloff-Smith. The definition of ‘success’ cannot include any characteristics of the finished drawing: In the previous studies, 2 of the children did not include arms on any of their drawings, and 1 did not draw a body for any of her men. None of the 4- to 6-year-olds consistently drew a neck. However, they all produced drawings on request and so fulfilled the ‘automaticity’ criterion.

Three-year-olds commonly produce identifiable ‘tadpole’ people. Most children do produce tadpoles, although the stage may last only days or a matter of months [Cox and Parkin, 1986]. Tadpoles may simply comprise a head with two stick legs, however the intention to depict a person is clear. In terms of communication, they are ‘successful’. Initially, the tadpole formalism may not be produced consistently ‘on demand’, and thus may fail to fulfil Karmiloff-Smith’s ‘automaticity’ criterion. However, Karmiloff-Smith does not make any attempt to define a criterion for ‘automaticity’, and it is possible that the initial ‘success’ in figure-drawing (represented by unanalysable procedures) occurs earlier in development.

There are other reasons to hypothesise that ‘automaticity’ might occur at this earlier stage. Previous research has indicated that there may be an atypical rigidity in representation at the tadpole stage. There is also some evidence of a ‘U-shaped’ performance on related tasks, suggesting that the tadpole stage might be associated with the opaque representation that the RR model requires. Cox and Parkin [1986] have argued that tadpole drawers are resistant to attempts to improve their drawings, and Taylor and Bacharach [1981] have shown how the tadpole representation dominates the child’s perception of schematic figures.

Cox and Parkin [1986] tried to improve the productions of ‘pre-representational’ drawers (2:0–4:11) by decreasing the task demands. They identified five (age-related) categories of children based on their free drawings: those who produced (a) scribbles, (b) distinct forms, (c) tadpoles, (d) transitional figures, and (e) conventional figures. They tried to get children to improve on their free-drawing category with three tasks designed to remove problems of recall. The tasks were: (a) to copy a conventionally drawn figure, (b) to assemble a jigsaw of simple pieces, and (c) to draw from a dictation of bodily parts.

Cox and Parkin [1986] did find that whereas most of the children improved on at least one of these tasks, only 33% of the tadpole and transitional drawers improved on any of the tasks. They concluded that whatever the representation is underlying the production of tadpoles, it seems to be a stable and resistant form.

It seems likely that as children develop a system of formulas and rules for representing information in drawings, other cognitive processes might be affected, as suggested in theories proposed by Arnheim (1974) and Harris (1963) [Taylor and Bacharach, 1981, p. 373].

Meili-Dworetski [quoted in Taylor and Bacharach, 1981] found that children who could not yet produce representational drawings could name more body parts than chil-
Children who drew tadpoles. Taylor and Bacharach [1981] argued that children's meta-
knowledge for drawing humans interferes with their ability to name body parts, such
that they named only the parts which they represented in their drawings.

Taylor and Bacharach [1981] presented children with three drawings characteris-
ting three levels of children's figure drawing: (i) a tadpole; (ii) a figure with a small body,
and arms extending from the head; and (iii) a figure with the same proportions as figure
(ii) but with the arms correctly located. Children were first asked to select the figure that
looked most like a real man. Then they were asked to draw a picture of a man, using the
most accurate representation as a model. They classified children's productions into
three categories: (i) abstract (scribbles), (ii) tadpoles (no body), and (iii) complete (with
body). They found that the selection of a figure was significantly associated with the
child’s type of drawing production. On closer examination it was shown that the selec-
tion behaviour of abstract and complete drawers was comparable (the majority selecting
the most complete figure) while the largest proportion of tadpole drawers selected tad-
poles as the best example.

To test the hypothesis that children younger than those previously tested may oper-
ate with procedural representations, experiment 1 was repeated with younger children.
Eight children aged between 3 years 6 months and 4 years 11 months (mean = 4 years 4
months) were tested. The youngest 3 children did not produce recognisable men on each
of the trials, so could not be said to have achieved the necessary consistent behavioural
success. For the older children the results were similar to those of experiment 1. Only 1
of the children exhibited the same production order for the common elements in all of
her drawings, and this child produced the beard in the middle of this sequence. All the
children inserted either the beard or their 'strange' element mid-procedure. There was,
again, no evidence of a procedural representation.

There was evidence of spontaneous metacomments made by these children who
seemed to be very self-critical, and aware of their production capabilities. For example,
'I can’t draw men, only women', due to an inability to draw short hair. ‘I can’t draw one
of those on top of that’ on having drawn a line (presumably the body), referring to
problem of situating a circle (presumably the head) on the top of it. There was also a
level of ongoing criticism of their production: 'That looks like his head' on having drawn
a rather rounded body. Far from executing an unanalyzable procedure, these young
children were critically evaluating every stage of their productions.

**Experiment 3: The Effect of Imagination**

Karmiloff-Smith’s account of children’s behaviour on the drawing task cannot be
explained in terms of the representational component of her model, i.e., children are not
executing procedures. Another explanation must be found for the absence of certain
modification types in the younger age group in experiment 1. As mentioned in the intro-
duction, Karmiloff-Smith has argued that this difference was not due to a lack of imagi-
nation. She describes how seven out of eight 5-year-old children were unable to draw a
man with two heads because this involved interrupting a procedure, and could only
succeed on drawing ‘a house with wings’ by adding wings to a completed house drawing.
In theory, the children who succeeded on the ‘house with wings’ task could just as easily
have added a second head to a completed man, but clearly they did not do this.
Rejecting the procedural explanation of the difference in modification type between age groups leaves an unanswered question. Are young children *incapable* of producing certain types of modification to their stereotyped drawings? This experiment aimed to answer that question. Children were asked explicitly to draw men with each of the modification types that Karmiloff-Smith had identified in spontaneous productions.

**Participants**

Fifteen 4- to 6-year-old children (not involved in the previous studies) were tested individually in a private room. Their ages ranged from 4 years 10 months to 6 years 2 months (mean age: 5:8).

**Procedure**

Children were asked to make a series of six drawings starting with the simple drawing of a man to provide a baseline for comparison, and to allow them to relax and succeed at a task. Children were then asked to draw a series of ‘strange’ men with very specific modifications. To make the instructions absolutely clear, the first 8 children were briefly shown an example drawing before they started their drawing. It was stressed that they did not have to produce the modification shown in the example, but that they were free to make up their own variant. As presenting this visual example seemed superfluous, a further 7 children were not shown the example drawing, although the same example was presented verbally. All the children were told that they could think of their own variant or reproduce the example as they wished. The categories and examples, in order of presentation, were as follows: (1) a man with some part of his body the wrong shape (e.g., a man with a square head); (2) a man with too many of something (e.g., a man with two heads); (3) a man with something missing (e.g., a man with no arms); (4) a man with some part of his body in the wrong place (e.g., a man with legs coming out of his arms), and (5) a man with some part replaced with part of an animal (e.g., a man with wings instead of arms).

Children were encouraged to describe what they were doing while they were performing the task or to describe their ‘strange man’ after they had completed it. The order of production of elements was noted whilst each child was drawing and their performance was videotaped.

**Results and Discussion**

The children in this experiment were clearly happier with these tasks than the children presented with the less specific ‘draw a man that does not exist’ task. The younger ones particularly found the requests highly amusing, indicating perhaps that they had not previously thought of making such modifications themselves. The youngest 4 children (4:10–5:3) did exhibit some lack of imagination in that they simply reproduced the examples given. Older children produced their own manipulations and tended to make multiple alterations to their drawings rather than being satisfied with the minimum,
Fig. 4. Problems in drawing men that do not exist (Michelle, 5:1). a Simple. b Shape change. c Deletion. d Insertion (same category). e Relocation. f Insertion (cross-category).
e.g., adding an extra head, two extra arms and an extra leg. Drawing sequence was again analysed and it was found that all these children made some of their modifications mid-procedure.

Only 1 child (age 5:1) failed on any of the tasks (fig. 4). She tended to copy the example given, and had problems with the man with two heads. However, the drawing was not drawn in a 'procedural fashion' as both heads were drawn before completion of either figure, and she did achieve the goal (of having too many of something) by adding extra arms. The problem may have been caused by difficulties with the attachment, as she did not draw necks. She had a further problem with the relocation task, drawing legs in the correct place before she drew the misplaced legs. However, she succeeded with the complex cross-category insertion, where she drew the wings mid-procedure and these replaced the arms.

**General Discussion**

The drawing data, presented in this paper, address the issue of the representational format associated with Karmiloff-Smith’s model, rather than the notion of RR per se. It could be argued that drawing skills are not represented as procedures, but in some other format consistent with the RR model. However, many of the characteristics of computational procedures are essential to the model: Any candidate representation would need to be inaccessible – otherwise there would be no need for a redescription process; and it would need to produce consistent performance over repeated executions – otherwise there would be no motivation (stable success) for the redescription process. Neither of these characteristics were found to be consistent with the flexible, accessible production process which was observed in these studies.

In her drawing task Karmiloff-Smith sought evidence of the rigidity of a basic procedural representation in children’s performance. It has been argued here that this type of rigid behaviour is not evident in children’s drawing. Children do not produce the elements of their drawing of a man in a strict sequence and they are easily able to make modifications to their productions in the middle of executing a drawing. Drawings are not produced by executing procedures (or a fortiori compiled procedures). It has further been shown that Karmiloff-Smith’s finding that younger children did not spontaneously produce certain types of modifications to their drawings could be explained simply in terms of children’s difficulties in understanding the requirements of the ‘draw a man that does not exist’ task together with a lack of inventiveness. By giving explicit instructions it was found that young children were able to make all the types of modifications to their drawings which, on Karmiloff-Smith’s account, should have been possible only for older children with ‘redescribed representations’.

The development of drawing skill seems to involve continual monitoring and adaptation of the production process, and it seems essential that the child does have conscious access to that process. Gearhart and Newman [1980] have described how children drawing in a nursery situation are not engaged in an isolated individual activity, but modify their work with reference to the productions of other children and the verbal descriptions provided by teachers. The children in our studies were not instructed to give verbal protocols, but a few spontaneous comments were made (particularly by the youngest children) that indicated that access to their production ‘procedures’ was possible – comments such as, ‘I’ll have to draw the head bigger’ (Leigh, 5:7), anticipating
problems with fitting in a beard and indicating the advance planning of his drawing. There was also evidence of the critical monitoring of productions, e.g., ‘that looks like his head’ (Neil, 5:3) on having drawn a rather rounded body. These comments, often made during the execution of a drawing, are not consistent with Karmiloff-Smith’s idea that 4- to 6-year-old children do not have verbal access to, or awareness of the production process. On the contrary, there were indications that children were using language to control and monitor their productions [consistent with a Vygotskian account – Vygotsky, 1978].

In the normal development of drawing skill, children must be able to make some modifications to their drawings in the middle of their ‘procedures’. For example, the progression from tadpole to normal figure drawing involves inserting a body between head and legs, and similarly drawing a neck is a late development which could never be tacked on at the end of a pre-existing man-drawing procedure. The idea of four representational formats, culminating in ‘awareness’, does not seem to capture the richness and variety of behavioural stages in the development of drawing.

Theoretical Problems with Representational Redescription

The study of children’s drawings highlights two specific problems with the RR model: the concepts of behavioural success and of stability as the motivation for redescription. These theoretical criticisms were mentioned in Spensley [1997] and are elaborated here. In conjunction with the data from the drawing experiment, they provide the basis for a new model of the process: Recursive Re-Representation (3Rs).

Defining Behavioural Success

The concept of behavioural success is central to the RR model as it is the starting point for a theory of development ‘beyond successful performance’. Stability of behavioural success is then the stimulus to the first level of redescription. Without a definition of success, the RR model cannot begin to be applied to a domain. Success appears to be a clear criterion in formal domains such as language or block balancing: either the child produces the correct linguistic output in the correct context or she does not; either the block balances or it does not. However, it is a more problematic notion in less clearly defined domains such as children’s drawings.

Karmiloff-Smith [1986, p. 105] attempts to define ‘procedural success’ thus: ‘when there is a match between the child’s output and adult output and the child’s output receives only positive feedback.’ However, this definition raises problems even in the apparently clear language domain. The child will not necessarily reach both these states at the same time. The child may receive only positive feedback when the output is merely communicatively adequate. Children are not continually corrected once they are understood. Far from it, many parents actually revel in their young children’s linguistic idiosyncrasies!

The issue of feedback is quite distinct from the second part of the definition when a match with adult output is required. For matching to occur, there must be a model of adult output available to provide the basis for the comparison. It is not clear where this model would be located or how the matching would occur. It cannot be an endogenous
process otherwise it presupposes that the child already possesses the adult model in some form. In the drawing domain, some children made reference to other children’s drawings as the source of a model – but this is not in the RR conception, where the redescriptions are predominantly endogenous processes operating over representations.

The concept of ‘behavioural success’ is, at best, underspecified in the RR model, and it is particularly difficult to define ‘success’ in the drawing domain: Children’s drawing abilities continue developing beyond the achievement of an initial recognisable depiction. From the child’s perspective, there may be a series of ‘successes’ on the way towards their final depiction formula, for example, when they manage to draw a person with a body, a clothed person, when they manage to draw hands with five fingers, and so on. The lack of any single recognisable point of ‘behavioural success’ means that it is impossible to apply the RR model, as it stands, to development in this domain.

In attempting to tie down this problematic concept, Karmiloff-Smith [1992] has suggested that ‘behavioural success’ might correspond to the stabilisation of the weights in a connectionist network. A network moves from continually adapting the weights on its connections in response to each new input to a state where additional input does not change the stable network. This does hold some hope of defining ‘behavioural success’ in formal domains, but there still needs to be some higher level endogenous metaprocess which recognises the stability, through having access to the network representation itself. In addition, it is not clear how a connectionist account of the initial representation would link to the higher levels of redescriptions in the model, and Karmiloff-Smith has not yet elaborated this account.

**Stability and Opacity**

The stimulus to redescription in the RR model is ‘stable success’. This concept is also problematic in the drawing domain. The 4- to 6-year-old children at the focus of Karmiloff-Smith’s account are still developing their drawing skills and their progress would seem to involve a continual series of minor modifications to successive productions rather than a stage of ‘stable success’. Many of these changes are based on observations of more capable peers, for example ‘I’m going to do hands like Julie does’. Karmiloff-Smith was pioneering in emphasising the role of internal factors in provoking representational change, but it may be that the balance between internal and external factors could be shifted towards the latter. External factors may have a more central role in representational development ‘beyond behavioural success’ than the RR account allows.

The idea of a stable success provides an intractable contradiction for the representations hypothesised by the RR model. The initial representations must be opaque and isolated – which Karmiloff-Smith states can even lead to multiple copies of the same procedures [Karmiloff-Smith, 1986, p. 105]. However, endogenous metaprocesses must be able to identify when these same procedures are in a state of stable success, which requires access to the contents of the (opaque) procedures to monitor which representations are ripe for redescription.

The concept of stable success also requires the identification of a distinct domain to which the state can be attributed. As there should be no access to the ever-increasing collection of opaque procedures, there is no obvious way to delimit such domains. The
identification of specific domains is essential given the ‘phase’ nature of the model, which hypothesises that different tasks will be ready for redescriptions at different times. Certain task domains need to be identifiable as ripe for redescriptions, when others are not. The implicit representations (associated with initial successful performance) are characterised as isolated procedures, with no cross-referencing of the contents of the procedures. With this type of opaque representation, there is no apparent way of either recognising whether a domain is complete or whether success is consistent across all instances within a domain.

**Four Representational Levels**

The limited passage from opacity to awareness on the RR model would seem to place an upper limit on knowledge development. Once ‘awareness’ had been achieved, for example in the drawing domain, no further development is hypothesised. It does not, therefore, account for the differences in cognitive flexibility between expert and non-expert adults. It is hard to believe that the 8- or 9-year-olds who can flexibly fulfil the ‘draw a strange man’ task will not develop their man-drawing representations any further, particularly, if they later become skilled artists. The RR model also implies a lower limit on flexibility, at least the development to the highest level of linguistic redescriptions will be impossible for infants and very young children.

**Overall Comments on the RR Model**

Karmiloff-Smith’s observation that children continue to develop beyond the point at which they can successfully execute a task was a significant insight for cognitive development. However, this observation does not justify the existence of an entirely new and separate developmental mechanism (i.e., RR) coming into operation after ‘success’ has been reached [Spensley, 1997]. Karmiloff-Smith [e.g., 1992] has rightly argued that theories which stress the role of children’s failure on tasks, in developing their representations, cannot account for development ‘beyond success’. But rather than supplementing these existing theories with an additional ‘post-success’ developmental mechanism, it is possible that these failure-based accounts are not the correct explanation of pre-success development. The first step in justifying a separate stage in development would be the identification of a clear division between pre- and post-success behaviors. It has been argued earlier that ‘success’ does not exist as a single developmental point within the drawing domain. More generally, Boden [1982] has argued against the notion that failure is important for development. If failure to achieve goals (negative feedback) is not required to enable the child to achieve successful performance, then the same processes which precede success in any domain could also take the child beyond it. The difficult problems of defining ‘behavioural success’ and ‘stable success’ are then not solved, but removed.

Karmiloff-Smith [1994, 1997] accepts that the concepts of ‘behavioural success’ and ‘stable success’ are hard to define, but does not draw the conclusion, offered here, that this may be because they are not useful concepts in a developmental model.
Towards a New Model: Recursive Re-Representation

The RR model suggests that cognitive flexibility is the result of a completely new developmental mechanism operating after success. A more parsimonious account is that the processes which created the first representations could also create subsequent re-representations. It seems reasonable that this simpler explanation should be considered and rejected before additional post-success processes are proposed. This is the position adopted in the 3Rs model. Dropping the fundamental distinction between pre- and post-success processes raises the possibility that a new model of the progression towards cognitive flexibility could provide a more general developmental model. However, removing this constraint requires a new model rather than a generalisation of the RR model, as it has implications for other parts of the model.

If ‘behavioural success’ is not the clear starting point for RR, then other aspects of RR theory must be changed – crucially, the concept of distinct representational formats. The limited iteration of three redescriptions requires a specific starting condition (‘success’), and ends with completely flexible, linguistically encoded knowledge.

The standard Artificial Intelligence solution to this problem of limits would be to propose a recursive redescription process or sequence of processes. This removes the specific problem of defining starting conditions, although it creates others. A recursive process requires a more generally applicable redescription mechanism than the specific metaprocesses described in the RR model [Karmiloff-Smith, 1986]. It also necessitates the dropping of the sequence of qualitatively different representational formats. Karmiloff-Smith [1992, 1993] has recently prefixed her description of the three phases with the word ‘recurrent’, although this change in the model is not explained. Although she has never suggested it, a ‘recurrent’ version seems to require a passage from opacity to awareness and then back to opacity. The passage from opaque representation to flexible representations could not be repeated unless the results of one RR subsequently became the opaque basis for the next RR.

Awareness and Cognitive Flexibility

In the RR model cognitive flexibility is associated with awareness. The 3Rs model maintains this. However, the model takes a different basic conception, arguing that awareness is a central feature of human information processing in any domain, and that people are always aware of something. This might equate to the contents of working memory [Baddeley, 1990]. As a result, the 3Rs model holds that cognitive flexibility is a feature of whatever the contents of awareness may be. What develops is the objective amount of information that can be held in awareness at any one time.

The RR model attributed awareness to specific representational formats, and so awareness was an all-or-nothing attribute of knowledge in a domain. In the 3Rs model there is no qualitative difference in accessibility between levels of representation, just a single representational level. The 3Rs model will argue that awareness is available to a limited number of ‘chunks’ of information [Miller, 1956; Simon, 1974] at any one time. The difference between children of different ages is in the level of ‘chunking’ in a domain, rather than in terms of the opaqueness of representational formats. Children will effectively possess a ‘window’ of flexibility which will encompass (objectively) different amounts of information, depending on the compactness of that knowledge [con-
sistent with Halford’s, 1993, general approach]. In the 3Rs model, chunking is seen as a function of developing expertise in a domain. There may also be an increase in processing speed [Kail, 1994] or in the capacity of working memory [Chi, 1977] with development, but the 3Rs model can remain agnostic on both issues as they would fine-tune rather than change the 3Rs model.

The difference in the scope of children’s awareness could explain the replicated result from Karmiloff-Smith’s ‘draw a man that does not exist’ task (experiment 1), i.e., that there is a significant difference in the types of transformations in drawings with age. The younger children spontaneously changed the size or shape of a drawing part or deleted parts of their drawing, but only the older children were able to insert parts either from the same or different categories, or to change the orientation of constituent parts. There was nothing preventing the younger children from executing the alterations when they were specified for the children, i.e., the creative part had been removed, but then they would follow the experimenter’s instructions. Young children did not appear able to generate their own variant.

The types of spontaneous changes produced by the younger children relate to individual parts of the drawing, and alterations to those parts. These changes could be made at a local level, where a specific body part was the focus of attention either for change or for deletion. In contrast, the changes made by the older children involved a broader focus, an overview, of the complete drawing (or at least more than one element of the drawing). Inserting an element from the same category requires some local reorganisation of, for example, the relationship between body and legs to insert an extra pair of legs. Transposing elements requires attending to the relationship between the two parts and holding both locations in attention at the same time. The final (and possibly the most advanced) category is that of cross-category insertion. This requires a comparison of, for example, the overall organisation of the parts of a man-drawing with the organisation of the parts of a pig. Then, generating an analogy of one element, e.g., trotters, from its position in the pig drawing, transferring it to the same relative position in the man drawing (i.e., replacing legs). It thus involves awareness of the relationships between the elements of two different animals at once. The differences in children’s spontaneous productions reflect the amount of information which needs to be held in central processing (or attention) for the modifications to be conceived. In the earliest modifications, only a single element of the drawing needs to be manipulated, i.e., the focus of attention. In the most advanced modifications, the whole man drawing plus a representation from another category must be considered together. To enable these higher-level modifications, the representations of constituents must be more compacted, or ‘chunked’ in the older child. This will be accompanied by a loss of flexibility at lower levels, with the most basic levels not requiring attention, for example the motor skills involved in drawing.

Cognitive Flexibility and Goals

To illustrate the 3Rs model’s proposed developmental sequence in the drawing domain, an additional element must be introduced: the child’s goals. Goals constitute the motivation for re-representing knowledge into a more compact form. The 3Rs model characterises three main levels of chunking of knowledge, although the content of these main levels will vary with development. The levels are subjective divisions, differing in terms of the relationship between the individual’s knowledge and awareness. The
three levels are basically those described by Activity Theory [Leont’ev, 1981], and the
caracterisation of the levels in terms of the allocation of attention is very similar to this
account. However, because the 3Rs model is concerned with the role of information
processing and representational change, the distinction will be used quite differently.
To avoid confusion with an Activity Theory account, a different terminology will be
adopted.

The focus of awareness in normal functioning will be called the task level. If a
person was asked what she was doing, this would be what she would generally report. To
use the drawing-a-man example, a task for a young child might be ‘drawing a head’. The
task will generally be contributing to some higher level goal, in this example ‘drawing a
man’. The goal level will organise the task level, providing a ‘map’, but it will not itself
be the constant focus of attention. Goals direct the activity, and may also be part of a
hierarchy of goals, in this example a higher level goal might be ‘create a picture’.

Below the task level will be the constituent level. These lower level actions will
generally be executed automatically without awareness. In this example, a constituent
would be ‘holding the pencil’. The constituent level might, temporarily, be brought to
the focus of awareness if something went wrong. For example, if the execution of the
drawing task was disrupted by the pencil lead wobbling. However, once the problem
had been remedied, attention would once again focus at the task level.

In a developmental context, the 3Rs model will argue that what is a constituent for
an adult may well be a goal or a task for a younger child. For some adults, ‘drawing a
man’ might be a task serving the higher goal of, for example, explaining something using
a diagram. Little or no thought will be given to the motor processes involved in making
the marks on the paper, or the sequencing of elements within the man drawing. For
other adults drawing a man might have the level of a goal, when the concern was to
produce a likeness or a caricature. More attention will then be directed to certain tasks,
e.g., drawing the head shape accurately. In contrast, for a toddler, holding a pencil is a
considerable problem, and would probably constitute a goal. Gripping the pencil with
the correct force to make a mark on the paper would require conscious attention. For an
adult these aspects would form constituents, or even subconstituents that are automati-
cally executed without awareness. The goal for a young child might be drawing a circle,
or a line. Consequently, a complete ‘man-drawing’ process could only be achieved by an
adult directing, or scaffolding the task, because ‘man drawing’ does not exist as a goal for
the child. The child might be able to produce the parts in isolation, but there would be
no continuation to the next element without external direction. At a developmentally
earlier stage, even the task of drawing a circle would be entirely out of conceptual range,
when the grasping of any object was the goal.

As development proceeds, and new goals are created, there will be constituents
which drop below the awareness window as knowledge levels are created above them.
The gripping constituent in the above example for a young child will be a sub- or sub-
sub-constituent for an adult and so on. The lowest levels will operate automatically, and
their execution will not place any load on working memory capacity. In the example of
gripping a pencil there will have to be continuous adjustments made between the fingers
and the pencil in drawing, but in the adult, all of these processes will operate entirely
without awareness. The argument here is that in infancy these processes did require
attention. At some stage ‘gripping a pencil’ or any other object was a goal, with eye hand
coordination being the attended task. This is in accord with Scaife’s [1987] argument
that there is a continuity between motor and cognitive development. Many of the motor
skills are fundamental building blocks of other activities, and have therefore become constituents, with the result that they are inaccessible. The 3Rs model holds that these will initially have been acquired with awareness.

Progression between levels of chunking will be achieved by re-representing the task, that is, using the same mechanisms which created the first representations to re-represent an activity in a more compact form. These processes might possibly be something akin to perceptual analysis [Mandler, 1992]. Re-representation can occur within and across codes, and is a more generally applicable process than RR.

In the RR model, Karmiloff-Smith claims that lower levels of procedural representation are not lost, but can be accessed when required. This is not a feature of the 3Rs model; an old representation will be replaced by a redescribed one, unless there is a separate use for the original representation and thus a distinct reason to maintain it. This replacement is likely to occur by the reinforcement of the new representation through repeated use, and the gradual decay of an unused representation. An example of the loss of earlier representations is the process of tying a bow. Bow tying is a constituent of many activities (e.g., putting on shoes) and is executed automatically. At some stage, though, it must have been consciously learned, in all probability with some verbal instruction. This verbal description is lost, as the bow-tying process becomes automatic. Annett [1990] asked adults to describe, in words, how they tie a bow and found they could not do it without executing the motor action in some way. The process was not directly available for verbal description; they had to carry out the bow-tying operation and then describe their resulting actions. Presumably, in childhood they were explicitly taught how to tie a bow, with some verbal accompaniments, and achieving success required attention. On the 3Rs account, these adults were having to re-represent in a verbal form their automatic, non-verbal, motor representation, which has been used for many years without awareness. They had lost their original explicit representation, but were able to create a new one by describing their actions. Levels below the constituent may have become inaccessible, and many motor skills will be in this category. However, if required, attention can always be focused on the detail of the constituent through the execution and observation of the behaviour, as in the bow-tying example, and a new representation generated.

The recursive process of chunking is always into units of meaning and these meanings will often be externally determined. The meanings will largely be shared between individuals, as they are interpreting similar environments, with similar goals, utilising the same basic encoding and processing mechanisms. In the early stages of development there will be a predictable sequence of development: the infant must represent her own body and acquire basic motor and cognitive skills. There will be a natural progression early on, because it is literally not possible to run before you can walk. At higher levels it will be less easy to predict sequences, although within a given domain, there will be a natural progression in knowledge development: it is necessary to know how to draw a circle before you can begin to draw a person.

Conclusion

Karmiloff-Smith [1986, 1990, 1992] has provided a detailed model of the development of cognitive flexibility. By employing the computational metaphor, her RR model makes very specific and testable claims which, it has been shown, are not supported.
Empirical and theoretical consideration of the RR model as it applies to the domain of children’s drawing has led to the development of an alternative model. The 3Rs model has been proposed, informed by information processing psychology and Activity Theory. The 3Rs theory views the development of cognitive flexibility as the recursive ‘chunking’ of knowledge which allows awareness, and thus flexibility, to reach objectively larger quantities of information with development. The 3Rs model has been shown to explain the drawing data presented in this paper and that collected by Karmiloff-Smith [1990], and it provides a more parsimonious explanation of the development of cognitive flexibility.

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