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 role 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, Koff 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 arrange-
ment of the numerals 1 to 9, as below, so that each row, col-
umn and diagonal sums to 15).

<table>
<thead>
<tr>
<th>2</th>
<th>7</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

Fig. 1. magic square

The initial representation of the game requires us to pro-
cceed 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 con-
figurations such as winning triples and forks are easily recogni-
ised 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 po-
sitional 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
{}ABC D 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 sys-
tems. 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 numer-
als 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 tal-
lies, and Roman numerals have the advantage that few pri-
mary symbols have to be remembered. But the overwhelm-
ing advantage of a positional system with zero is that a divide-
and-conquer strategy for the basic arithmetic operations of ad-
dition, subtraction, multiplication and division becomes pos-
sible whereby a simple operation (involving 'carrying'), iter-
ated 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 nota-
tion, 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 phylo-
getic 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 'sponta-
nous' 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 represen-
tation, and Roman engineers did design bridges and aque-
ducts 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 de-
gree 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 triplets which sum to 15, and about the intersection pattern of these triplets 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.

References


Boden M. 1987, Artificial Intelligence and Natural Man, 2nd ed., MIT.


