Title	Experimental verification of mental-space theory and its problem at issue
Sub Title	
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Publisher	慶應義塾大学大学院社会学研究科
Publication year	1979
Jtitle	慶応義塾大学大学院社会学研究科紀要 : 社会学心理学教育学 (Studies in sociology, psychology and education). No.19 (1979.) ,p.91- 97
JaLC DOI	
Abstract	
Notes	論文
Genre	Departmental Bulletin Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=AN0006957X-00000019-0091

Experimental Verification of Mental-Space Theory and its Problem at Issue[1]

Tomoko Kawata, Takashi Naito, Hiroshi Namiki, Junko Yamamoto, and Ryuta Yasuoka

One hundred and eighty-one kindergartenchildren (ages 43 months to 78 months) were administered the Block test, forward and backward Digit Span test, Matching Familiar Figure test, and five classificatory tasks. Based upon the Mental-Space theory, originally proposed by Pascual-Leone (1969), task analysis was made, and the predictive power and validity of the theory were examined. The results from the present experiment seem to support Mental-Space theory in the following three points: 1) M-Space is one of the critical factors in predicting the task performance. 2) M-Space is one of the important factors in predicting the improvement through training. 3) Field-independence regulates the task performance as a factor which makes M-Space work fully. Furthermore, several new findings on the M-Space theory might be summarized as follows: 1) Although two qualitatively different types of scheme were trained by way of two instructional treatments, no main effect of this variable was observed on the task performance after training. 2) The factor of Reflectivity-Impulsivity can be regarded as one of the factors that make M-Space work fully. But we failed to predict the task performance sharply, and it indicates that M-Space theory has some problematic points. Futher experimentation is needed to determine the validity of M-Space theory.

Piaget's developmental stage theory assumes fundamental necessary transformations of cognitive structure, and does not include a probabilistic conception as is often the case with test theories. Many ad hoc concepts, for example, *horizontal décalages*, are postulated in his theory, and tend to weaken its persuasiveness.

On the other hand, the concept of general intelligence, which stems from the theory and practice of traditional testing, can be regarded as nontheoretical and empirical, and has insufficient predictive power to specify the performance on a particular task.

Several views have been offered relating Piaget's theory to psychometric theories (Green,

1) The research program was performed by the members of PP Study Group, which was named after Piaget and Pascual-Leone. Among them are Miss Masako Suzuki and Mr. Nakamitsu Ryo, graduates of Literature Department of Keio University.

Thanks are due to Mrs. Toshiko Fukuda, the principal of Nishi-Kamakura Kindergarten, for her help in offering their children as experimental subjects. Thanks are also due to Miss Elanna Yalow, Ph. D. candidate at the School of Education, Stanford University, for her scrupulous assistance in translating into English.

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D. R. et al, 1971), for example, the scalogram analysis of Piagetian tasks (Wohlwill, 1960), and the application study of Lord's test theory (Namiki, 1976). These studies were performed to demonstrate that the theories are complementary. Although they treated the two theories complementarily, they simply used Piagetian tasks as test items instead of using traditional items. Theoretical necessity, therefore, can not obviously be recognized between the structure of a particular task and the score on a scale.

The Mental-Space theory, originally proposed by Pascual-Leone (1969), is based on the Piagetian notion of *schema* and is called the *Neo-Piagetian* theory. It specifies the structure of the acquisition of intellectual ability more functionally, and advances a quantitative rather than a qualitative analysis of Mental Space. Furthermore, the Neo-Piagetian model of development has been proposed to predict the subject's performance on a particular task. This theory is, therefore, expected to relate Piaget's theory to test theories. As will be mentioned later, however, this theory has some problematic points, and requires modification based on experimental data.

The Mental-Space theory postulates that the following four conditions are necessary for successful performance in a specific task situation:

1) The child must possess appropriate *figurative schemas* and *operative schemas* in his cognitive repertoire.
2) The child must have obtained a certain degree of field independence relevant to the given situation.
3) The child must have a tendency, when two incompatible schemes might be activated, to activate the scheme which is compatible with the largest number of other schemes.
4) The child must have a mental capacity large enough to coordinate the required schemas (Lawson, 1976).

In addition, from the developmental point of view, Mental-Space theory says that Mental-Space increases as a function of age; *e.g.*, 5-6 years old children have a maximum M-Space of e+2. The e represents the mental effort, or executive schema, and the 2 represents the number of schemes children can activate.

The purpose of the present study is to examine the validity of Mental-Space theory by experimentation using classification tasks of varying difficulty.

Method

Subjects. Subjects were one hundred and eighty-one kindergarten children (91 males and 98 females) in Kanagawa prefecture. They ranged in age from 43 months to 78 months.

Measures of Ss' traits. The following tests were individually administered to measure the children's traits: the Block test from the WISC, forward and backward Digit Span test also from the WISC, and Matching Familiar Figure test (MFF). The backward Digit Span test was assumed to be a measure of M-Space (Case, 1972a). The Block test was used to measure Field-independence, a widely acknowledged cognitive style. The MFF was assumed to measure Reflectivity-Impulsivity, also a cognitive style. The authors are of the opinion that Reflectivity-Impulsivity is an important factor which restricts the activation of M-Space.

Tasks. The following five tasks were individually administered to each child.

Task I—Simple collecting: Ten figures varying in colour, shape, and size were presented to S. S was to pick out the figures with common dimensions. E told S, *e.g.*, "Pick up all red figures." S passed when S succeeded in two out of three problems.

Task II—Outsider seeking: S was to seek the outsider, that is, the one that did not belong to a group of five figures, for example, a fish, a shell, a snail, a prawn, and an octopus. S passed when S succeeded in two out of three problems.

Task III—Peer collecting: Given pictures of, for examsle, a ship, a car, a pen, a ruler, an airplane, and a fish, S had to identify all peers of ship; that is, all members belonging to the same group as a ship. If S succeeded, S was again required to collect peers of the ship, from a different point of view. For example, if S just collected peers of ship as a vehicle, S was then expected to collect peers in terms of objects related to the sea. In this problem, the criterion was to classify the pictures using two categories and to verbalize the rationale for classification. S passed when S succeeded in one out of two problems.

Task IV—Dual dimensional sorting: First, S had the following training trial. Several colored figures were placed in a rectangle above three plates, two large ones and a small one between them (see Fig. 1). S was instructed to place, for example, all red figures into the left plate, all triangles into the right plate, and a red triangle, which could reasonably be placed into either plate, into the small plate. Then S was presented problems similar to the training trial. S passed when S succeeded in classification, and verbalization of the rationale, in one out of two problems.

Task V—Classification based on the hierarchical concept: S was presented the frames as shown in Fig. 2, and eight figures were randomly put into the top frames, for example, eight vehicles—helicopter, propeller-driven plane, jet plane, rocket, monorail train, train, bicycle, and car. S was first instructed to divide them into two groups (*i. e.*, on the land, or in the sky), and then divide each group into two groups (*i. e.*, land—on the rail or not; sky—propeller or jet). When S made a correct classification and could state the rationale for one out of two problems, S passed.

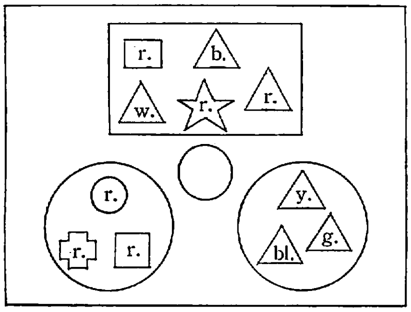

Fig. 1 Task IV

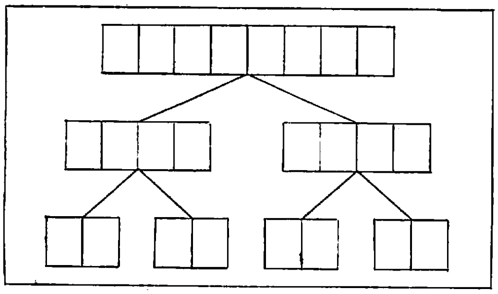

Fig. 2 Task V

Two instructional treatment groups. When S failed to pass a certain task, S received a training procedure without delay. Following this procedure, the outcome of training was examined by a similar problem.

Ss had been assigned to one of two treatment groups randomly before the tasks were administered. They were the concrete treatment group (CR Gr.) and the conceptual treatment group (CP Gr.). In Task III, for example, CR Gr. received training with concrete objects. Specifically, Ss were presented a picture that suggested the classificatory categories, and were required to put the peers in it. In contrast, the CP Gr. received training at the conceptual level, through verbal instructions, and did not move concrete objects.

These two treatment conditions were assumed to yield differences in the quality and quantity of the scheme S might activate.

Procedure. The experiment was composed of two sessions. In the first session, traits of Ss were measured, and Tasks I and II were administered in succession. In the second session, about one week later, Tasks III, IV, and V were administered. The first session took about 15 minutes, and the second session took 15 to 30 minutes depending on S's ability. In addition, questions were asked of S to measure intrinsic motivation. Further mention will not be made of this in the present paper.

Task analysis. Following the procedure of Mental-Space theory, the number of M-demands in each task was calculated. For example, the M-demand of Task IV was obtained as follows:

1) A figurative scheme representing the category of figures in the right plate.

2) A figurative scheme representing the category of figures in the left plate.

3) An operative scheme to synthesize 1) and 2), and represent the features of the figure to be placed in the small plate. Using this

procedure, the M-demand of each task is as follows:

Task I: e+1
Task II: e+2
Task III: e+2
Task IV: e+3
Task V: e+2

Results and Discussion

The proportion of correct responses on each task as a function of M-Sace. We divided all subjects into four groups in terms of M-Space level (See Table 1). The proportion of correct

Table 1 The number of subjects on each M-Space Level

	e+1	e+2	e+3	e+4
Total	69 (36.6)	46 (24.3)	67 (35.4)	7 (3.7)
CR Gr.	32 (34.8)	19 (20.7)	37 (40.2)	4 (4.3)
CP Gr.	37 (38.2)	27 (27.8)	30 (30.9)	3 (3.1)

Note. Figures in parentheses represent percentages of subjects on each M-space level.

responses was calculated on each M-Space level for each task. There proportions were obtained from performance before and after training (Fig. 3 and 4). In both cases, the proportions of correct respose on each task were nearly

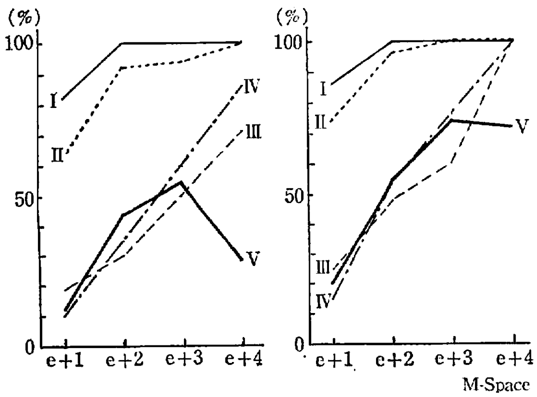

Fig. 3 Before training Fig. 4 After training

Fig. 3 & 4. The proportion of correct responses on each task as a function of M-Space

linear functions of M-Space, with the exception of Task V. The following hypothesis can be derived from M-Space theory: If M-demand obtained from the task analysis of each task is larger than the M-Space S has, successful performance in the particular task is impossible for the S. Although M-demands of Tasks II to V are e+2, or e+3, 62.3% of Ss with e+1 passed Task II, and 10 to 20% on Tasks III to V. These findings seem to counter the validity of M-Space theory.

The proportion of correct responses on each task as a function of M-Space and cognitive style. Ss with above average scores in the Block test were classified as field-independent (FI), and below average as field-dependent (FD). We calculated the proportion of correct responses on each task at each M-Space level, treating FI and FD separately. As shown in Fig. 5 and 6, the proportion of correct reponses for FI Ss is higher than that for FD Ss at each M-Sace level.

The factor of reflectivity-impulsivity as measured by MFF was added by calculating the proportion of correct responses at each M-Space level. Ss scoring high above the mean in response latency in MFF were classified as reflective, and below the mean as impulsive. An overall increase in the proportion of correct responses was observed as expected (see Fig. 5 and 7).

Correlation between M-Space and age in months, and task performance. The correlations between M-Space and task performance with no training procedure ranged from .416 to .645, and the correlations between age and task performance were nearly equal.

Partial correlations between M-Space and task performance with age held constant were calculated as shown in the parentheses of Table 2. These positive and significant partial correlations suggest that M-Space is a comparatively independent factor in determining the task performance. Consequently this result seems to give positive support to the M-Space theory.

Aptitude-treatment interaction when M-Space and other traits are used as aptitude dimension. We examined whether the two instruc-

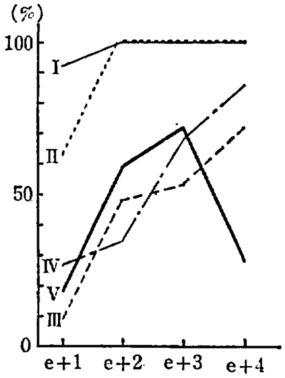

Fig. 5 FI *Ss.*

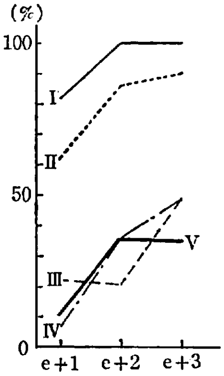

Fig. 6 FD *Ss.*

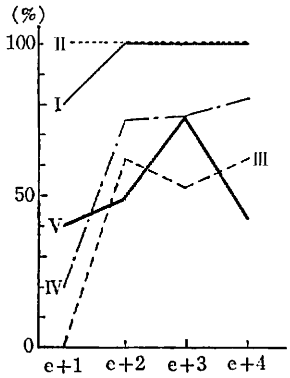

Fig. 7 Ss who are both FI and Reflective

Fig. 5, 6 & 7. The proportion of correct responses on each task as a function of M-Space and Cognitive style

Table 2 Correlations between M-Space and age in months and task performance

Task	Before training		After training (CR Gr.)		After training (CP Gr.)	
	M-Space	Age	M-Space	Age	M-Space	Age
I	.645** (.568**)	.370**	.561** (.067)	.893**	.538** (.392**)	.455**
II	.553** (.249**)	.732**	.666** (.361**)	.873**	.517** (.107)	.898**
III	.416** (.261**)	.384**	.569** (.385**)	.504**	.357** (.157)	.481**
IV	.617** (.507**)	.418**	.674** (.505**)	.571**	.673** (.561**)	.486**
V	.441** (.222**)	.500**	.592** (.318**)	.672**	.559** (.272**)	.781**

Note: figures in parentheses represent partial correlations with age held constant.
** $p<.01$.

tional treatments, concrete and conceptual, interacted with aptitude dimensions. The proportion of improvement through training was used as a measure of payoff. Age in months and the M-Space, composite score of Block test and Digit Span, were used as aptitude dimensions. A disordinal interaction was identified on Task V using M-Space as aptitude (Fig. 8).

In order to clarify the difference between instructional treatments, we identified only those subjects who received training on Tasks III, IV, and V, and examined the ATI. The measure of payoff in this case was the percentage of the total number of tasks where improvements were observed through training divided by total number of tasks (3×number of Ss). Patterns of ATIs differed considerably depending on the aptitude dimension (Fig. 9, 10, and 11). It is difficult, however, to explain these differences theoretically.

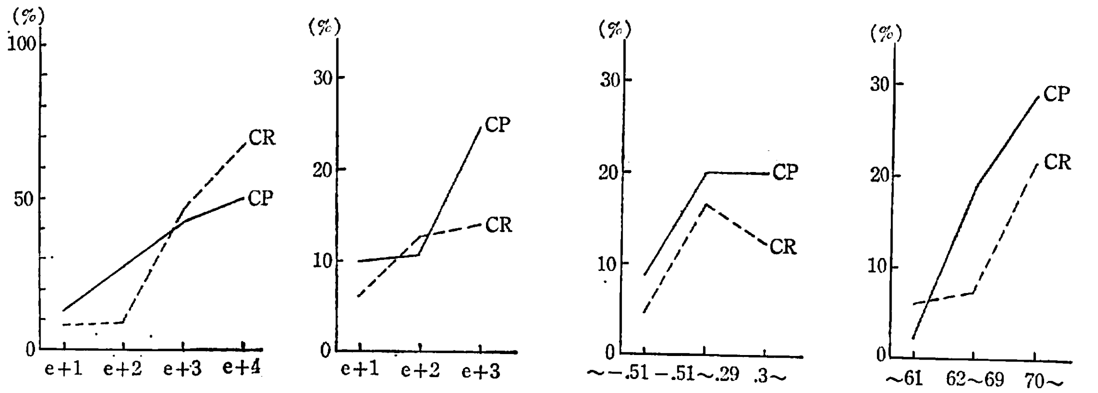

Fig. 8
When M-Space was used, on task V

Fig. 9
When M-Space was used (on task III, IV and V)

Fig. 10
When composite score of Block test and Digit span was used (on task III, IV and V)

Fig. 11
When age in months was usd (on task III, IV, and V)

Fig. 8, 9, 10 & 11 Aptitude-treatment interaction when M-Space and other traits are used as aptitude dimension

Concluding Remarks

The results from the present experiment seem to support Mental-Space theory in the following three points:

1) M-Space is one of the critical factors in predicting the task performance.

2) M-Space is one of the important factors in predicting the improvement through training.

3) Field-independence regulates the task performance as a factor which makes M-Space work fully.

Furthermore, several new findings on the M-Space theory might be summarized as follows:

1) Although two qualitatively different types of scheme were trained by way of the two instructional treatments, no main effect of this variable was observed on the task performance after training.

2) The factor of Reflectivity-Impulsivity can be regarded as one of the factors that make M-Space work fully.

Now, the most critical and negative finding against the Mental-Space theory must be touched upon. Quite contrary to our expectations, we failed to predict the task performance sharply in terms of M-Space and M-demand. Thus, on the basis of the present findings, it is doubtful that M-Space has more predictive power than, for example, general intelligence.

One possible interpretation of this result is that even when M-Space is short of M-demand, there exist several other strategies for performing tasks successfully. To increase the validity of M-Space theory, it is essential to objectively develop procedures to specify the scheme subjects might use.

Moreover, success in prediction of the performance depends upon the valid measurement of the traits involved. Closer examination is needed to determine the validity of the Digit Span test as a measure of M-Space.

Finally, mention with be made of the ATI effect. The authors are of the opinion that the concept of Mental-Space should have substantial implication when we consider an aptitude as a process variable (Melton, 1967; Namiki, 1978; Snow, 1976). We must await further experimentation before any conclusion can be reached about this possibility, although the present experiment yielded no clear evidence on the ATI in terms of M-Space.

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