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The Balance Effect on the M-Space by Spatial Interaction

A theoretical foundation is given for the concept of Balance which is related to the Piagetian concept of cognitive equilibrium. A discussion is given concerning possible interactions of Balance with Spatial Ability and M-space, i.e., the span of short-term memory. Graduate statistics students were subjects in the investigation of these possible interactions. The investigation revealed a sizable Balance by Spatial by M-space triple interaction. A statistical interpretation was given to the results along with a discussion of the concurrence of the results to theory.

The purpose of this study is to make operational the concept of "balance" (Piaget, 1977) and to investigate its interactive effects with spatial ability (McGee, 1979; Smith, 1964) and M-space (Case, 1972, 1974, 1975, 1977; Pascual-Leone, 1970) on graduate level statistics course work.

Piaget's (1977) theory of equilibration describes the dynamic balance of an organism with its environment and that maintained among the subsystems of the organism and its relation to cognitive development. Two postulates of his theory of equilibration are as follows:

"First postulate: Any scheme of assimilation tends to feed itself; that is, to incorporate outside elements compatible with its nature into itself" (p. 7). This suggests that a person by virtue of being alive tends to integrate into his/her action or conceptual schemes those elements that are consistent with the nature of that scheme.

"Second postulate: The entire scheme of assimilation must alter as it accommodates to the elements it assimilates; that is, it modifies itself in relation to the particularities of events but does not lose its continuity. . . nor its earlier powers of assimilation" (p.7). This is essentially a postulate that assimilation and accommodation remain in balance "in order for the accommodation to succeed" (p.8).

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Piaget suggests that there are three kinds of equilibration, or balancing. The first occurs during a subject-object interaction. "There is the equilibration between the assimilation of schemes of action and the accommodation of these to the objects" (p. 9). The balance then has to be maintained between bringing an object into an action scheme and the modification of the action scheme to the object. Nonbalance occurs in this sense when an object cannot be assimilated into an action scheme.

The second form of balancing occurs during the interactions of the subsystems of the subject; that is, the interaction of action or conceptual schemes. Two or more conceptual or action schemes equilibrate, or come into balance, through reciprocal assimilation and accommodation. Nonbalance is caused here by the fact that "the subsystems are generally constructed at different speeds " (p. 9). One may understand one concept better than a second, and, therefore, missing components of the second make an emerging concept incomplete.

The third form of balancing is that between integration and differentiation of schemes.

> On the one hand, to differentiate a totality, T, in subsystems, S, means not only to confirm what each of these possesses but also to exclude, or deny, the characteristics each subsystem does not have. On the other hand, to form (to integrate) a total system, T, means to free positively the characteristics common to all the S, but this also means to distinguish — this time negatively — the common features of special characteristics not belonging to T. (p. 11)

Both Phillips (1975) and Ginsberg and Opper (1979) have put Piaget's theoretical abstractions into more concrete, lexical, and perhaps measurable terms. Phillips describes the development of play as a process of differentiation of means separate from ends. Phillips states:

> The separation of means from ends has far reaching implications. When the two are completely separated and the ends drops out (the means becomes an end in itself), we have *play*; when they are differentiated but continually related, we have *problem-solving* behavior. Both originate in this primitive separation. (p. 36)

According to Piaget (1970), play is the "assimilation of reality into the self" (p. 22). Ginsberg and Opper (1979) suggest imitation as a concrete example of accommodation. Children may imitate the shape of a fish hook by bending one finger (they have accommodated the finger-bending action scheme to a fish hook). On the other hand, children in play may pretend that two sticks crossed together is an airplane, in which case they have assimilated the object into an airplane scheme. In adults, intellectual play may take the form of "brainstorming" where unusual associations, and diverse ideas are generated, usually by noting similarities between unrelated things. In adults, imitation may take the form of "cookbook" problem solving, where one's actions accommodate directly to step-by-step instructions. Rote memorization becomes simply an imitation of previously perceived material.

It has been attempted to measure via a self-report questionnaire the degree to which assimilation and accommodation are generally in balance among students during the course of studying graduate level statistics. Questions were inspired by Samples' (1968, 1976) balance of metaphorical mode (or playful) vs. substantive mode (or work) in natural problem-solving behavior of children as well as by Piagetian concepts described above. Both Piaget's and Samples' play-like components of problem-solving involve assimilating similarities between the external material and an internal scheme or metaphor. Piaget (1977) suggests that

a nonbalance occurs when "an obstacle" holds an "assimilation in check" (p. 187). One cannot assimilate the elements of the external reality unless one has the systems to do so. Just as the grasping action scheme accommodates to a large object by having the hand open wide, students accommodate their conceptual schemes to extremely difficult subject matter through imitation. They may imitate the problem-solving procedures given by the teacher, take prolific notes as a verbal imitation of the teacher's knowledge, or read passages out of the text numerous times until they are capable of imitating the text verbatim. These methods in lexical terms are simply rote memorization. Questions pertaining to a general nonbalance in favor of accommodation and work stressed this memorization aspect.

Questionnaire

Instructions: Circle the number next to the statement according to the degree of your agreement whether the statement describes you or your feelings.
0 = do not agree
1 = agree
2 = strongly agree

1. I do statistics problems the same way as following a recipe to cook something.	*0*	*1*	*2*
2. When I listen to a lecture in statistics I take a lot of notes so that I can learn the material later.	*0*	*1*	*2*
3. I look forward to statistics class.	*0*	*1*	*2*
4. Statistical ideas are so similar to some non-mathematical things I already know, I feel as if I understand statistics because of this similarity.	*0*	*1*	*2*
5. In order to understand statistics I have to do a lot of memorizing.	*0*	*1*	*2*
6. I am taking statistics more for the reason that I enjoy the material than to fulfill a requirement of my program.	*0*	*1*	*2*
7. Studying statistics is more like playing with ideas than working at a job.	*0*	*1*	*2*
8. I don't take notes in statistics lecture because everything seems to "just fit" into what I already understand.	*0*	*1*	*2*
9. It seems that I have to repeat an idea in statistics many times before I can even begin to understand it.	*0*	*1*	*2*
10. Doing statistics is real work.	*0*	*1*	*2*

A student who takes a very playful approach to the course material, like a child at play, will see similarities in just about everything. But again Piaget (1977)

suggests that the initial cause of the nonbalance is the "systematic primacy of the positive characteristics" and the "assimilation at the beginning of affirmations almost exclusively" (p. 189). That is, a student will be unbalanced by assimilating only the similarities between the course material and the chosen scheme of assimilation. It is on this perception of similarities between course material and other unrelated material and self-reports on playful approaches that questions pertaining to a nonbalance in favor of assimilation were based. A complete description of the instrumentation of the Balance concept will be discussed below.

A second variable suspected of accounting for variance in graduate level statistics scores is M-space. This is the maximum number of figurative or operational schemes that a person's short-term memory may hold at one time. Pascual-Leone (1970) suggests that problem-solving ability depends on this span of short-term memory, because it is in short-term memory that reciprocal assimilation of schemes occurs. The complexity of one's conceptual schemes is determined by the way in which they are constructed and directly by M-space. Case (1975), however, suggests that with the appropriate teaching strategy all that is required is an M-space equal two. This is because a concept can be analyzed into component concepts, and sequentially and pairwise be brought together into the superordinate concept. In the absence of this kind of instruction, M-space would be expected to be a deciding factor in course outcome.

A third variable of interest is spatial ability. Spatial visualization is defined by McGee (1979) as the "ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object" (p. 893). Smith (1964) suggests that spatial ability is required to make configural transformations in two and three dimensions, but also suggests that it is related to reasoning ability and the ability to grasp the Gestalt of a situation; i.e., think holistically. Piaget and Inhelder (1971) suggest that one's mental imagery is contingent upon one's operational level and, hence, one's abilities for problem-solving in general. In this sense the static, reproductive image is at the lower end of development, while the transformational, anticipatory image is at the higher end of development. This point of view was substantiated by Forisha's (1975) study in which verbal and imagery abilities were shown to develop in parallel and as a function of developmental level. A spatial score is used therefore as an inferential measure of one's level of holistic thinking and problem-solving ability in general.

Other variables were also recorded: sex and number of years of college mathematics experience. While these may be good predictors of success (Jacklin & Maccoby, 1972; deWolf, 1977), they provide little understanding of underlying processes of learning.

Of special interest to this investigation is the possible interaction of variables. It is logically expected that those with higher spatial and M-space scores do well regardless of Balance (i.e., balance of work vs. play or accommodation vs. assimilation). The differences occur under deficiencies of spatial and/or M-space scores. Logically it is expected that students deficient in both abilities would do better in a work or accommodative orientation to a complex topic such as statistics, because they lack the structures for easy assimilation.

Method

Thirty graduate students enrolled in a graduate level statistics course for behavioral sciences received course credit for completion of the following instruments:

Paper Folding Part 1 (French, Ekstrom & Price, 1963) is a test of spatial visualization involving the selection from a set of distractors the picture of an unfolded square piece of paper that had previously been folded and had a hole punched in it. The test appears to require at the highest level transformational, anticipatory imagery.

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Space Relations (Differential Aptitude Test Psychological Corp.) is a test of spatial visualization and surface development. One selects from a set of distractors which representation is possibly the result of folding together a cut-out and rotating it in space. The test appears to require the ability to form a transformational, anticipatory image.

A spatial score was computed by standardizing the sum of standardized scores of Paper Folding and Space Relations.

Backwards Digit Span (Case, 1977). Subjects listened to a tape of numbers being read off. Starting with three digits, going up to six digits, subjects were required to reverse the order in which the numbers were read and then write the same reversed set of digits. Subjects were monitored to make sure instructions were followed properly. Subjects had three chances for each digit span. M-space was considered to be that highest digit span for which the subject obtained at least one correct reversal.

Balance Questionnaire contained five questions pertaining to the degree with which students perceived themselves as tending to memorize statistics and their opinion as to whether statistics was "real work" (accommodative or work nonbalance). There were also five questions pertaining to the degree to which students perceive similarities between statistics and other nonmathematical material and as well whether statistics was more play than work (assimilative or play nonbalance). The final form of this questionnaire was the result of a factor analysis of an earlier form. The original questionnaire contained (as interpreted from this theoretical reference frame) three factors after rotation. These were accommodation-work, assimilation play, and affect towards statistics. Questions loading solely on affect were not used in the final form of the questionnaire. The inter-item reliability (Brown, 1976) for the five accommodation questions was 0.85, and for the five assimilation questions was 0.75. Each item was scored 0 for not agree, 1 for agree, and 2 for strongly agree. The difference between the sum of the assimilation questions and the sum of the accommodation questions was the Balance score. Typical examples are as follows:

> It seems that I have to repeat an idea in statistics many times before I can even begin to understand it.

> Statistical ideas are so similar to some non-mathematical things I already know, I feel as if I already understand statistics because of this similarity.

The total points received in the statistics course (multiple regression) for the behavioral sciences served as criterion. Majority of exam points went to application and computation type questions.

Results

Zero-order correlations were computed among the following variables: Statistics total points, sex of the student, years of mathematics during college experience, spatial score, M-space and Balance. Years of mathematics did have a significant zero-order correlation with the criterion ($r=0.436$, $p<0.05$). However, once spatial ability, M-space, and Balance were partialled out, years of mathematics had no independent contribution to variance in the criterion ($F=1.78$, df=1,21, $p>0.15$).

TABLE 1

INDEPENDENT SOURCES OF VARIATION
IN COURSE SCORES

Source	Independent SS[a]	MS	F(1,24)	Probability
Spatial score	3.286	3.286	6.62	0.017
M-space	3.155	3.155	6.35	0.019
Balance	4.512	4.512	9.08	0.006
Spatial*M-space	5.028	5.028	10.11	0.004
Spatial*M-space*Balance	3.583	3.583	7.21	0.013
Residual (Full Model)	11.932	0.497		
Total	29.000			

[a]The change in residual sum of squares upon removal of the one source from the full model.

A statistical model was constructed by way of multiple regression (Kerlinger & Pedhazur, 1973) to account for variance in the criterion. All scores were converted to standard z-scores. In Table 1 are listed the sources of independent contributions, independent (Type IV) sums of squares, F-ratios and levels of significance (probabilities of Type I error). All main effects of interest reached levels of statistical significance ($p<0.02$). A spatial by Balance and an M-space by Balance interaction both were nonsignificant ($F=0.28$ and $F=0.19$ respectively, df=1,21, and $p>0.60$) and subsequently were pooled with the residual. Two important interactions revealed themselves through this analysis. The first is the spatial by M-space double interaction, and the spatial by M-space by Balance triple interaction. A χ^2 test for homogeneity of sample does not substantiate a possible hypothesis of a departure from sample homogeneity ($\chi^2(3)=4.003$, $p>0.20$). The regression model ($R^2=0.589$, df=5,24, $F=6.87$, $p<0.0004$) is as follows:

$$\text{Statistics} \quad 0.4^*\text{Spatial} + 0.4^*\text{M-space} + 0.4^*\text{Balance} + 0.5^*\text{Spatial}^*\text{M-space} - 0.5^*\text{Spatial}^*\text{M-space}^*\text{Balance}.$$

This equation is plotted as three, two-dimensional manifolds of a four-dimensional hypersurface in Figures 1a, b and c. Figure 1a is a section of the hypersurface at

which Balance =-1 standard deviations from the mean; i.e., a predominantly work or accommodative nonbalance. Figure 1b is a section in which Balance equals zero; i.e., assimilation and accommodation are in mean balance as determined by the sample. Figure 1c is a section at which Balance= · 1 standard deviations above the mean; i.e., a predominantly playful or assimilation nonbalance.

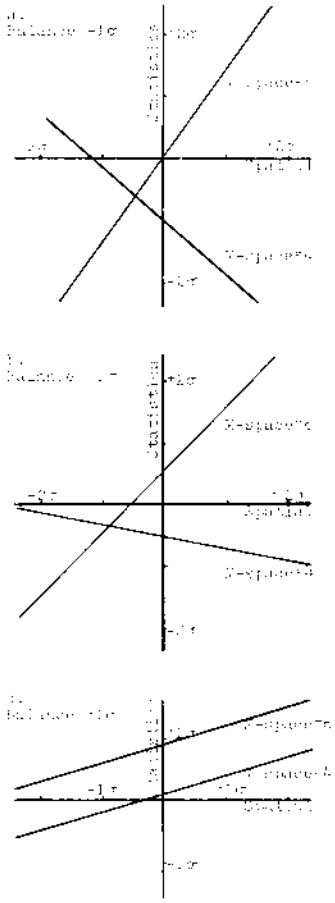

Figure 1. Three two-dimensional sections showing a Balance by M-space by Spatial interaction.

It should be noted that for spatial≥0 and M-space=6, statistics course work remains high as expected across the three values of Balance. For spatial≥0 and M-space=4, statistics course work increases with an increasingly assimilative or playful (Balance≥0) orientation. This same trend occurs for spatial≤0 and M-space=6. However, for spatial≤0 and M-space -4, statistics course work increases with an increasingly accommodative or work (Balance≤0) orientation. The mean M-space value for the sample was 5.13, standard deviation equals 0.86.

Discussion

It is apparent from the data that, in main effect terms, students tend to do better depending on the spatial score, M-space score, and their general nonbalance

in favor of assimilative or playful orientation. Piaget (1977) does suggest that in order for a conceptual scheme to come into "increasing equilibration" or for an accommodation to succeed, the initial nonbalance occurs by the "assimilation at the beginning of the affirmations almost exclusively" (p. 189). That is, a conceptual scheme undergoes permanent modification as a re-balancing after the similarities between the external material and the unmodified conceptual scheme have been assimilated into that same scheme. It is with respect to this theoretical point of view that the Balance main effect is interpreted. The spatial and the M-space main effects are expected by the theories discussed previously.

The disordinal interaction between spatial and M-space scores on course outcome for Balance less than or equal to mean value is complex. The regression surfaces would predict that among students with less than average spatial scores and less than positive Balance, those with a below-average M-space generally do as well as or better than others. This result is implied perhaps by Case's (1975) idea that with a proper instructional method the minimum M-space required is two. In the present situation, it would have to be the students providing their own instructional method through their learning strategies outside of class. In fact, five out of six students in this category reported taking a lot of notes so that they could learn the material out of class. It is apparent that these students did not do their learning while in class. A comparison of Figures 1a and 1b indicates that students with deficiencies both in spatial and M-space scores do better with an accommodative or work orientation than with an assimilative or playful orientation to this subject. While they do better with an accommodative orientation there is no evidence to suggest that the information is retained beyond the final exam, or in Piagetian terms, whether the conceptual schemes undergo a successful accommodation of "increasing equilibration."

For ease of interpretation, the two interaction terms uncovered through this investigation can be combined into one expression. These two terms, 0.5*Spatial*M-space and -0.5*Spatial *M-space*Balance can be factorized as follows:

0.5*(1 - Balance)*Spatial*M-space.

It is then interpreted that Balance affects the Spatial by M-space interaction via its regression weight.

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