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THE ARCHITECTURE OF CHILDREN'S PHYSICS KNOWLEDGE
A PROBLEM-SOLVING PERSPECTIVE

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ABSTRACT

The project investigated the nature of young children's physics knowledge and the architecture of its development. I utilized two contexts of development for this purpose: comparison of cross-age developments in knowledge of a domain and fine-grained analysis of developments that occurred in the context of problem-resolution. The empirical base consisted of three conditions, under which preschoolers were asked to establish equilibrium on the pan balance. Analysis focused on the child's transformation of a number-based to a weight-based approach to the problem. All the conditions employed the same nine sets of elements to be balanced; the conditions varied *a*) whether or not the child received feedback from the apparatus and *b*) order of set presentation (total *n*= 56). A sequence of fine-grained analyses of the videotaped data lead to a view of children's physics knowledge as localized and context-sensitive; with the steps involved in its development as remarkably limited in extension : in *a*) the scope within which they come to represent weight or weight differences (e.g. discrete elements versus collective weight of elements in a pan) *b*) the scope ot contexts in which they come to view weight as relevant to the goal of mechanical equilibrium and *c*) the bounds of diagnostic and causal implications.

INTRODUCTION

The project investigated the nature of young children's physics knowledge and the architecture of its development. More specifically, what is the nature of the knowledge that the child brings to bear in the resolution of physics tasks? How does one approach to the task become transformed into another; i.e. in what form(s) does change enter in and how does the new become elaborated into a another more adequate approach to the task?

The literature posits incompatible models concerning the architecture of children's developing scientific knowledge. On the one hand, one finds models emphasizing the impact of improvement in *general* structures, processing capacities, or theoretical constructs, viewed as leading to broad-based improvements in the child's scientific knowledge. In Inhelder and Piaget's (1958) model, development of the underlying logical-mathematical structures enables a more adequate experimental plan and more adequate interpretation of empirical results. In a more physics-framed model, Kaiser, McCloskey and Profitt (1986) look to the adequacy of the general theoretical constructs held by the child, which they argue largely account for the nature of the child's performance in a broad range of relevant tasks. On the other hand, one finds models such as DiSessa's (1987) and Lawler's (1985) that characterize knowledge and its evolution as *localized and fragmented* and take a more particulate view of what a child knows and the steps involved in knowledge-transformation.

This project exploits both the *macro*-developmental context of cross-age improvements, as well as the *micro*-developmental context of task-based learning, to examine the architecture of children's evolving knowledge of a physics domain. Inhelder and her research team have argued that microanalysis within the problem-solving context is much better suited to elucidate how knowledge-structures become transformed than comparison of cross-age differences employed by most studies (cf. Inhelder et al, 1976; Karmiloff-Smith & Inhelder, 1974). This tact enables fine-grained analysis of the nature of the chunks and pathways of connections formed in the transformation of children's domain-specific physics knowledge.

RESEARCH BASE

Subjects

The projects drew subjects from a university laboratory school, of upper-middle and middle S.E.S.. Each of the first two conditions included 24 preschoolers, evenly divided across sexes and among 3, 4, & 5 year olds. The last condition included 8 five year olds, evenly divided across sexes.

Experimental Set-up

Materials consisted of a pan balance and 9 sets of little people. The standard figure was plasticine throughout, weighed one ounce, and was 5 *cm.* in length. Other figures varied in size and/or weight from the standard, by means of hidden styrofoam or hidden weights or by simple addition of more plasticine. The number of figures in a given set ranged from 2 to 9.

The child sat at a small table, facing the V.C.R. camera. The apparatus rested on the table, directly in front of the child. E sat to S's right, from which she handed S the sequence of people sets.

Experimental Procedures

In each condition, E began by instructing S, "*The people go in these things* [the pans]. *When all the people are in these things, it should stay like this*" [horizontal position of beam demonstrated]... As S engaged in the process of placements and immediately thereafter, E probes " *What are you doing?*' or *What did you do*?". If S fails on the first attempt, E encourages repairs by saying "*Try to fix it.*". E presents the next set of elements after S has succeeded with this first set (of two identical elements).

Under the first two conditions, E continues in this same mode with another eight sets of figures. Subjects receive feedback from the apparatus in each of these conditions; the conditions vary the order of set presentation. In the first order, the first few sets can be successfully placed via an equal number strategy. The other order introduces goal-relevant inter-object differences earlier on. In the third condition, following successful placement of the first set, E tells S, *"Now the game is to put the people under the pan they should go into. You don't put these things in anymore. You put the people under the pan they belong in".* This no-feedback condition employed the first order of the feedback condition.

FRAMEWORKS OF ANALYSIS

The author and her research assistant carried out an extensive series of analyses of the videotapes. This paper considers two: analyses of strategies employed and the much finer-grained analysis of extent of knowledge-strand elaboration. In both cases, the two independently coded the complete data set. Differences were resolved by means of joint reviewing of the tape.

Analysis One: Strategies employed

This top-level analysis consisted of coding the strategies each child employed, to obtain the goal-state of mechanical equilibrium. We parsed as an episode each attempt to get the apparatus to work, either initial placement strategy or repair.

The schema of strategies, formulated across the course of two pilots, included the following categories:

equate # in two pans
one-to-one correspondence of placements
equal weight in two pans
visual feedback
compensation by force of hands (yank on wires)
correct spatial alignment (gently place apparatus into position)
fiddle with knobs (knobs built into the beam)
reject (element or pair of elements from the current set)
exchange (pair or complete sets of elements across pans)

Each coder assigned one or more strategies to each attempt at the goal. Where more than one strategy was assigned, the coder specified the form of their combination: whether the child's actions integrated the two strategies (as in the application of one-to-one correspondence, stopping after each pair of placements to check visual feedback; and where one pan rests higher, placing just one there instead of an element in each) or where the child employs one strategy as a means to another (e.g. equating weight, by means of equating number under conditions of identity of elements in the set). After completing the assignment of strategy-codings, we reviewed the protocols for stable patterns of strategy application. These patterns encompassed the distinctions that the child used in determining initial placements and the basis on which he or she selected repairs.

Analysis Two: Extent of knowledge-strand elaboration

This finer-grained analysis aimed to elucidate how one stable pattern of strategy- application became transformed into a more adequate approach to the problem. Given the fine-grain employed here, we restricted this analysis to the 24 Study I subjects. The analysis focused on the child's knowledge of two aspects of the task domain *vis-a-vis* this goal of mechanical equilibrium: *a)* knowledge of the pan balance apparatus and *b*) knowledge concerning the sets of elements to be balanced; as well as *c*) knowledge of connections between the two.

Each coder specified: 1) the set of features by which S had represented each aspect of the domain 2) which of these features he or she conceptualized as relevant to goal-attainment and 3) the entailments of this feature for goal-attainment. We specified the entailments S had elaborated in terms of diagnostic and causal implications.

We define diagnostic and causal implications as follows. The child who constructs a link of the type *when x happens that means y is the problem* has formed a diagnostic implication (e.g. when one pan goes down, there are too many things in it.) The child who constructs a link of the type *when you do x, y happens*, has formed a causal implication (when you put the same number in each, it works).

The framework underlying this last analysis thus distinguishes between representing some variable within some aspect of the task domain from the recognition of that variable as relevant to task-attainment. The aspect may actually be relevant to goal-attainment (e.g. relative weight of the elements) or irrelevant (color of the elements) or imperfectly correlated with the relevant (size of the elements).

By specifying the set of implications the child has constructed involving the variable and goal-attainment, the analysis can capture degrees of feature-goal elaboration: from the dawning of relevancy prior to specific implications (a suspicious "*Why did you give me a heavy one*?") to the construction of all the entailments of the feature for goal-attainment.

RESULTS AND DISCUSSION

Patterns of strategies employed

Across the 1093 data-points of strategies employed, a 91.3% inter-rater reliability was achieved. Two patterns of strategy application and a third intermediary, more transient approach, appeared across the data set. Using a criterion of 80% fit of strategies employed, application of these patterns correlated with age. Furthermore, we found an invariant order of the three, within protocols that exhibited learning.

In the first approach, the children began by placing the same number of elements in each pan (by means of one-to-one correspondence or equal number). When this failed, they would try to fix the apparatus itself (using compensation by force of hands, correcting spatial alignment, and/or fiddling with the knobs).

In the second approach, typically applied only briefly, the child relied upon visual feedback. The child would either start by equating number and then do repairs by means of visual feedback, or do visual feedback from the beginning.

The third approach constituted a much more adequate approach to the task. Children conceptualized the task in terms of the creation of two classes of equal weight. They drew flexibly upon a range of strategies for this purpose (including one-to-one correspondence, equate number, visual feedback, equate weight). Their pattern of application revealed two principles of strategy-selection: cognitive/motoric economy and knowledge of the limits of each strategy's valid application.

Elaboration of a new approach to the task

This analysis attempted to capture how this first approach, based on equal number with repairs restricted to spurious manipulations of the apparatus, becomes transformed into the last approach, whereby the child flexibly draws upon the range of strategies to efficiently arrive at equating of weight. In this paper, we focus on the child's knowledge of the weight variable vis-a-vis this domain and the steps by which this knowledge becomes elaborated. Again, we base our steps on distinctions found in fine-grained analysis of both macro-developmental and micro-developmental contexts of knowledge-transformation.

Extension of the variable's representation

Fine-grained analysis in both micro- and macro-developmental contexts indicates that coming to characterize the task in terms of the critical weight variable occurs in steps of surprisingly restricted extension. Whereas Siegler's (1981) model asks *do they or don't they encode weight*, I found coming to represent a variable within a domain isn't an all or nothing phenomenon.

This analysis revealed three aspects in which children need to expand their thinking in terms of weight: *a*) weights (equal or unequal) of discrete elements and *b*) the collective weight of the sets of elements in a pan and *c*) the tilt of the apparatus as an indicator of relative weight of sets of elements in each of the pans. Children frequently exhibited representation of the weight-variable in one aspect, without the others (e.g. repeatedly referring to comparative weight of the pans, while ignoring the critical distinction between weight of the discrete elements).

Extension of goal-variable coupling

Another form of extension considered by our analysis involved the scope of the context, in which the child linked the weight-variable with the goal. Again, we found steps incorporating differentiations, non-intuitive to the adult. The pathway of connecting the weight -variable to the goal came in steps corresponding to the three contexts of weight, elaborated above. For example, we observed children (throughout their protocol or at some phase of their experimental session) who represented weight in all three aspects, and yet failed to construct the relevancy of the difference for goal-attainment.

Extension of implication

The analysis also considered the pathway of implications, by which the most adequate equating-of-weights approach became elaborated. Protocols in which learning took place were the most informative.

We found that children consistently formulated the diagnostic implications before the corresponding causal implications. Although it appears obvious that the child would need to construct a new sense of what was wrong before constructing a new approach to action, the diagnostic implication frequently did not function as a constraint upon the search for an operator: the child would diagnose the problem in terms of unequal weights, and yet frequently carry out an extensive search for a repair, ignoring the weight variable.

The presence of different types of elements within the same set constituted a major obstacle for many children. Without the idea of compensation, one cannot construct a state-algorithm for placements of these sets. We observed two pathways by which children constructed implications incorporating compensation.

In one route, after repeatedly failing in the formulation of an adequate placement-algorithm, some children shifted strategically to the feedback algorithm. They attained the goal-state, by successive visual-feedback repairs. Their characterization of the goal-state, in terms of lots of little/light ones in one pan and one big/heavy one in the other, functioned as a catalyst in their construction of the compensation state-algorithm.

In the other route, children who had failed to construct the compensation implication in the context of weight-differences were able to do so in the context of size differences. (The typical rationale offered here that three of the little "make" up the big one suggest that simple composition supported the idea.) For some children, construction of the compensation idea in the size-difference context functions as a bridge for the construction of the idea in the weight-difference context. For other children, most frequently under conditions of no-feedback, the implication does not extend to the weight context.

CONCLUSIONS

This project investigated the architecture of children's developing knowledge of a physics domain. For this purpose, I took the tact taken by Inhelder's research group for the study of conceptual change: micro-analysis of learning that results from solving physics tasks. This approach enabled us to observe knowledge-fragments and pathways of connections formed, in the transformation of the preschoolers' physics knowledge-structures.

A sequence of three action-plans appeared in the micro- and macro-developmental contexts. In the first, children approached every set in the same way, placing the same number in each pan, regardless of the weight or size differences. After a pan descends, they do not adjust elements across the pans, but seek to directly fix the apparatus: by placing the apparatus into the correct alignment and gently releasing and/or hanking down on the side that rests too high. In the second, they determine initial placements through either equal number or feedback of the apparatus; they rely on feedback to determine repairs. The third action-plan integrates weight-based placement algorithms with feedback information, in a flexible system wherein the child efficiently constructs two classes of equivalent weight.

A series of micro-analyses focused on the nature and scope of the chunks and the pathway of connections manifested in the change from the initial numerically-based action-plan to the most adequate weight-based action-plan. For this purpose, we used a framework of analysis noting *a*) the scope of the domain within which the child represented a particular variable *b*) whether or not the child thought of the variable as relevant to goal-attainment; and if so, the scope of the domain in which the child assumed the mapping, and *c)* the nature and extension of diagnostic and causal implications the child had constructed.

In the spirit of diSessa's "knowledge in pieces" view of physics understanding, I found preschoolers' knowledge of mechanical equilibrium and pathway of its transformation to be comprised of remarkably small and context-sensitive fragments. Limited extension appeared in three contexts: a) representation b) conceptualization of goal relevancy and c) implication.

Children did not come to encode weight in all aspects of the domain at the same time, but first one context (e.g. relative weight of the pans) and then another (relative weight of the constitute elements). Some children, who over the course of the session came to encode weight throughout the domain, recognized the goal-relevancy of the variable in one context only. Similarly, many children did not evoke the relevant compensation structure all at once; but failed to apply it in one context (with inter-object differences in weight) and yet consistently applied it in a slightly different context (with differences in amount).

In short, the architecture of young children's physics learning appears to demand an atomistic perspective. There clearly are general structures and constructs whose states-of -evolution map onto states-of- knowledge at various levels of adequacy. However, these structures may yield a misleading account of the architecture of change, the nature of the steps by which children's knowledge becomes transformed. The young child's physics knowledge appears remarkably localized and context-sensitive. The pathway of its development consists of steps, involving a surprisingly small range of implication.

Methodologically, micro-analysis of problem-solving appears to be a fruitful means to consider the transformation of children's physics knowledge. Presenting the task, with immediate feedback and carefully selected task variations, lead to significant learning. Micro-analysis of the videotaped data allowed inference of how change entered into the child's approach and the manner by which the more adequate knowledge became elaborated.

REFERENCES

diSessa, A. (1987). *Toward an Epistemology of Physics* (Report No. 48). Berkeley, CA: Berkeley Cognitive Science Program, University of California.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence.* New York: Basic Books.

Inhelder, B., Ackermann-Valladao, E., Blanchet, A., Karmiloff-Smith, A., Kilcher-Hagedorn, H., Montangero, R., & Robert, M (1976). Des structures cognitives aux procédures de découverte. *Archives de Psychologie, 44*, 57-72.

Karmiloff-Smith, A., & Inhelder, B. (1974). If you want to get ahead, get a theory. *Cognition, 3*, 195-212.

Kaiser, M. K., McCloskey, M., & Profitt, D.R. (1986). Development of intuitive theories of motion: Curvilinear motion in the absence of external forces. *Developmental Psychology, 22,* # 1, 67-71.

Lawler, R. W. (1985). *Computer experience and cognitive development: A child's learning in a computer culture.* New York: Halstead Press.

Siegler, R.S. (1981). Developmental sequences within and between concepts. With commentary by Sidney Strauss and Iris Levin. With reply by the author. *Monographs of the Society for Research in Child Development, 46*(2, Serial No. 189), 75-81.