Operational development and individual differences

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OPERATIONAL DEVELOPMENT AND INDIVIDUAL DIFFERENCES

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STATEMENT OF THE PROBLEM

Theoretical problems

One of the main questions raised in the research program to be presented here is whether development takes the same form or different forms for different subjects, and how important these differences can be. The main focus of the present paper will be on methodological aspects. From a fundamental point of view, it is argued that the definition of variations in the form of development constitutes a privileged means for bringing out underlying processes. It can, nevertheless, also present implications for educational research. Indeed, if cognitive development can take different forms in different children, school programs have to be geared not only to the students’ level of operational development, and to differences of speed along this development, but also to the different manners in which a same level can be actualized.

In Piaget’s theory, cognitive development is described as taking the same form across subjects. The development of knowledge is seen as a
process of construction of structures which follow an invariant order, on the one hand, and which can be generalised to all domains of knowledge as soon as they are constructed, on the other hand. The transition of one structure to the next is accounted for by a single process of equilibration, and the organization of the various aspects of knowledge (perception, mental imagery, memory, language, etc) is considered to be subordinated to that of the operational structures. Under these conditions, development is modelled as unidimensional; the only individual differences allowed for are differences of speed along a same development.

Two types of observations have, however, concurred to restrict the generality of the Piagetian structures, and, therefore, to cast doubts about the validity of the model. First an important *situational variability* has been noted, that is, great variations in the average ages at which a same concept (i.e., a concept similar from a structural viewpoint) is mastered, depending on situational characteristics. Piaget and Inhelder (1959) had already noted that the quantification of inclusion, for instance, could be solved at around 7 or 8 years of age with material consisting of flowers, but only at about 9 or 10 years of age when the material consisted of pictures of animals. These temporal delays between notions of a same structural level were labelled “*horizontal decalages*” by Piaget. The second set of questions results from the observation of an important *individual variability* across domains. The fact that different concepts pertaining to a same operational structure (for instance conservation, inclusion, transitivity) appear at approximately the same average age in terms of groups was taken by Piaget as an empirical support to the existence of different structures (structures d'ensemble). However, each time children were examined with several operational tasks, correlations proved rather low (e.g., Dimitrovsky & Almy, 1975; Dodwell, 1960; Laurent & Pinard, 1968; Tuddenham, 1971). Piaget did not consider these facts contradictory to his theory and provided a similar explanation for both: variations in the resistances that situations oppose to the subject’s structuring activity (e.g., Piaget, 1971); these resistances can vary from situation to situation, but the subjects’ structuring activities are considered to be invariant, provided they have reached a same structural level.

The present paper defends the thesis that individual differences play a truly fundamental role: decalages do no longer depend solely on situational variations (nor are they the product of purely individual characteristics), but result from interactions between individual characteristics and specific *situational variables* that individuals encounter, through processes similar to those described by Cronbach and Snow (1977) in terms of aptitude-treatment interactions. Development would thus prove multidimensional. An empirical support for this hypothesis could be provided by the existence of different types of decalages. Indeed, a unidimensional model such as the Piagetian interpretation can only be retained—even if it is not the only possible one—if situational factors have all the same effect on all subjects; this is the case of *collective decalages* (Longeot, 1978; de Ribauquier, Rieben & Lautrey, 1985). However, when the decalage is not in the same direction for all subjects—i.e., when two situations A and B are mastered in the order AB for certain subjects and in the order BA for others—the source of difference cannot be considered to be only external to the subject. Such *individual decalages* mean that a same situation is not treated identically by all subjects, since it represents a source of facilitation for certain subjects and a source of resistances for others. Stable individual decalages can be understood to indicate variations in the form of cognitive development (differences between subjects are no longer restricted to speed) that in turn reflect different types of cognitive processes. Bringing out individual decalages raises, however, important methodological problems.

**Methodological problems**

When subjects are administered two tasks A and B, relationships between these tasks can be studied from the standpoint of their intensity (through correlations) and of their form (by examining the distribution of subjects among the cells of a contingency table). Most research projects have dealt with the first type of approach. Only a few have attempted to analyse the form of contingency tables (for instance, Jamison, 1977; Wohlwill, 1973). In this case, authors have generally assumed the existence of structural links between the different levels of performance in a task A (for instance, conservers, intermediate, non-conservers) and the different levels in a task B (for instance, includers, intermediate, non-includers). However, as it has already been mentioned, horizontal decalages constitute a serious obstacle to the definition of such structural correspondences; levels of performance strongly depend on situational characteristics of the tasks chosen to tap each concept. Working with pictures of animals instead of flowers in an
inclusion task can modify both the magnitude and the form of the relationships that the task presents with other tasks.

Different methods can be used to overcome the difficulty raised by the existence of these horizontal decalages and have been presented elsewhere (Lautrey, de Ribaupierre & Rieben, 1981; Lautrey, de Ribaupierre & Rieben, 1985; de Ribaupierre et al., 1985). The method adopted here does not rest on structural links between notions, and seeks to uncover the possible multidimensional structure in the data while remaining at a nominal level, that is, in the present case, at the item level. The *analysis of correspondences* developed in France by Benzecri (1973, 1980) appeared particularly adequate, so much more so that it can simultaneously deal with items and with subjects. Indeed, analyses of correspondences treat directly—without a preliminary computation of correlations—a matrix of response categories (defining the items or variables space) by subjects (defining the subjects space). In the items space, each response category is defined by its profile on the support of subjects; in the subjects space, each subject is defined by its profile on the support of items. In both spaces, the method used for computing distances between profiles is that of the chi-square, or more precisely, of the phi-square. The phi-square of the matrix is broken down into factors according to the rationale of a principal components analysis (orthogonal factors, each of which accounts for the maximal remaining variance). The choices in terms of metrics retain the correspondences—hence the name of the method—between the subjects space and the items space; both spaces can accept the same factorial axes. Those items that show a similar profile on the subjects can be grouped, as well as those subjects that present a similar profile on the items. It is not possible, within the limits of this presentation, to detail further the characteristics of the method; some of its advantages will be enhanced in the remainder of the presentation, through some results. Again, results are essentially meant here as an illustration of the method, rather than as an exhaustive presentation of the research.

**EXPERIMENTAL PROCEDURE**

**Subjects**

The tasks have been administered to 154 children, aged 6 to 12 (22 per age group), and chosen so as to be representative of the Genevan primary school range population.

**Tasks**

All subjects have passed eight operational tasks representative of different domains: Two logico-mathematical tasks (Intersections of Classes, Quantification of Probabilities), two tasks tapping physical notions (Conservations, Islands), two spatial tasks (Sectionings of Volumes, Unfoldings of Volumes) and two mental imagery tasks (Folds and Holes, Foldings of Lines). These four domains (the term of domain of knowledge has to be understood rather loosely, corresponding to the groupings in Piaget's writings) can be further reduced into two broad categories, consisting of logico-mathematical and infra-logical tasks. It will be interesting to determine whether the distinction established by Piaget (e.g., Piaget and Inhelder, 1947) between logico-mathematical and infra-logical tasks emerges in the analysis of correspondences. Each task consists of various items supposed to assess, in different ways, the same concept. For the analyses presented below, 38 items have been retained. Details about the tasks can be found elsewhere (Rieben, de Ribaupierre & Lautrey, 1983; Lautrey et al, 1985).

**Results**

Each of the 38 items has been scored twice, once in terms of passes, and once in terms of failures; the matrix can therefore be constructed on the basis of 76 response categories (two categories per item) in column and 154 subjects in line. Only the plane defined by the first two factors will be described below. Results will be analysed first in terms of the items space and then in terms of the subjects space.

**Items space.**

The first factor (horizontal axis) opposes pass categories of items (indicated by black surfaces in Figure 1) to fail categories (white surfaces). Moreover, items are ordered on each side of the center of gravity according to their difficulty: from the most frequently passed to the least frequently passed on the pass side (right side in Figure 1), and from the most frequently failed to the least frequently failed on the fail side (left side). Both orders are obviously symmetrical, and the line joining the two categories of a same item goes through the center of
Figure 1: Localization of the different categories of response in the plane formed by the first two factors.

- Δ Logical items: failed
- ○ Infralogical items: failed
- ▲ Logical items: passed
- ▼ Infralogical items: passed

Gravity (e.g., IL2 and IL for the most difficult item and PR1 and PR for the easiest item). A weight is attached to each response category, corresponding to its frequency. Thus, the line joining the two response categories is like a lever arm: a category with a heavy weight at a small distance from the center is equivalent to a category with a small weight at a larger distance. The first axis can be understood as the tendency to progress from easier items to more difficult, in the different domains; therefore, its interpretation is that of a general factor of complexity corresponding to a general factor of development in the subjects' space (analogous to the differentialists' factor g'). The second factor (vertical axis) is more crucial to the thesis of this paper since, by contrast with the first one, it stresses aspects that cannot be understood within a unidimensional model. In Figure 1, in order to facilitate the reading without having to detail the meaning of each item, all items supposed to require logico-mathematical operations are indicated by triangles, and all items supposed to require infra-logical operations by circles. Recall that, in Piaget's terminology, logico-mathematical operations deal with relationships between discrete objects (i.e., are discontinuous), while infra-logical operations deal with relationships between parts of a same object (i.e., are continuous). The figure, and the definition of this second factor, clearly attest the clustering of the two types of items; this demonstrates that variations can be coherently attached to situational differences without being reduced to variations in difficulty. The use of correspondences between variables space and subjects space can thus bring precisions about the form of situation-subject interactions underlying such variations.

Subjects space.

Since both spaces can be described by the same axis, it is possible to project the subjects directly into the items space; this can be done not only for each of the actual subjects included in the analysis, but also for “supplementary” subjects, actual or fictitious: The average profile of an age group can, for instance, be treated as the profile of an individual subject and projected into the items space.

This possibility of projecting the average profile of age groups is demonstrated in Figure 2, and can be used to validate the interpretation of the first factor as a general developmental factor (limited, in the items space, at one pole by a fail score at the easiest item —item PR1— and at the other pole by a pass score at the most difficult item —item IL—, as shown in Figures 1 and 2). The progression of the different age groups from 6 to 12 along the first axis, as can be seen in Figure 2, is quite clear. The existence of plateaux at 8–9 and at 10–11 years of age is interesting to
Table 1: Pass-fail patterns of subjects contributing most to either pole of factor 2

<table>
<thead>
<tr>
<th></th>
<th>LOGICAL POLE</th>
<th>INFRALOGICAL POLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>IAAPPSPULSL</td>
<td>TIRERIEINNEI</td>
</tr>
<tr>
<td>Rate of</td>
<td>34435537453224</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>10076684401818644532392419</td>
<td></td>
</tr>
</tbody>
</table>

L Subjects  
O Sex Age  
G M 7 11111100000000  
I M 9 1111111000001000  
C M 9 1101101010000000  
A F 12 1110111000000000  
L M 10 1111111000000000  

I O F 1100000000111100  
N G M 1210000000111011  
F I F 1000000000110000  
R C M 1211001001111111  
A A F 6000000001001000  
L  

Note, but a hypothesis of sampling problems cannot be presently rejected; a longitudinal study, now in progress, may bring a clarification.

The method also makes it possible to sort out the most characteristic subjects. Table 1 presents the five individual subjects that, at each pole, contribute most to the variance of the second factor: it shows their pass/fail scores for items that (in the items’ space) also contribute most to the variance of the same factor. These patterns appear to correspond to what was defined above as individual decalages: some subjects completely fail infra-logical items while passing almost entirely logical-mathematical items (for instance M7 in Table 1), whereas the reverse is true for others (e.g., F11). If there is indeed a progression for each of the two domains (and it seems to be the case, although strictly speaking the order has only been tested within tasks, through hierarchical scale

Note that, in Table 1, items that contribute most to each pole of the factor are ordered from left to right as a function of their decreasing contribution; the subjects that contribute most to the definition of each pole, in the subjects space, are ordered from top to bottom. The symbols of items correspond to the task to which they belong: PR for Quantification of Probabilities; AI and IT for Intersection of Classes; UN for Unfolding of Volumes; LL for Lines Foldings; SE for Sectioning of Volumes. The total number of subjects (out of 154) with pass scores is indicated below each item. The symbols in the subjects’ list correspond to their sex and age.

analyses (Rieben et al., 1983), such patterns show that the progression in one domain is certainly not subordinated to the progression in the other, but that both progressions are rather independent. Such patterns cannot for the moment be related to group differences such as age or even sex (see, in Table 1, the sex and age of subjects).

Discussion

A first interesting result to note concerns the fact that patterns as contrasted as those described above can be found; this provides a support to the hypothesis of the existence of individual decalages and confirms earlier results obtained by relying on ordinal methods, that is, on methods treating each task as a whole instead of breaking it down into items (see, for instance, Lautrey et al., 1985; de Ribouvier et al., 1985).

In terms of the Piagetian model, it is not very surprising to find subjects who pass logical-mathematical items while still failing infra-logical items; it is more surprising to find subjects who are ahead in infra logical tasks with respect to logical-mathematical tasks. The fact that both types of subjects can be found simultaneously on the same tasks is no longer accountable for within a unidimensional model.

Since a situational characteristic (i.e., the relation of continuity or discontinuity between elements) yields inverse patterns for different subjects, it can be assumed that it is treated through distinct processes with relatively independent developmental patterns. This diversity of processes can only be detected because their accessibility is variable from subject to subject, that is, because of individual differences. This shows first that an individual differences approach is useful for a process analysis (de Ribouvier & Pascual-Leone, 1984; de Ribouvier & Rieben, 1985); it also indicates that the source of variability resides jointly in the environmental and in the individual characteristics: certain environmental properties are more particularly geared to certain types of processes, and certain subjects use preferentially certain processes rather than others.

Results suggest thus the existence of different cognitive developmental paths. In the present case, at least two paths leading to a same general operational level can be assumed: a logical-mathematical trajectory and an infra-logical trajectory. This is not to imply that certain subjects develop only one type of processing (e.g., logical-mathematical) to the detriment of the other; both types are probably present in all subjects,
but can be more or less easily accessed. Depending then on the preferential development and use of either, the nature of their interactions can differ. Thus, development is not to be considered unidimensional, but probably results from different developmental processes in interaction.

Since determining whether cognitive development can take different forms proves an interesting means of outlining different processes and their interactions, the present research has obviously a fundamental facet. However, it also presents implications for educational research. First it contributes to generalizing the use of a method, the analysis of correspondences, that is also appropriate for educational purposes. Indeed, educators have been led before psychologists to postulate the existence of interactions between situations and subjects (such interactions showing through the fact that some types of instruction are more fruitful with some subjects than with others) and are often in need of methods for clustering subjects with situations. Second, in terms of results, the individual variability found is important enough for education to have to take it into account. In particular, the fact that relations between discrete objects and relations between parts of a same object seem to be processed differently (corresponding perhaps to the distinction between propositional coding and analoguous or iconic coding) and yield two relatively independent developmental paths could incite educators to present, whenever possible, the content of their teaching under both forms of coding. Indeed, the two types of presentation could have different effects depending on the form of cognitive development adopted preferentially by different subjects. The knowledge of different developmental trajectories and the use of appropriate methodology should thus improve educational methods, by leading to the use of differentiated teaching.

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REFERENCES


1Note that, even if only 10 patterns out of 154 have been described here, corresponding to those subjects whose contribution to the factor is greater, i.e., whose intra-individual variability is really striking, most patterns can be considered heterogeneous.
