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ABSTRACT

Eighty-two children (ages 4.4 to 6.5 years) were administered a Backward Digit Span test to measure M-space and four conservation tasks (number, substance, continuous quantity, and weight). Based upon a neo-Piagetian theory of intellectual development proposed by Pascual-Leone (1969), two hypotheses were tested: (1) A significant relation should exist between a child's M-space and his/her ability to conserve; (2) Children should not conserve when the number of "figurative schemes" required to solve the task exceeds their M-space. Significant correlations were found among M-space and number, substance, and continuous quantity tasks. As predicted, none of 11 children with M-spaces of e + 1 demonstrated conservation. Contrary to theoretical predictions, a substantial number of children with M-spaces of e + 2 conserved all four quantities. It is argued that it may be possible to retain the idea of M-space as a constraint on reasoning ability if theoretical statements regarding the number of required figurative schemes are modified. (Author)

M-SPACE:

IS IT A CONSTRAINT ON REASONING ABILITY?

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ABSTRACT

Eighty-two children (ages 4.4 to 6.5 years) were administered a Backward Digit Span test to measure M-space and four conservation tasks (number, substance, continuous quantity, and weight). Based upon a neo-Piagetian theory of intellectual development proposed by Pascual-Leone (1969) two hypotheses were tested. (1) A significant relation should exist between a child's M-space and his ability to conserve; (2) Children should not conserve when the number of "figurative schemes" required to solve the task exceeds their M-space.

Significant correleations were found among M-space and number, substance, and continuous quantity tasks. As predicted none of 11 children with M-spaces of e + 1 demonstrated conservation. Contrary to theoretical predictions, a substantial number of children with M-spaces of e + 2 conserved all four quantities. It is argued that it may be possible to retain the idea of M-space as a constraint on reasoning ability if theoretical statements regarding the number of required figurative schemes are modified.

A neo-Piagetian model of intellectual development proposed by Pascual-Leone (Pascual-Leone and Smith, 1969; Pascual-Leone, 1969; in press) has recently received a good deal of support by the work of Case and others (Case, 1972a, 1972b; Case, 1974a, 1974b; Case, 1975; Case and Globerson, 1974). In brief, the Pascual-Leone model postulates four necessary factors for successful reasoning in specific task situations: (1) The child must possess appropriate "figurative schemes" in his cognitive repertoire. The construction of these schemes is interpreted as a function of learning; (2) The child must obtain a certain degree of field independence with respect to the given situation; (3) The child must have a tendency, when two incompatible schemes might be activated, to activate only that scheme which is compatible with the largest number of other schemes. This is interpreted as a universal tendency and is roughly synonymous with Piaget's concept of equilibrium, and (4) the child must have a mental capacity (M-space) large enough to coordinate the required schemes.

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According to Pascual-Leone, M-space increases as a function of age. Children 3-4 years old have a maximum M-space of e + 1, while 5-6 year old children have a maximum M-space of e + 2, and so on up to age 15-16 when the growth of M-space stops at approximately e + 7. The e represents the mental effort (or energy, or capacity, or space) required to attend to specific easily understood and remembered questions posed by given tasks. The numerals represent the maximum number of figurative schemes which can be successfully coordinated at a given time to answer the specific questions. Pascual-Leone uses this idea to explain why children of limited M-space do not demonstrate conservation reasoning. The reason is that conservation requires coordination of a certain number of figurative schemes and in many instances this number simply exceeds the child's M-space. For example, children age 5-6 have a maximum M-space of e + 2. They normally will not demonstrate conservation of substance because this conservation, according to the theory, requires the activation of the following e + 3 schemes:

(e) an executive scheme representing the question 'do the balls still have the same amount of clay in them'? and directing the child's attention to the task materials;
(1) a figurative scheme representing the information that 'nothing has been added to or taken away from the ball which was transformed';
(2) a figurative scheme representing the rule that 'if nothing is added to or taken away, then the amount stays the same';
(3) a figurative scheme representing the fact that 'the balls were originally equal in amount'.

Likewise children with an M-space of e + 3 or less will not demonstrate conservation of weight because this conservation requires activation of the above e + 3 schemes plus a figurative scheme representing the information that 'equal amounts of clay weigh the same'.

This theory then allows for precise predictions. It has what Popper has called falsifiability which is characteristic of powerful theoretical statements (Popper, 1959). The prediction based on Pascual-Leone's theory which this investigation sought to test was this. If M-space does place a constraint on the number of figurative schemes a child can coordinate, and if conservation does in fact require the coordination of a specific number of figurative schemes, then not only should a positive relationship exist between a child's M-space and his ability to demonstrate conservation reasoning, but children should not demonstrate conservation of quantities for which the required number of figurative schemes exceeds their M-space.

METHOD

Subjects. Eighty-two children (37 males and 45 females) who ranged in age from 4.4 years to 6.5 years, mean age = 5.6 years, served as subjects. The children were enrolled in nursery school and kindergarten classes from three schools located in upper-middle class neighborhoods in the San Francisco Bay Area. In none of the classes had the children been instructed with newly developed curricular materials which placed emphasis on conservation skills. IQ data were not available for these children, however, data gathered from older students in the same school districts showed the average IQ to be approximately 115.

Tasks and Procedures. M-space was measured by using a test of Backward Digit Span (Case, 1975). Each child was tested individually. The instructions and actual series of random digits were tape-recorded. The test was preceded by an instruction period which included a number of practice items. Following the practice period, subjects (Ss) were asked to repeat ten two-digit series, ten three-digit series and ten four-digit series backward. The rate of digit presentation was approximately one per second and each series was preceded and followed by an auditory signal. Testing was discontinued after S failed four consecutive series of digits. If at any time during the testing S was in need of more time, the tape was stopped and not started again until S was ready for the next series. Each S's score was obtained by summing the total number of digit series that was accurately reversed. If an S failed to correctly reverse any of the two digit-series he was considered to have an M-space of e + 1.0. If he correctly reversed all ten of the two-digit series and none of the three-digit series he was considered to have an M-space of e + 2.0. If he correctly reversed all of the two-digit series and 5 of the three-digit series he was considered to have an M-space of e + 2.5 and so on. The split-half reliability of the measure was .83.

The conservation tasks administered were conservation of number, substance, continuous quantity and weight. All conservation questions were asked in a counterbalanced order. The tasks were individually administered in the order in which they are listed below. Since each task has been employed by previous investigators, only brief descriptions of the tasks and materials used are included.

For weight (e.g., Elkind, 1961), two balls of clay were presented S. One ball was then transformed into a pancake shape. According to Pascual-Leone the M-space requirement of this task is e + 4 as mentioned previously.

To measure continuous quantity (e.g., Goldschmid, 1967) two identical beakers (100 ml) were filled with equal amounts of water. The water from one beaker was then poured into a 50-ml pyrex graduated cylinder.

For substance (e.g., Elkind, 1961) two balls of clay were presented S. One ball was transformed into a 'hotdog' shape.

For number (e.g., Goldschmid, 1967) two rows of plastic poker chips were placed on the table. Each row contained six chips. One row was shortened by pushing the chips together while the other row was lengthened by spreading the chips apart.

The M-space demand for the continuous quantity, substance, and number tasks is assumed to be e + 3. The executive scheme and figurative schemes required for the conservation of substance have been listed above. Those required for the continuous quantity and number tasks are the same except, of course, S must reason about liquid amount and number of plastic chips rather than solid amount. For Ss to be judged conservers they had to respond 'same' and offer valid explanations for their answers, e.g., identity--they are the same because you did not add anything or take anything away, inversion reversibility--it is the same because you could pour the water back into the glass to the same level, reciprocity reversibility--is the same because it is shorter but it is also wider. A conservation response followed by a correct explanation was awarded two points. A conservation response followed by an incorrect explanation was awarded one point while a nonconservation response was awarded zero points.

RESULTS

Responses on the Backward Digit Span (BDS) measure ranged between M-space values of e + 1.0 to e + 3.2, with a mean of e + 2.2 and standard deviation of .53. For children of these ages (4.4 to 6.5 years) this range is very close to that stated by Pascual-Leone (Case, 1972b; Case, 1974a).

Intercorrelations among the conservation task scores, M-space, and age are shown in Table I. Inspection of the table shows positive and significant correlations between M-space and the conservation of number, substance, and continuous quantity tasks (.29 to .50 $p<.01$ to .001). M-space correlated significantly with age as well (.38, $p<.001$). Intercorrelations among the conservation tasks were substantial (.52 to .84, $p<.001$). The conservation of weight task, however, did not correlate signficantly with M-space (.13) or with age (.07).

TABLE 1

SPEARMAN CORRELATION COEFFICIENTS FOR TASKS ADMINISTERED AND AGE (N = 82)

Variable[a]	M-Space	Num.	Sub.	Cont.	Wgt.	Age
M-Space........	1					
Num.............	.50**	1				
Sub.............	.29*	.67**	1			
Cont............	.35**	.62**	.84**	1		
Wgt.............	.13	.52**	.63**	.65**	1	
Age.............	.38**	.31*	.34**	.34**	.07	1

[a]M-Space = Backward Digit Span, Num. = conservation of number, Sub. = conservation of substance, Cont. = conservation of continuous quantity, Wgt. = conservation of weight.

*$p<.01$

**$p<.001$

In order to group Ss into discrete M-space levels, scores on the BDS test were rounded off to the nearest whole number. Three groups of Ss were formed in this manner. The number of Ss at each M-space level and the proportion who demonstrated conservation reasoning (a response of 'same' followed by a correct explanation) are shown in Table 2. None of the Ss with M-space values of e + 1 demonstrated conservation reasoning on any of the four tasks. Also, for each task, Ss with M-spaces of e + 3 demonstrated a higher percentage of conservation responses than Ss with M-spaces of e + 2. Group differences were anlyzed for significance by calculating chi-square values for each task. The calculated chi-square values are shown in Table 2. On the conservation of number task group differences were significant beyond the .001 level ($X^2 = 23.99$). Group differences on the conservation of substance and continuous quantity tasks were also significant ($X^2 = 9.38$, $p<.01$). On the conservation of weight task, group differences reached significance at the .10 level ($X^2 = 3.43$).

Of particular importance with regard to the predictions which this investigation sought to test, a substantial percentage of Ss with M-spaces of e + 2 demonstrated conservation reasoning on all four tasks (53% on number to 23% on weight). Also a substantial percentage of Ss with M-spaces of e + 3 demonstrated conservation of weight (26%).

TABLE 2

PROPORTION OF CONSERVATION RESPONSES AND CORRECT EXPLANATIONS FOR SUBJECTS WITH DIFFERENT M-SPACES

Conservation Task	M-Space e + 1 (n = 11)	e + 2 (n = 40)	e + 3 (n = 31)	Total	Chi^2 (d.f. = 2)
Number	(00) 0/11	(53) 21/40	(84) 26/31	(57) 47/82	23.99***
Substance	(00) 0/11	(45) 18/40	(52) 16/31	(42) 34/82	9.38**
Continuous Quantity	(00) 0/11	(35) 14/40	(52) 16/31	(37) 30/82	9.38**
Weight	(00) 0/11	(23) 9/40	(26) 8/31	(21) 17/82	3.43*

Note: Figures in parentheses represent percentages of subjects who demonstrated conservation responses and correct explanations.

*p<.10
**p<.01
***p<.000

DISCUSSION

The initial prediction that a positive relationship should exist between M-space and conservation reasoning ability has been confirmed. Although only eleven Ss were found to have M-spaces of e + 1, none demonstrated conservation reasoning. This result is supportive of Pascual-Leone's position that M-space places a constraint on reasoning ability. Further, since a significant positive correlation (.38, p<.001) was obtained between M-space and age, the hypothesis that M-space increases with age was also supported. The obtained M-space range (e + 1.0 to e + 3.2) for Ss of this age range (4.4 years to 6.5 years) also was very close to that predicted by the theory.

A number of results, however, were found which appear to be quite contradictory to the theory. Recall that M-space is interpreted by Pascual-Leone as a necessary condition for solving a Piagetian task at the normal age level and under normal learning conditions (Case, 1972b, p. 342). Since the maximum measured M-space for Ss in this study was e + 3.2, none of the Ss, according to the theory, should have demonstrated conservation of weight since it theoretically requires the coordination of e + 4 schemes. Also none of the 40 Ss with M-spaces of e + 2 should have demonstrated conservation reasoning on any of the tasks since all the tasks supposedly required coordination of at least e + 3 schemes for successful completion. It should be pointed out, once again, that in none of the classes from which Ss had been selected had learning activities been conducted which were specifically designed to train conservation skills. In other words these students were found to have normal M-spaces for their age range, and the learning conditions in their classrooms were also 'normal,' nevertheless, a large percentage of students demonstrated conservation reasoning. This result clearly appears contradictory to the theoretical predictions.

Prior to discussing a process which may make it possible for e + 2 Ss to conserve, a brief comment on the measurement of M-space should be made. Pascual-Leone, distinguishes two measures of M-space, functional M-space and M-space capacity. Functional M-space is that M-space brought to bare in specific situations and, in some cases, it may be less than the maxium M-space or M-space capacity. Whether or not a person uses his full M-space capacity depends upon the situation. With this distinction in mind, it may be that the BDS test produced a measure of functional M-space less than Ss maximum M-space capacity. The conservation tasks, on the other hand, may have been conducted in such a way as to allow S to use his maximum M-space. If this were the case, then the reason some of the Ss were able to conserve was because they did in fact have M-spaces if e + 3 or e + 4 and this fact simply did not show up on the BDS test since it measured functional M-space. This explanation is, however, quite inadequate for the following reason. Ss performed very well on the BDS test relative to M-space capacity norms established by Pascual-Leone and Case (Case 1972b; Case, 1974a). In other words, the obtained M-space range of e + 1.0 to e + 3.2 was not below what would be expected for children of these ages. In fact, it was slightly above the norm. Since M-space capacity varies little from population to population (Pascual-Leone, personal communication), the obtained M-space values for this sample were most likely very close to maximum.

One additional result appears to be in need of explanation. Since the number, substance, and continuous quantity tasks all presumably required the coordination of e + 3 schemes for successful completion, it might be expected that these tasks would be of nearly equal difficulty. Reference, once again, to Table 2 shows that 47 of the 82 Ss conserved number (57%). On the substance task, this figure was only 42%, while on the continuous quantity task the percentage was still smaller (37%). This difference in proportion of conservation responses was found to be significant (Cochran's

Q = 20.17, d.f. = 2, p<.001; Siegel, 1956, pp. 161-166).[1] Perhaps these differences can be accounted for by differences in amount of "perceptual pull" of the tasks themselves. The misleading perceptual cues of the continuous quantity and substance tasks may be greater than those for the number task. Indeed, the continuous quantity and substance tasks involve perceptual transformations in two dimensions while only a tranformation in length is performed during the number task. This hypothesis would lead one to predict that Ss who demonstrated conservation of all three quantities are more field independent than those who conserved only number. This hypothesis, however, will not account for the fewer number of correct responses on the weight task (21%), since the pull of the perceptual field for this task and the substance task would seem to be nearly identical.

How can these data be accounted for and still retain the idea of M-space as a constraint on the growth of conservation reasoning across different quantities? The theory states: (1) correct judgments result from a coordination of psychologically unitary elements called figurative schemes; (2) the number of such schemes which can be coordinated at any one time is limited by the size of the person's field of centration or M-space; and (3) the size of this M-space can be determined by a measure of Backward Digit Span. Secondarily, and independent of the theory, the number of figurative schemes used for any task is determined by analyses of explanations given on tasks. This provides for specification of the precise number of figurative schemes (n) which appear to be activated for any one task. The theory uses the result of this to predict that conservation responses will not be obtained from an S whose M-space is exceeded by n. Success of this prediction depends upon the theoretical statements being accurate, upon an accurate determination of the number of schemes required by each specific task and upon accurate measurement of the variables involved. Our results indicate failure but do not reveal its source.

Some support for the theoretical statements comes from performance of the M-space = e + 1 Ss. The theory predicts failure on the conservation tasks by these Ss since it holds that judgments (by definition) require a minimum of two figurative schemes. A limitation of one figurative scheme implies no possibility for inferential judgment. It remains to comment on the success of the M-space = e + 2 Ss. If no way can be found to argue the possibility of an M-space = e + 2 conservation response, then it will be that much more difficult to believe the theory. If, however, it is possible to arrive at a conservation response under the e + 2 constraint, then it may be that the theory can be retained while only statements regarding the required number of figurative schemes need be modified.

As an example of an e + 2 conservation response, the following sequence could apply to the substance or continuous quantity tasks. The experimenter (E) asks S 'Is there the same amount of clay in both, or does one have more than the other (or some equivalent question)?' S "reasons" with the following schemes:

(e_1) An executive scheme representing the question 'do the balls have the same amount of clay in them?'

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[1] In fact the four conservation tasks formed a unidimentional ordered scale as determined by a Guttman scalogram analysis. This analysis is a test of the invariant order of acquisition of the conservation concepts. A coefficient of reproducibility of .97 was obtained with the scaled order as follows: number, substance, continuous quantity, weight.

(1) A figurative scheme representing the fact that 'the balls were the same at the start.'

(e_2) An executive scheme representing the question 'did E change this amount?'

(e_3) An additional executive scheme representing the question 'how does one change the amount?'

(1) A figurative scheme representing the rule 'to change the amount you must add clay to or take clay away.'

(e_4) A figurative scheme representing the fact that 'E did not add clay to nor take clay away from the ball which was transformed.'

Correct conservation reasoning then requires the coordination of the following e + 2 schemes:

(e_5) An executive scheme representing the question 'do the pieces still have the same amount of clay in them?'

(1) A figurative scheme representing the rule 'to change the amount you must add clay or take clay away.'

(2) A figurative scheme representing the formation 'E did not add clay to or take clay away from the ball which was transformed.'

Therefore E did not change the amount i.e., they are still the same.

By introducing additional executive schemes in this way the M-space constraint of e + 2 is never exceeded and successful conservation reasoning is possible. Crucial to the validity of this explanation is S's use of self-chosen executive schemes replacing E's original question. If S can indeed do this, he then can presumably coordinate the final two figurative schemes without overloading M-space. There is, however, a credibility trade off here. Too many executive schemes lowers credibility since it suggests highly skillful ability to ask the right question at the right time. The other conservations require no different arguments but others can be offered. For example, the conservation of number could be coded by S into the executive scheme 'count the two rows.' S must retain in memory the number obtained for one row, however, he need not pay attention to nor use knowledge of the transformation of the rows. As for conservation of weight, suppose that 'amount' and 'weight' become interchangeable in the context of the experiment, i.e., S recognizes that you can change the one only by changing the other Then S need only proceed as outlined above. In response to counter-suggestions or to justify their original responses, S's need only point out that E did nothing to change the amounts involved. This does not imply that S required a separate step in M-space to explicitly use the equivalence of amount and weight. Some Ss make no reference to the amount. This further supports the idea that it is not necessary to reason in terms of amount and <u>then</u> substitute weight for amount in the conclusion. Presumably Ss with M-spaces of e + 2 who do equate weight and substance demonstrate conservation of weight, while those who do not make this equivalence do not conserve weight.

It would appear that a truly stringent test of the theory would require construction of a task (other than conservation) for which it is necessary (at least compellingly reasonable) to conclude that an M-space of e + 3 is needed for success. The data presented here suggest that use of the ideas of increasing M-space and coordination of specific figurative schemes to explain the order of acquisition of conservations has district limitations.

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