A Problem Space Perspective on the Development of Children's Understanding of Gears

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Abstract

This paper investigates two contexts of children's developing knowledge of the physical world: (1) the macro-context of different age cohorts (8-9 years versus 11-12 years); and (2) the micro-context of a one-hour experimental session. Twenty subjects were video-taped, constructing goal-states for a task involving gears. Four distinct systemic approaches or problem spaces were identified: (a) Euclidean, (b) Kinematic, (c) Dynamic, and (d) Topological. The Arithmetic Modifier, effecting a numerical characterization of a problem space, can operate on any of the four. Cross-age, there was the substantial overlap of initial problem space employed, and minimal overlap of final problem space. This frequency of adaptive shift in problem space, strongly and positively correlated with age, suggests that, when confronted with an unfamiliar task domain, the capacity to recognize a problem space as inappropriate and to evoke another more adequate problem space appears to be a component of the answer to the classic question, "What develops?"

Introduction

It is proposed here that the Information Processing construct of problem space is a potentially powerful conceptual and representational tool for the investigation of children's thinking, particularly well-suited to the critical analysis of the systemic view of understanding and change. This research project uses the problem space construct to compare different aged children's capacity for understanding a physical task domain with which they are not familiar, and their capacity for adaptive change. The physical task domain chosen for this study is gears; in particular their models of relative directionality.

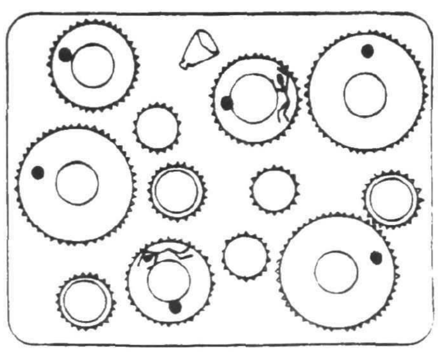
An instructionless experimental procedure has been developed, so as to enable the ecological investigation of systems of understanding and possible systemic changes. The procedure was derived from a line of research recently developed in Geneva by Bärbel Inhelder and her team, utilizing micro-analysis of conceptual change occurring in the context of children's problem-solving (c.f. Blanchet, 1977; Inhelder **et al**., 1976).

Method

Subjects were drawn randomly from the population of graduates of a university laboratory preschool, who still lived in the area. The population is predominately middle and upper-middle SES.

The set of materials given to the subject consists of 12 gears, 3 each of 4 different sizes, a Velcro board, and a knob. The gears can be easily attached or removed from the board, by means of a Velcro adhesive on the inner circle of the gear-back. Two of the gears have tape on them, with a drawing of a man in the course of somersaulting. Turning a marked gear counterclockwise gives the appearence of a man somersaulting head-first; turning clockwise, of somersaulting feet-first. The knob can be placed in any of 6 of the 12 gears, including both of the marked gears.

Figure 1 · The Materials



The instructions to the subject are: " There are a bunch of these things. Two of these have men on them. Lots of them don't. The men can do head-somersaults like this. Or feet-first somersaults like this. The game is to make something, using any of these things you like, so that when you turn the knob (See, the knob can fit into any of these holes) both men do head-first somersaults. Make something, using any of these things you like, so that when you turn the knob, this man and this man are both doing head-first somersaults. Please think outloud. " After the child has built one successful construction, the experimenter extends the task:" Good! Now the game is to see how many **different** ways there are to get the two men to do head-first somersaults. Here's a pen and some paper. Use them to keep track of the ways you find. Remember! It's important to think outloud!"

The simplest and most efficient means of resolving the task entails the consideration of only one relation found within the gear-configuration in a state of no-motion: the parity or non-parity of gear-elements between the marked gears. When there is an odd number of gear-elements between the marked gears (and no other connections with an even number of gear-elements), then the two marked gears will turn in the same direction. Other approaches, such as the abstraction of patterns of relative motion or the calculation of the directional effects of pushes across pathways of transmission of movement, although less efficient, offer progressively more adequate models of the phenomenon of relative directionality of gear movement, and alternative paths to goal attainment.

Results and Discussion

The results are organized into two levels: first, a description of each problem space, as summarized from the coding criteria (criteria, developed across three pilot studies, by the gradual refining of the match between data and models); and second, a cross-age comparison of range and distribution of problem spaces, and the frequency of adaptive problem space shift. In the coding of the protocols, the trained raters' agreement was 91.3 %.

1. The four problem spaces

The Euclidean Problem Space

The Euclidean Problem Space is composed of elements and relations of Euclidean geometry, such as size of gear elements, particular alignment among gear placements or positioning on the board surface, gears-configuration shape, and symmetries. Each of these is irrelevant to the attainment of the goal.

A particularly interesting and common type of error is the use of symmetry as a means to achieve correspondence of displacements. Two strategies were based on symmetry. One entailed symmetrical matching of men-orientations. These subjects vascillate between mirror and slide symmetry, convinced that the correct symmetrical relation between men figures (in addition to the correct positioning of one element relative to the other) should solve the problem. In the second type, the subject tries to attain the goal by means of the bi-laterally symmetrical placement of the marked gears in a bi-laterally symmetrical gears-configuration. It is hypothesized that visual symmetry is one primitive heuristic employed by young physics-naive subjects, seeking to create identity of actions (as in this task) or equilibrium (as Inhelder and Piaget (1958) reported of their youngest subjects in their balance beam task).

The Kinematic Problem Space

The Kinematic Problem Space entails the enactment of a new data base, gears in motion. This focus on motion is manifested by extensive motion study, above and beyond that necessary to evaluate constructions as failures or successes (**e.g.** an examination of motion of non-marked as well as marked gears; setting gears into motion with only one or with no marked gears on the board; continuing to turn the gear construction, even after it has been evaluated as a success or failure).

The conceptual framework consists of these motions, and secondarily, the placements that effect them, defined either in terms of a Euclidean relation (**i.e.** the particular alignment of each element relative to the others) or Topological relations (more simply, which elements are touching). This data base enables the abstraction of goal- relevant kinematic relations and patterns.

In contrast to the Euclidean Problem Space, the Kinematic Problem Space is a fundamentally goal-appropriate conceptual framework. The sphere of relative motions of all gears, marked and nonmarked, is an effective way of observing one's evolving constructions, of abstracting relations and patterns, and formulating constraints for gear-constructions. A weakness of the space is that these relations and patterns among the motions remain arbitrary empirical observations; **i.e.**, they do not transcend the descriptive.

<u>The Dynamic Problem Space</u>

In the Dynamic Problem Space, on the basis of such entities as agents and patients, and pathways of transmission of movement, inferences are formulated concerning how objects **act** upon other objects, so as to effect particular patterns of displacements. Subjects conceptualize the turning of the knob as creating a force that is transmitted across the device, along the pathways of transmission of movement.

As the Dynamic framework involves inferring the sequence of the displacements across each pathway, it can impose significant demands on STM, particularly when the subject does not linguistically tag the directionalities. The space's strength is the initial explanation it offers of the phenomenon.

<u>The Topological Problem Space</u>

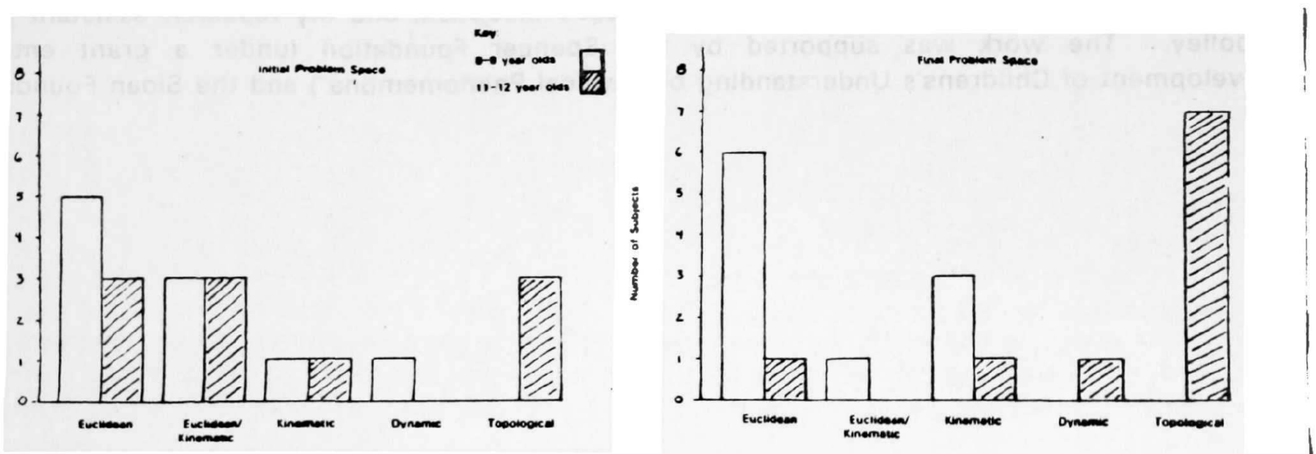
The conceptual framework of this problem space is based upon Topological Geometry . It is similar to the Euclidean, in that it is a static geometric framework, but different in that many distinctions within the Euclidean framework are not considered differences in the Topological. In the Topological, the subject assumes only connectedness of gears is relevant to the goal criterion, and ignores particular alignments among gears, their sizes, and the visual gestalt the gear construction may form.

The primary strength of the Topological Problem Space is that it facilitates the highly efficient enumeration of the complete set of possibilities (as defined by the conceptual system). The primary problem with the Topological Problem Space is the arbitrary quality of understanding of relative directionality, as manifested by the common confusion concerning which elements to count, the subjects' spontaneous descriptors of the odd/even rule (**e.g.**as the "trick" or the way the Experimenter "fixed the game"), and subjects' inability to offer explanations of the phenomenon.

<u>The Arithmetic Modifier</u>

The Arithmetic Modifier does not affect the conceptualization of the task domain, nor the heuristics, apart from the numerical characterization of the units of meaning, as defined by the semantics and syntax of that particular problem space. The benefits of such formalism are comparatively obvious, **i.e.** greater efficiency of task resolution or ease in identifying patterns. The primary liability identified in this data set is the dissociation of the arithmetic from the semantic and syntactic referent.

Cross-age Comparison of Initial and Final Problem Spaces



Cross-age comparison of range and distribution of problem spaces, and frequency of problem space shift

There is substantial cross-age overlap in initial problem space (See Figure 2.) With the exception of the first 5 episodes of one 8-9 subject, **all** of the 8-9's began the task in the Euclidean or Kinematic problem spaces, or some utilization of both (in vascillation or combination); 70% of the 11-12's did as well.

The cross-age overlap of final problem space is much smaller (See Figure 2). Seventy percent of the 11-12's end the task in the Topological space, a space that no 8-9 employed under the conditions of this experiment. One 11-12 ended the task operating confidently in the Dynamic Problem Space, a space no 8-9 was able to sustain. **All** of the 8-9's ended the task in the Euclidean or the Kinematic, or some utilization of both, as compared to only 20% of the 11-12's.

One intriguing cross-age difference embedded in the comparison of initial and final problem spaces is the frequency of adaptive change of problem space. There is a strong tendancy among the 8-9's towards absence of problem space shift. Conversely, there is a strong trend among the 11-12's who do not begin in an adequate space, towards adaptive change of problem space.

Conclusions

The dramatic cross-age difference in range was the eventual high frequency of the Topological Space among the older subjects, and its complete absence amoung the younger subjects. It is hypothesized that the reason that the Topological framework, documented in the literature as the most developmentally primitive geometry (**e.g.**Piaget, Inhelder & Szeminska, 1960) is the last employed is that its usage here implies the recognition of highly salient Euclidean features as irrelevant, and hence constitutes a less perceptually-bound, more abstract choice.

Second, the high frequency of adaptive problem space shift among the older subjects suggests that the abilities to recognize a space as inappropriate and to evoke a more appropriate one are components to the answer to the classic developmental question of "What develops?".

Finally, the study documents that children's understanding of physical phenomena can be described in terms of systems or paradigmatic approaches, and that the development of understanding can be represented in terms of changes in these systems.

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Acknowledgements I would like to thank Herbert Simon and James Greeno, for numerous discussions that had a substantial impact on the study, Alex Blanchet and Barbel Inhelder for suggestions and critical comments at the project's inception, and my research assistant Jacqueline Woolley. The work was supported by the Spencer Foundation (under a grant entitled "The Development of Childrens's Understanding of Physical Phenomemona") and the Sloan Foundation.