THE REPRESENTATIONAL RE-DESCRIPTION HYPOTHESIS COMPARED AGAINST TWO CASES

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Abstract. Re-representation is an interesting variety of creativity. The 'Representational Re-description Hypothesis' of Karmiloff-Smith *et al* is a theory of individual cognitive functioning and development emphasising the rôle of re-representation. We ask here whether this can be seen as a general theory of re-representation, and answer in the negative.

1. Introduction

Knowledge is not just a matter of what is known, but also the manner in which it is represented — and the re-representation of a problem or a domain can constitute an epistemic advance of a significant and distinctly creative type (Boden 1990, and 1987 chapter 11).

Treatments of re-representation are to be found in a variety of contexts — for example in literature on the psychology of problem solving (e.g. Duncker 1945, Wertheimer 1961, Holyoak 1990), on mathematical problem solving (e.g. Polya 1948), and on knowledge representation in artificial intelligence (e.g. Amarel 1968, Korf 1980).

A new and especially interesting treatment is to be found in the 'Representational Re-description Hypothesis' or 'RRH' (Karmiloff-Smith 1992, Clark and Karmiloff-Smith forthcoming, Clark 1993). On the basis of evidence from experiments on children's cognitive development, Annette Karmiloff-Smith has argued that human beings have an internally-driven propensity to re-represent implicit, procedural, domain-specific knowledge as explicit, declarative, abstract knowledge. What starts as a procedure *of* the system becomes a data-structure *to* the system (Karmiloff-Smith 1990), and thus becomes manipulable and flexible. The capacity to re-represent in this way, it is suggested, constitutes an evolutionary point past which only humans have passed (Karmiloff-Smith 1992, pp191-192).

The RRH, then, attributes the following characteristics to re-representation:

1. *Breakpoints*: it constitutes a phylogenetic breakpoint, in that creatures lower down the evolutionary scale cannot perform it.
2. *Spontaneity*: the RRH appeals to an 'endogenously driven' propensity to 'spontaneous' re-representation after 'behavioural mastery' has been achieved.
3. *Abstraction*: 'the re-descriptions without doubt constitute some form of *abstraction* from the phase one details' (Clark 1993).
4. *Procedural → declarative transformation*: the RRH addresses the reformulation of procedural knowledge as declarative knowledge, only the latter being a manipulable object of the system.
5. *Implicit → explicit transformation*: knowledge which is implicit in the system's procedures becomes available as an explicit and hence manipulable datastructure.

The consequences of the RRH are far reaching. It has been argued that its implications extend to the problem of intentionality and the traditional debate between rationalism and empiricism (Dartnall 1993), and to the issue of whether or not cognitive fidelity attaches to purely connectionist cognitive models (Clark 1993).

It seems fair to ask whether the characteristics identified by the RRH are true of *all* or only *some* cases of re-representation. Accordingly, the strategy of the present paper will be to analyse two cases — a re-representation of the game of 'number scrabble' and the replacement of Roman by Arabic numerals — and to ask to what extent these conform to the pattern set out in the RRH.

2. Number Scrabble

The initial representation of the game of number scrabble is as follows. Nine cards, each bearing a different numeral between 1 and 9, are placed face-up between the two players. The players draw cards alternately, and the first player to acquire three cards which sum to 15 wins. (If the cards are exhausted without either player acquiring a winning triplet, then the result is a draw.)

This may not be the world's most difficult game, but it is quite hard to pick cards which will:

- produce a winning triple
- prevent one's opponent from gaining a winning triplet, and
- create a 'fork' situation in which either of two cards will produce a winning triplet (so that whatever the opponent chooses, one still wins on the next draw).

Newell and Simon (1972, p62) present a striking re-representation of the game which involves playing noughts

and crosses over a 3 by 3 magic square (this being an arrangement of the numerals 1 to 9, as below, so that each row, column and diagonal sums to 15).

2	7	6
9	5	1
4	3	8

Fig. 1. magic square

The initial representation of the game requires us to proceed by using arithmetic calculation. In the magic square re-representation, the arithmetic features of the game are 'built into' the diagram, and we can proceed by using our capacities of spatial reasoning and pattern recognition. The crucial configurations such as winning triples and forks are easily recognised in this way. Moreover, the procedures in question are familiar to anyone who already knows how to play noughts and crosses.

If number scrabble were played over the telephone, and one player secretly used the magic square representation, it seems clear that this would put that player at an advantage. And the point for our general theme is that performance is affected here not just by *what* is known about the game, but also by *how* it is represented.

3. Numerical Notation

A well known case of re-representation is the replacement of Roman numerals with the now familiar positional notation. The modern system of decimal Arabic numerals uses a positional notation, the base 10, and the numeral zero. In this system a numeral signifies a sum of products of powers of the base, the power being indicated by position: a numeral $ABCD$ signifies

$$(A \times 10^3) + (B \times 10^2) + (C \times 10^1) + (D \times 10^0).$$

Through history there have been a great many numeral systems. The Babylonians had a positional system with base 60 but without a zero. The Mayans had a positional system with zero and base 20, although here the 3rd digit indicates not multiples of 20^2 but of 2018 in order to give the days in their year a simpler representation. The system of Roman numerals has many variants, but generally few primary symbols are used (e.g. I, V, X, L and C), and these are arranged according to additive and subtractive principles.

Different systems, of course, suite different purposes. 'Grouping systems' are useful for keeping incremental tallies, and Roman numerals have the advantage that few primary symbols have to be remembered. But the overwhelming advantage of a positional system with zero is that a divide-and-conquer strategy for the basic arithmetic operations of addition, subtraction, multiplication and division becomes possible whereby a simple operation (involving 'carrying'), iterated along the numerals , achieves the purpose. It is not the expressive power of the notation which is at issue here, but its syntactic consistency and the effect this has on the application of arithmetic procedures.

Each digit has an associated multiplier (a power of the base), and this multiplier is 'built into' the syntax in the form of the digit's position. Thus if two numerals are 'lined up', so are their digits' multipliers, and arithmetic operations can proceed in a simple iterative manner.

With Roman numerals, however, lining two numerals up together does not produce such a concordance. For example, the numeral 'XVII' is built on additive principles, while 'XIV' is built on additive and subtractive principles, and accordingly the positions of the digits cannot be interpreted as with '17' and '14'.

The advantage of positional over Roman numerical notation, then, is not a matter of expressive power over a domain, since both systems can denote numbers. Rather, it is due to the possibility in positional notation of applying simple and uniform arithmetic procedures.

4. Comparison with the RRH

Two cases of advantageous re-representation have been given brief consideration above, and we now turn to the question of how well these fit the picture given by the RRH.

4.1 Breakpoints

RRH re-representation is put forward as constituting a phylogenetic breakpoint. There is no evident reason to deny this in our two cases — it seems unlikely that monkeys or other non-human creatures could have invented these re-representations.

4.2 Spontaneity

RRH re-representation is 'endogenously driven' or 'spontaneous' in the sense that 'behavioural mastery' has already been achieved but re-representation takes place all the same.

The spirit of this account can be seen in our two cases — people do play number scrabble using its standard representation, and Roman engineers did design bridges and aqueducts using Roman numerals. It seems clear therefore that behavioural mastery did precede our re-representations.

However behavioural mastery is a matter of degree, and in our two cases it increases with re-representation. Number scrabble and arithmetic become easier, and we become better at them once we are equipped with these re-representations. Therefore we can only say that their inventions followed a *degree* of behavioural mastery, not that they followed complete mastery.

Spontaneity, further, is not a unitary issue. It may be true, as the RRH suggests, that humans have a unique propensity to re-represent in the absence of exogenous pressure. And it may be true that non-positional systems were successful to a degree. But it cannot be said that positional systems were developed in the absence of 'pressure' to improve arithmetic facility.

4.3 Abstraction

RRH re-representations are more 'abstract' than their procedural predecessors. However it is not clear that this is true in our two cases. The change to Arabic numerals involves liberation from burdensome syntax, but this is hardly 'abstraction'. And in the case of number scrabble, the re-representation is if anything less abstract and general, since it will only work if the rules remain unchanged and winning triplets sum to 9. The initial representation in contrast could easily be changed in this respect.

4.4 Procedural → declarative transformation

In RRH re-representation the initial representation is procedural, supporting behavioural mastery but inflexible, and the re-representation is declarative, and therefore manipulable by the system.

In the case of number scrabble, however, both the initial representation and the re-representation are procedural — in both representations the user is not told a set of declarative propositions, rather he or she is asked to engage in rule *following*. The re-representation comprises the magic square diagram together with a set of heuristic rules for playing noughts and crosses, and although declarative knowledge might be needed to create and check this re-representation, the end result is improved *procedural* knowledge.

Accordingly, the virtues of the re-representation are not of a declarative variety — it does not allow more expressive or more succinct *statements* about a domain. Rather they are of a procedural type — the load on working memory and calculation is reduced, since at any time the diagram has a current state, and it is relatively easy to determine how to proceed to the next state.

In the case of numerals it might be said that both representations are broadly declarative, since both allow us to name numbers. However this is a weak sense of 'declarative' since we can formulate only denoting expressions and not propositions. And more importantly, the *point* of the re-representation concerns the operation of arithmetic *procedures* on numerals. We do not just want to write down numbers, but also to perform addition, subtraction, multiplication, division etc. on them as easily as possible. And this is greatly facilitated by the positional system with zero.

In neither of the present cases, then, is it accurate or sufficient to say that procedural knowledge is re-represented as declarative knowledge.

4.5 Implicit → explicit transformation

In RRH re-representation, what is made explicit in the declarative re-representation is implicit in the initial procedural representation.

It is hard to see that something of this sort obtains with our two numeral systems. A simpler syntax has been introduced, allowing easier application of arithmetic procedures, but it is not evident that this essentially constitutes the emergence of previously implicit propositions about numbers.

In the case of number scrabble, declarative knowledge about triples which sum to 15, and about the intersection pattern of these triples has been *built in* to the diagram, and we might suppose therefore that it was used in creating and checking the re-representation. However this information is not *explicit* in the final diagram without some extra explanation — the diagram does not itself tell us, declaratively and propositionally, that its rows columns and diagonals all sum to 15.

More significantly, the point of the re-representation is not to make this knowledge explicit, but rather to build it into the syntax in such a way as to facilitate the application of appropriate procedures, in this case those of noughts and crosses. The knowledge in question has not become explicit, declarative and an 'object of the system' through re-representation — rather it was explicit in the first place, has been used in creating a re-representation, and is now 'built in' to a diagram in the service of easy application of procedures.

Symptomatically, in using the re-representation of number scrabble, it is not even necessary to know how to interpret it in terms of explicit, declarative propositions about numbers summing to 15. It would be quite possible for one player to play using the re-representation, while being unaware that he or she was playing number scrabble — and win.

In contrast to RRH re-representation, then, it does not seem that the conversion of implicit into explicit knowledge is essential to either of our cases.

5. Conclusion

The cases of number scrabble and arithmetic notation have been presented in order to assess whether the 'Representational Re-description Hypothesis' of Karmiloff-Smith *et al* can be treated as a *general theory of re-representation* (and not to assess it as a theory of cognitive development). Our conclusion is in the negative, since the cases considered fit the pattern of the RRH only in some respects, and in particular do not embody the procedural → declarative and implicit → explicit transformations which the RRH predicts.

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