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ACHIEVEMENT IN CHEMISTRY PROBLEM-SOLVING AS A FUNCTION OF THE MOBILITY–FIXITY DIMENSION [1,2]

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Summary.—The present studies explored the relation between students' achievement in chemistry problem-solving and the Mobility–Fixity dimension. Fixity characterizes consistency of function of field-independent subjects in a field-independent fashion, while Mobility provides for variation according to circumstances. The effect of this cognitive variable was examined as a function of the type and the complexity of the problem. Two kinds of problems were used, chemical equilibrium problems with varying mental demand and logical structure, and organic synthesis problems with varying mental demand. The subjects had to carry out different mental tasks, such as manipulation of logical schemata, applying algorithmic procedures, solving nonalgorithmic problems. In all cases, Mobile subjects demonstrated higher achievement than Fixed subjects. The results of this study support the hypothesis that the Mobility–Fixity dimension can serve as a predictor variable of students' performance on chemistry problem-solving.

Recent research has shown the importance of cognitive variables, such as working memory capacity, mental capacity, developmental status, and cognitive style (or disembedding ability, that is, scores on field-dependence–independence) as predictor variables for problem-solving in science. Johnstone (e.g., 1984; Johnstone & El-Banna, 1989) proposed the working memory overload hypothesis, according to which a subject will not be successful in solving a task, e.g., a problem, unless the mental demand (*M*-demand, see below) of the task is less or equal to the subject's working memory capacity. Tsaparlis (1998) examined mechanisms that may block the solution of a problem and stated a number of conditions necessary for the successful operation of the Johnstone hypothesis. Using organic synthesis chemical problems of varying *M*-demand, the operation, validity, and usefulness of the above hypothesis was examined, together with the effect of cognitive style (Tsaparlis & Angelopoulos, 2000). In numerous studies, Niaz (e.g., 1988, 1989a; Niaz & Logie, 1993, and the references therein) examined the rela-

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tion between the *M*-demand of chemistry problems and mental capacity or *M*-capacity [the latter deriving from Pascual-Leone's neo-Piagetian theory (Pascual-Leone, 1970)]. In addition, he studied the effect of developmental status and cognitive style. Finally, Bitner (1991) considered the role of developmental status as predictor of critical thinking abilities in science and mathematics.

The Mobility–Fixity dimension, which is associated with the theories of Werner (1957), Witkin and Goodenough (1981), and Pascual-Leone (1989), has also been shown to be a good predictor variable. According to Werner (1957), during individual development, perception is first global, i.e., field-dependent, and later analytical, i.e., field-independent, and finally, in the mature individual, synthetic, i.e., field-mobile. Witkin and Goodenough (1981) pointed out that appropriate life circumstances might lead subjects to acquire characteristics of both field-independent and field-dependent cognitive styles. The characteristic of field-independent subjects to function consistently in a field-independent fashion, i.e., Fixity, and of others to vary more according to circumstances, i.e., Mobility, has been referred to as the 'Mobility–Fixity dimension' by Witkin (1965) and as a 'Mobile/Fixed cognitive style' by Pascual-Leone (1989). According to Pascual-Leone (1989), field-independent subjects are individuals for whom the "overcoming process," i.e., "strategy *x*," is stronger than the "embedding context" created by "strategy *y*"; the converse is true for field-dependent subjects. The scores obtained by subjects on measures of field-dependence–independence are a function of the weight of strategy *x*, relative to the weight of strategy *y*. As a result, the same scores on measures of field-dependence–independence can be obtained by subjects with vastly different absolute weights in strategies *x* and *y*. Pascual-Leone (1974) suggested that "Mobile field-independent subjects are precisely those who exhibit *both* a very high absolute weight overcoming process and a very high absolute weight embedding context. This expectation implies, of course, that the subjects' scores on field-dependence–independence measures will show them to be moderate (but not extreme) field-independent" (p. 33). The procedure for classifying subjects as Mobile or Fixed are described below in the Method.

Based on the above considerations the theoretical rationale suggests that the ability to shift, i.e., mobility, facilitates problem-solving in chemistry. The purpose of the present study is to test the hypothesis that the Mobility–Fixity dimension can be considered as a predictor variable for students' achievement in chemistry. It is predicted that students with a mobile cognitive style ("Mobile students") would perform better than students with a fixed cognitive style ("Fixed students").

The achievement of upper-secondary students was examined in various types of chemistry problems, which require different abilities, skills, and flexibility of functioning. Two kinds of problems were used, chemical equilibrium problems and organic synthesis problems with varying complexity. The complexity of the problem was set according to the number of logical schemata (Inhelder & Piaget, 1958) or the mental (M) demand, i.e., amount of information processing required by a problem (Niaz, 1988, 1989a).

METHOD

The present work was based on two studies of problem-solving. Study A was on chemical (molecular) equilibrium problems (Tsaparlis, Kousathana, & Niaz, 1998); Study B was on organic synthesis problems (Tsaparlis & Angelopoulos, 2000). The subjects were high school students in Grade 12 in Greece and were preparing to take entrance examinations for tertiary education (age 17–18).

In Study A, the subjects ($N=154$) had to solve nine chemical-equilibrium problems, with varying logical structure and M-demand. The logical structure is specified by the number of *operative schemata* entering the problem. According to Piaget, a *schema* is an internal structure or representation, while the ways we manipulate schemata are called *operations*. In Piaget's theory, schemata are continually growing and developing rather than remaining fixed. M-demand of a problem can be defined as "the maximum number of thought steps and processes which have to be activated by the least able, but ultimately successful solver, in the light of what he has been taught" (Johnstone & El-Banna, 1989). The determination of the M-demand of chemistry problems is based on a dynamic interaction between the general and figurative models constructed by the students and the logical structure of the problem (Niaz, 1989a).

Four logical schemata were identified in molecular equilibrium problems (Tsaparlis, *et al.*, 1998). Consequently, the nine problems of Study A were each labeled by an ordered pair of integers, the first number standing for the number of schemata, and the second number for the maximum number of (thought) steps that enter the various schemata: (2, 4), (2, 5), (2, 6), up to (4, 6). An example of a problem will clarify the method used for problem complexity estimation:

> In a vessel of fixed volume $V=4.5$ liters, 198 grams of a chemical (phosgene gas, $COCl_2$) plus 44.8 liters of another chemical (carbon oxide gas, CO) are introduced. The mixture is heated to 1000° Celsius and let to reach chemical equilibrium [$COCl_2 \rightleftharpoons CO + Cl_2$ (chlorine gas)]. Calculate the equilibrium constant (K_c), taking into account that at equilibrium the total pressure of the gas mixture is 82 atmospheres at 1000° Celsius.

Three schemata enter here: (1) the process of "establishment of the chemical equilibrium," (2) the "ideal-gas equation," and (3) the "condition of chemical equilibrium." Schema (1) involves five steps for its solution, schema (2) involves four steps, and schema (3) involves three steps. For further details see Tsaparlis, *et al.* (1998). Since schema (1) involves the largest number of steps (five), we postulate an *M*-demand of 5 for this problem.

Students' percentage achievement was measured separately for performance in schemata and performance in steps. The reliability of the used test was judged on the basis of two coefficients. Cronbach coefficient alpha was .77 for the schemata, .94 for the steps, and .91 for the summary scores (schemata plus steps). Split-half reliability coefficient was .84 for the schemata, .94 for the steps, and .93 for the whole problems.

In Study *B*, the students' achievement in organic synthesis problems, as a function of the *M*-demand of the problems, was examined for the various values of working-memory capacity (WM-capacity) and the cognitive style of the students (scores on field-dependence–independence). These problems, e.g., "using dimethylether as starting material, suggest a synthesis route for the preparation of the chemical compound propene" do not involve algebraic or numerical manipulations, are not algorithmic, and in addition have a unique chemical logical structure. The subjects ($N=281$) were different from those of Study *A* and had to solve seven problems of varying *M*-demand from 2 to 8. The *M*-demand followed directly from the minimum number of synthetic steps, i.e., the number of separate chemical reactions, required to accomplish the synthesis. The Kuder-Richardson coefficient of reliability for this test was .74. The students' achievement taken into account was measured by assigning for each problem 2, 1, or 0 marks, and then converting the mark for each problem into a percentage.

All subjects of Study *A* were pretested to establish their *M*-capacity, the WM-capacity, and the cognitive style as described below. On the other hand, for the subjects of Study *B* only WM-capacity and cognitive style were measured.

M-capacity was assessed by means of the Figural Intersection Test (Pascual-Leone & Burtis, 1974). The test was used for measuring the *functional* *M*-capacity of the subjects according to the method of Niaz (Pascual-Leone & Burtis, 1974; Niaz, 1988). To 'enforce' all students to deal with all the test items, the test was administered in a modified way by projecting onto a screen the nonoverlapping figures on a 35-mm slide. Each item was shown for a short period according to the number of overlapping figures, during which the students had to spot the intersection of the overlapping figures printed on paper. For details see Tsaparlis, *et al.* (1998). The evaluation of the *M*-capacity was made using the procedure suggested by Johnson (1982; see also Al-Naeme, 1988). The split-half reliability coefficient was reported in the Tsaparlis, *et al.* study as .93. A mean functional *M*-capacity of 5.12 ($SD=1.25$) was calculated.

WM-capacity was determined by means of the Digit Span Backward test. The test is part of the Wechsler Adult Intelligence Scale (Wechsler,

1955) and involves both storage and processing. It has been used as a measure of WM-capacity by Johnstone and his group in all their relevant work. To avoid the possibility of cheating, some modifications were introduced in the administration of this test. For details see Tsaparlis, *et al.* (1998). Working-memory capacity was taken as the maximum number of digits which were successfully written for at least two out of the three corresponding sequences. Half-integer values were assigned in some cases. A split-half reliability coefficient of .88 has been reported for the Study *A* sample. The mean WM-capacity was 4.86 ($SD = 0.88$) for Study *A* and 4.81 ($SD = 0.82$) for Study *B*.

Cognitive style or disembedding ability is usually assessed by means of the Group Embedded Figures Test (Witkin, Dyk, Paterson, Goodenough, & Karp, 1962; Witkin, Oltman, Raskin, & Karp, 1971; Witkin, 1978). In the two reported studies, however, a similar test was used; this was a timed (20-min.) test which was devised and calibrated by El-Banna (1987) from Witkin's original test materials, using hidden figures of the Hidden-Figures Test. The test has been used by the Johnstone group in all relevant work and is assumed to provide an equivalent Group Embedded Figures Test's measure of subjects' field-dependence–independence. On the Hidden-Figures Test, students had to locate a hidden figure, which is embedded inside a complicated one. Eighteen such items were given. Subjects with 13 or more successes were classified as field-independent, with 7 to 12 successes as field-intermediate, and with six or fewer successes as field-dependent. Split-half reliability coefficients were .78 and .68 for Studies *A* and *B*, respectively. The mean scores were 10.43 ($SD = 2.83$) and 9.84 ($SD = 3.15$), respectively.

The Mobility–Fixity Dimension

The procedure for classifying subjects as mobile or fixed was the same as that used in previous studies by Niaz (Niaz, 1989b; Niaz & Saud de Nunez, 1991; Niaz, Saud de Nunez, & Ruiz de Pineda, 2000). It was hypothesized that those field-independent students who obtain high scores on the Figural Intersection Test could be classified as Fixed, as they consistently demonstrate characteristics of field-independence. Similarly those field-dependent students who obtain low scores on the Figural Intersection Test could also be classified as Fixed. Those field-independent students who obtained low scores were classified as Mobile, as they show diversity in their modes of functioning. Similarly those field-dependent students who obtained high scores could also be classified as Mobile. Table 1 shows the classification and distribution of students of Study *A* according to the Mobility–Fixity dimension.

An alternative mobility–fixity classification can be postulated on the basis of the data from the Digit Span Backward in place of the Figural Intersection Test. This postulation is supported by the fact that both tests involve information-processing, that is, thinking, hence working-memory capacity and *M*-capacity must share a common space as is evidenced also by the high correlation between the two tests: $r = .66$ for our case Study *A*. Tables 1 and 2 show the alternative classification for Studies *A* and *B*, respectively.

TABLE 1

CLASSIFICATION (BIVARIATE FREQUENCY DISTRIBUTION) OF STUDENTS ($N = 154$) ON MOBILITY–FIXITY AND *M*-CAPACITY DIMENSIONS*: CHEMICAL-EQUILIBRIUM PROBLEM STUDY (*A*)

Classification	*M*-capacity			
	4	5	6	7
Field Independent	Mobile	Mobile	Mobile	Fixed
	2/5	11/14	12/18	13/1
Field Medium	Fixed	Fixed	Mobile	Mobile
	21/37	30/32	25/20	14/1
Field Dependent	Fixed	Fixed	Fixed	Mobile
	18/18	4/8	4/0	0/0

*The first number in each cell refers to classification on the basis of cognitive style and mental capacity; the second number refers to classification on the basis of cognitive style and working memory capacity.

At this point it is imperative to check the extent to which the above two classifications coincide in assigning students in the different cells of the Mobility–Fixity dimension (Table 1). Since we have a 2×2 contingency table where both measures are dichotomous, the appropriate statistical test is a pair-by-pair comparison measure of association, such as Yule's *Q* (Cohen & Holliday, 1982, pp. 79-80). For the present sample, *Q* has a value of 0.867, indicating high association between the two classification schemes.

TABLE 2

CLASSIFICATION (BIVARIATE FREQUENCY DISTRIBUTION) OF STUDENTS ($N = 281$) ON MOBILITY–FIXITY AND WORKING-MEMORY CAPACITY DIMENSIONS*: ORGANIC SYNTHESIS STUDY (*B*)

Classification	Working-memory Capacity			
	4	5	6	7
Field Independent	Mobile	Mobile	Mobile	Fixed
	20	25	20	6
Field Medium	Fixed	Fixed	Mobile	Mobile
	82	66	31	6
Field Dependent	Fixed	Fixed	Fixed	Mobile
	16	6	3	0

*Classification on the basis of cognitive style and working memory capacity.

All differences in achievement between subjects classified as Mobile and Fixed were checked for statistical significance by using the Student *t* statistic.

RESULTS AND DISCUSSION

Study A: Chemical-equilibrium Problems

Table 3 shows the achievement of Mobile and Fixed groups in the schemata, and the steps, respectively, with the Mobility–Fixity dimension based on the combination of scores for the Figural Intersection Test and Hidden-Figures Test, as described above in the Method. In achievement in schemata only we observe that, when the complexity of the problem is low [(2, 4), (2, 5), (2, 6), and (3, 4)] there is no difference in achievement between Mobile and Fixed groups. As the complexity of the problem increases, both Mobile and Fixed groups show a decrease in achievement, but the Mobile group achieves higher scores in all cases. The Mobile group appears to be better at manipulating logical schemata. All score differences between groups after problem (3, 4) are statistically significant. In achievement in steps only, all score differences are statistically significant.

TABLE 3

MEANS AND STANDARD DEVIATIONS FOR ACHIEVEMENT BY MOBILE AND FIXED STUDENTS FOR CHEMICAL EQUILIBRIUM PROBLEMS (STUDY *A*): FIXITY–MOBILITY BASED ON COGNITIVE STYLE AND MENTAL CAPACITY

Problem Code		(2, 4)	(2, 5)	(2, 6)	(3, 4)	(3, 5)	(3, 6)	(4, 4)	(4, 5)	(4, 6)
					Achievement in Schemata					
Mobile ($n=64$)	*M*	100.0	99.2	97.7	98.9	98.4	93.2	85.2	88.7	78.5
	SD	0.0	6.2	10.6	5.8	7.1	14.7	23.0	19.9	27.0
Fixed ($n=90$)	*M*	100.0	99.4	98.9	96.3	89.9	86.6	73.1	71.9	62.3
	SD	0.0	5.3	7.4	14.5	22.6	21.1	24.6	28.0	27.5
t			–0.24	–0.79	1.57	3.32	2.27	3.12	4.34	3.62
p			ns	ns	ns	.001	.03	.002	.001	.001
Error Type I						*	*	*	*	*
Error Type II									*	*
					Achievement in Steps					
Mobile ($n=64$)	*M*	100.0	91.0	82.8	95.0	92.0	64.5	82.2	85.3	68.7
	SD	0.0	18.2	26.0	11.6	18.6	28.6	26.2	24.5	32.5
Fixed ($n=90$)	*M*	95.4	78.1	67.9	80.4	70.2	48.5	66.8	66.4	46.1
	SD	11.8	28.1	31.6	24.8	30.9	28.8	27.8	31.7	33.1
t		3.69	3.47	3.20	4.90	5.45	3.41	3.51	4.16	4.22
p		.002	.001	.002	.001	.001	.001	.001	.001	.001
Error Type I		*	*	*	*	*	*	*	*	*
Error Type II					*	*	*	*	*	*

*Statistically significant (for Type II errors statistical significance corresponds to $p=.05$ at least and power $=.80$).

Table 4 shows the achievement of the Mobile and Fixed groups in the schemata, and the steps, respectively, with the Mobility–Fixity dimension determined by the combination of scores on Digit Span Backward and Hidden-Figures Test. The same patterns are observed in these cases, but the dif-

TABLE 4

MEANS AND STANDARD DEVIATIONS FOR ACHIEVEMENT BY MOBILE AND FIXED STUDENTS FOR CHEMICAL EQUILIBRIUM PROBLEMS (STUDY *A*): FIXITY–MOBILITY BASED ON COGNITIVE STYLE AND WORKING MEMORY CAPACITY

Problem Code		(2, 4)	(2, 5)	(2, 6)	(3, 4)	(3, 5)	(3, 6)	(4, 4)	(4, 5)	(4, 6)
		Achievement in Schemata								
Mobile ($n=58$)	*M*	100.0	99.2	97.4	99.4	97.1	95.4	90.5	93.1	87.5
	SD	0.0	6.5	11.1	4.4	11.3	13.2	19.8	17.4	23.1
Fixed ($n=96$)	*M*	100.0	99.5	99.0	96.2	91.3	85.7	70.6	70.3	57.9
	SD	0.0	5.1	7.2	14.4	21.2	20.9	24.3	26.9	25.5
t			–0.34	–0.94	2.06	2.21	3.51	5.55	6.37	7.41
p			ns	ns	.04	.03	.001	.001	.001	.001
Error Type I					*	*	*	*	*	*
Error Type II								*	*	*
		Achievement in Steps								
Mobile ($n=58$)	*M*	100.0	94.8	89.5	95.6	93.7	73.0	89.2	91.4	80.6
	SD	0.0	14.2	22.5	10.7	16.8	27.8	22.2	20.9	28.3
Fixed ($n=96$)	*M*	95.7	76.6	64.8	80.9	70.5	44.3	63.6	63.9	40.4
	SD	11.5	27.9	30.7	24.5	30.6	25.4	27.0	30.5	28.9
t		3.67	5.56	5.74	5.11	6.06	6.41	6.36	6.61	8.48
p		.005	.001	.001	.001	.001	.001	.001	.001	.001
Error Type I		*	*	*	*	*	*	*	*	*
Error Type II			*	*	*	*	*	*	*	*

*Statistically significant (for Type II errors statistical significance corresponds to $p=.05$ at least and power $=.80$).

ferences between scores of the Mobile and Fixed groups appear to be a little larger.

Study B: Organic-synthesis Problems

Table 5 shows the achievement scores of the Mobile and Fixed groups, with the Mobility–Fixity dimension determined by the combination of scores for Digit Span Backward and Hidden-Figures Test only. We observe that, when the *M*-demand of the problem is low (2, 3, or 4), there is small difference between the Mobile and the Fixed groups. As the *M*-demand of the problem increases, the Mobile group achieves higher scores.

Statistical Analyses

Statistical analyses were carried out, using the SPSS software, to test for significance differences in achievement between Mobile and Fixed subjects. The analyses concerned minimizing both the probability of Type I error and the probability of Type II error. Whereas Type I errors deal with the problem of finding a difference that is not there, Type II errors concern the equally serious problem of not finding a difference that is there (Cohen, 1988; Howell, 1997). The Student *t* test used, assuming unequal variances, is included in Tables 3–5. The differences between Mobile and Fixed subjects'

TABLE 5

MEANS AND STANDARD DEVIATIONS FOR ACHIEVEMENT BY MOBILE AND FIXED STUDENTS FOR ORGANIC SYNTHESIS PROBLEMS (STUDY *B*): FIXITY–MOBILITY BASED ON COGNITIVE STYLE AND WORKING-MEMORY CAPACITY

Problem *M*-demand		2	3	4	5	6	7	8	*M*
Mobile ($n=102$)	*M*	96.1	90.7	78.9	64.2	48.5	32.4	28.4	54.7
	SD	19.5	27.0	40.1	47.9	50.0	46.5	44.8	24.9
Fixed ($n=179$)	*M*	89.7	80.4	72.3	43.0	19.6	19.3	10.1	40.6
	SD	29.8	39.1	43.7	49.4	39.1	39.4	29.2	23.9
t		1.94	2.34	1.25	3.50	5.39	2.50	4.15	4.66
p		.05	.01	ns	.001	.001	.01	.001	.001
Error Type I		*	*		*	*	*	*	*
Error Type II					*	*	*	*	*

*Statistically significant (for Type II errors statistical significance corresponds to $p=.05$ at least and power = .80).

achievement are marked statistically significant or nonsignificant (ns) for power = .80 and at probability level $p=.05$ at least.

Conclusion

This analysis has provided further evidence to support the hypothesis that the Mobility–Fixity dimension is an important predictor of students' achievement in problem-solving in chemistry. In all cases, it was apparent that Mobile subjects have an advantage over Fixed subjects. To be good at solving chemistry problems, one requires flexibility of functioning and potential for adapting to a wide spectrum of experiences facilitated by the Mobility–Fixity dimension.

An important aspect of this analysis is that it is based on an alternative Mobility–Fixity classification based on working memory capacity, measured by means of the Digit Span Backward test, instead of mental capacity, measured by means of Pascual-Leone's Figural Intersection Test. For the data of Study *A*, the classification based on working-memory capacity led to somewhat larger differences, and this can be explained by the fact that Digit Span Backward had as a rule somewhat larger correlations with achievement in chemistry problem-solving than scores on the Figural Intersection Test (Tsaparlis, *et al.*, 1998, Table 6). It cannot be excluded, however, that in other chemical problems the reverse would be true.

Mobility–Fixity is clearly a cognitive style different from but complementary with field-dependence–independence. This is evidenced also by the significant correlation between the two measures: $r=.44$ between Figural Intersection Test and Hidden-Figures Test for our Study *A* (while $r=.36$ between scores on the Digit Span Backward and Hidden-Figures Test). Working memory and functional *M*-capacity pertain to two different theoretical frameworks, viz., Baddeley's (1986, 1990) and Pascual-Leone's (1970) theories of information processing. Recent literature has reported differences in the extent to which the two theories explain academic performance (Niaz & Logie, 1993; Vaquero, Rojas, & Niaz, 1996). On the other hand, the two constructs must share a common space, as is evidenced also by the high correlation between Digit Span Backward and Figural Intersection Test: $r = .66$ for our Study *A*. This explains the success of working-memory capacity as an alternative measure for defining the Mobility–Fixity cognitive style. We must be aware, however, that the Mobility–Fixity dimension is conceptually connected with mental capacity rather than working-memory capacity.

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