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ANALOGIES IN CHEMISTRY TEACHING AS A MEANS OF ATTAINMENT OF COGNITIVE AND AFFECTIVE OBJECTIVES: A LONGITUDINAL STUDY IN A NATURALISTIC SETTING, USING ANALOGIES WITH A STRONG SOCIAL CONTENT

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ABSTRACT: A longitudinal study of the use of chemical analogies and their effect on cognitive and affective factors of tenth- and eleventh-grade Greek students in a naturalistic setting is reported. Attention was paid to the structural correspondence between the analogue and the target. Regarding the analogue domain, emphasis was placed on using analogies with a strong and familiar social context. An experimental-control group design was adopted. Although it is difficult to separate the direct effect of the analogies from the social relevance and the enjoyment factors, our findings from questions set immediately after the introduction of each analogy, as well as from final examinations, provide evidence for the possible usefulness of the long-term use of analogies in the teaching of chemistry. Gender was found to make no difference. Analogies can be more effective for lower cognitive development students. A positive affective effect to most students was also found. Both developmental level and motivational trait play a definitive role, with the concrete students on the one hand, and the curious students on the other found to be more favourably disposed to this teaching strategy. Finally, recommendations for the proper and effective use of analogies in chemistry teaching are made. [*Chem. Educ. Res. Pract.:* 2004*, 5,* 33-50]

KEY WORDS: *instructional analogies; chemical analogies; analogue domain; target domain; developmental level; motivational trait*

INTRODUCTION

In a review of studies on the effectiveness of instructional analogies in science education (Dagher, 1995a), a synthesis of the findings was provided, and implications for teachers and researchers in science education were presented. Among various suggestions for future investigations were that "longitudinal studies in naturalistic (formal and informal) settings are needed to broaden our notion of the spontaneous and creative uses of analogy and metaphor as they relate to the learning of new concepts, the restructuring of old ones, and the interpretation of knowledge networks across domains over time." Friedel, Gabel and Samuel (1990) also considered it very likely that to be effective, analogies must be used for a long time. The desirability of longitudinal studies in science education, that is of following up the same subjects from the short to the long-term, has been repeatedly advocated, particularly in 'implications' and 'recommendations' sections of research articles. Yet, there is a mismatch between the importance placed on longitudinal studies and the actual number of such studies in science education (Arzi, 1988, p. 17).

Dagher (1995a), further pointed out that "studies reviewed affirm that meaningful learning via instructional analogies is not a function of whether an analogy *is* used, as much as it is a function of *how it is actually* used (in text, presentation, or discussion), *by* whom, *with* whom, and *consequently how it is evaluated.*" The *interaction* of all these factors could provide a clearer understanding of the contribution of analogy to science learning.

Although the work described in this paper was undertaken prior to the publication of the review by Dagher, we hope that it addresses at least some of the above recommendations. This work is longitudinal, in a naturalistic setting, with the junior researcher being the teacher himself, and an enthusiastic user of instructional analogies before undertaking the research work reported here. A consistent method of using the analogies throughout the instruction was used, a method that concentrated on the proper understanding of each analogy by the students, with the aid of the structural correspondence between the analogue and the target domains. We have paid special attention to the analogue domain of the analogies, so that it was familiar and interesting to the student; thus, we have used in chemistry teaching, *analogies with a strong social context.*

In recent years, there has been an increased number of studies on the role of analogies in students' learning of science (including chemistry). A special issue of the *Journal of Research of Science Teaching* (Vol. 30, Issue No. 10, 1993), plus a number of reviews (Duit, 1991; Goswami, 1991; Dagher, 1995a) and additional studies demonstrate the related interest of the science education community.

Glynn, Duit and Thiele (1995) provided an overview of the teaching-with-analogies (TWA) model (Glynn, 1989), which shows how to use an analogy systematically to explain fundamental concepts in a meaningful way. In addition, Glynn, Duit and Britton (1995) have examined the use of analogies by students when solving problems to plan, monitor, evaluate, and improve their problem-solving efforts. Dagher (1994) has reviewed the contribution of analogies to conceptual change and noted a modest contribution of analogies to normal conceptual change. In another paper (Dagher, 1995b), the analogies used by science teachers in naturalistic instructional settings were analysed, and some of their special characteristics highlighted. On a similar line, the use of analogies in science instruction by student teachers has been examined by Jarman (1996). The effectiveness of teaching science with pictorial analogies has been tested, through a conceptual problem-solving test, on the concepts of density, pressure, and atmospheric pressure in Year-8 classrooms (Lin, Shiau, & Lawrenz, 1996); it was found that students taught with pictorial analogies scored significantly higher than the control group, while low achievers benefited more from this teaching than high achievers. Learning from analogy-enhanced science text, where an elaborate analogy having both graphic and text components was used, has been found conducive to better biology learning by sixth and eighth graders (Glynn & Takahashi, 1998).

Concentrating on the use of analogies in chemistry teaching, Thile and Treagust (1994) reported the relevant practice by four teachers. The teachers used analogies spontaneously and on a planned basis, both for the whole classes and individually for students who had conceptual difficulties. The study described why the teachers chose to use analogies, the variation of the characteristics of the analogies from teacher to teacher, and the origin of the analogies. According to the authors, the analogies used had a motivational impact on the students.

HISTORICAL AND THEORETICAL BACKGROUND

Analogies have been used by the followers of the *mechanism doctrine* (17-18 century), such as that used by the French physician and alchemist Nikola Lemery (1675-1715) for acids and bases, in his text *cours de chymie,* published in 1675 (Lemery, 1716, cited in Westfall, 1977). In addition, analogies have often been used as mechanisms for theory change in science (Vosniadou, 1989b; p. 432); examples are Newton's theory on the corpuscular nature of light, Thomson's and Rutherford's models of the atom, the duality (particles and waves) of the nature of particles proposed by de Broglie (Vosniadou, 1989b, p. 433), and the analogy between classical mechanics and geometrical optics for the justification of the Schrödinger equation (Landau & Lifschitz, 1965; Atkins, 1970). Needless to add that the use of analogies by distinguished scientists constitutes both an incitement and an invitation to the teacher of chemistry to use analogies in teaching.

We assume that an analogy is a system of relations (correspondences) that hold between parts of the structure of two domains. The *analogue* domain (called also *source* or *base* domain) is a domain that exists in memory, from which the analogy is drawn; and the *target* domain, which contains the science concept under study, that is the instructional objective of the analogy. The analogue domain then contains the analogical representation of the target (Dagher et al., 1993). An analogy involves the transfer of relational (structural) information from the analogue to the target, a transfer which is accomplished by mapping or matching processes, which consists of finding the correspondences between the two systems (Vosniadou, 1989a; 1989b, p. 414).

The two systems may belong to different domains, but share a similar explanatory structure. In this case, we have the *between-domain* (or metaphorical) analogies. One example is the analogy between the atom and the solar system, which is based on the similarity in the structure of the two systems. It may also be that the two items of the analogical mapping are drawn from the same or very close domains. In the latter case we have the *within-domain* (or literal) analogies, such as the use of examples of solved problems to work out how to solve other (similar) problems (Anderson & Thomson, 1989; Thagard, 1992). The two kinds of analogies represent the two ends of a continuum rather than a dichotomy (Vosniadou, 1989b, p. 415).

The plethora of analogies published in the feature *'Applications and Analogies'* of the *Journal of Chemical Education,* (edited by R. DeLorenzo), together with analogies from other sources (for example, chemistry textbooks) demonstrate that quite often we use situations from everyday life as analogues in chemistry teaching, that is between-domain analogies. We have used such analogies in this work, and will term them *analogies with a strong social context.* They have the feature that the analogue domain is familiar to the student, an important requirement for an effective instructional analogy. The familiarity and the closeness of the analogue domain favours the mapping of the elements of the two domains, and allows students to construct and examine their own knowledge, by attracting them to see and examine it through the process of the analogy (Black & Solomon, 1987). Note that the ineffective use of certain analogies has been attributed to the fact that students were not familiar with the analogue domain (Gabel & Sherwood, 1980).

According to the multiple-constraint theory (Holyak & Thagard, 1989; Thagard et al., 1990; Thagard, 1992) an analogy should satisfy three fundamental constraints to be effective in teaching. One constraint is the *pragmatic relevance* of the analogue to the target, that is analogical thinking that is sensitive to the purpose for which the analogy is being used; we are concerned with analogies whose purpose is to convey an understanding of unfamiliar material of chemistry to students. The second constraint is the *structural correspondence* between the analogue and the target. Finally, there must exist *semantic similarity* between the elements of the analogue domain and those of the target domain. Note that the multiple-constraint theory of Holyak and Thagard differs from the *structure-mapping* theory of Gentner (1983, 1989) in adding the pragmatic and semantic constraints to the structural one. An important factor which should also be carefully checked and controlled is the *information-processing demand* of the analogy, since the student has to hold the analogy and the chemical actuality in working memory at the same time. If the demand exceeds a student's processing capacity, it may lead to mental overload, and this may be a major problem for some students (Johnstone, 1995).

Analogical reasoning can be used in two distinct cases (Vosniadou, 1989b, p. 422). In one case, the underlying structure shared between the analogue and the target domains is present in the subject's representation of both domains at the time when the analogy is used. In the other case, the underlying structure needs to be present only in the subject's representation of the analogue. This latter case is important for the acquisition of new knowledge. Thus, the instructional use of analogy where the analogue is given, and similarity in explanatory structure is discovered by the learner on the basis of similarity in the salient properties of two systems, is an instance where analogical reasoning can lead to the acquisition of new knowledge. This case is therefore of paramount importance to the chemistry teacher, and it has been used in our work.

With the instructional objectives in mind, analogies are further distinguished into clarifying and why-answering ones (Thagard, Cohen & Holyoak, 1989; Thagard, 1992). In our opinion, the former tend to satisfy objectives of the Bloom cognitive categories of *knowledge* and of *understanding,* while the latter extend their effect to the higher categories, *viz., application, analysis, synthesis* and *evaluation.* Taking into account that the effectiveness of an instructional strategy is a function of the fulfillment of its instructional objectives, the above distinction provides a crucial criterion for the selection of the proper analogy in instruction.

Finally, a good knowledge of the analogue domain, as well as a realisation of the limitations of the application of an analogy, are crucial for an analogy to be effective (Vosniadou, 1989b, p. 425; Duit, 1991, p. 664; Thagard, 1992, p. 542). Ignorance or lack of consideration of the limitations entails the risk of misconceptions, which are among the most serious pitfalls of the instructional use of analogies. It is generally acknowledged, however, that it is impossible to find perfect analogies within the context that do not lead to *any* misconceptions (Dagher, et al., 1993).

METHOD

One hundred and forty-eight students, of which 61 were males and 87 females, attending year 1 (tenth grade) of a state upper secondary school in Athens, Greece, participated in the study. The school draws its students from an urban district, with an average family income. The subjects were randomly divided into an experimental group (N = 82, 35 males and 47 females), and a control group (N = 66, 26 males and 40 females). Of these 148 students, 116 (45 males and 71 females) continued in year 2 (eleventh grade), with 68 (31 males and 37 females) in the experimental group and 48 (14 males and 34 females) in the control group. The subjects were drawn from two consecutive cohorts, in the school years 1992-93 and 1993-94. [We define *cohort* as a group of subjects all of whom are at the same chronological stage at the same period, and hence share similar environmental influences (Arzi, 1988, p. 21).] Students were informed that the research aimed at helping them understand chemistry.

Table 1 shows the units taught and the total teaching time. The teacher throughout the study was one of the authors (PS), with about nine years of teaching experience, and a strong personal interest in the use of analogies in the teaching of chemistry.

In the control group, formal instruction was used, with the teacher lecturing in the traditional way, that is, presenting the new knowledge, with the students just listening and

TABLE 1. *Chemistry taught to tenth- and eleventh- grade students of this work.*

Tenth Grade*	Eleventh Grade**
1. Basic concepts. 2. Modern atomic theory. 3. Periodic table of the elements. 4. Chemical bonds - Chemical notation. 5. Solutions. 6. Acids, bases, and salts.	1. Thermochemistry. 2. Chemical kinetics. 3. Chemical equilibrium. 4. Acids, bases, and salts. 5. Oxidation and reduction. 6. Introduction to organic chemistry. 7. Chemical formulae and structure of organic compounds. 8. Hydrocarbons.

* 22-25 periods of teaching (45 minutes each).
** 31-36 periods of teaching (45 minutes each).

paying attention; in the experimental group analogies were used. The method adopted included the three stages of analogical reasoning: (i) retrieving the analogue, (ii) mapping it to the target, and (iii) transferring to the target the relevant components of the analogue. Furthermore, the method showed considerable agreement with the teaching-with-analogies model (Glynn, 1989, p. 198).

The elements of the analogue domain (that is the analogy itself) were first presented to the students. A discussion followed or students answered questions concerning the analogue in writing. The aim was to find out the extent to which they were familiar with the analogue domain, as well as possible misconceptions or misunderstandings with respect to this domain. Subsequently, students were supplied with a list of one-to-one correspondences of the elements of the analogue with those of the target, and were asked immediately to answer a number of chemical questions, aiming at all categories of the cognitive domain of the Bloom taxonomy. The students were encouraged to make use of the correspondences, and informed that their correct or wrong answers would have no effect on their assessment. Each student was supplied with a sheet showing the analogue-target correspondences, and giving the chemical questions that the student had to answer. Table 2 has the structural correspondences for two of the analogies used. The possibility of cheating in these and all other examinations was reduced to a minimum, by having each student on a separate desk, and by the occasional presence of a second invigilator. The whole procedure took 15-25 minutes. After the sheets had been collected, a new discussion was held, this time with the aim of finding possible misconceptions and misunderstandings with respect to the target. In addition, students were invited to state their views orally, while the teacher made reference to the limitations of the analogy.

A total of twenty-eight analogies was used, sixteen with tenth-grade students, and twelve with eleventh-grade students. The analogies were mainly between-domain, but some why-answering and some clarifying analogies were also given. Ten analogies had been suggested and used by one of the authors (PS). The rest of the analogies were taken from various school books, as well as from the *Applications and Analogies* feature of the *Journal of Chemical Education.* All analogies were designed or modified so that the target was in agreement with the school curriculum, as well as to best meet the criteria of an effective analogy (see the theoretical background).

TABLE 2. *Examples of structural correspondences between analogue and target domains.*

Analogy # 16 *Concentration calculations (the calculation of the income of a married couple): Lubeck, 1983*			Analogy # 23 *Dancing couples (and yield of reaction): Last, 1983*		
Mr. Jones - Mrs. Jones	⇔	Solutions (of the same solute)	Males	⇔	Moles of hydrogen chloride (HCl)
Pay per hour	⇔	Molarity of solutions	Females	⇔	Moles of ammonia (NH_3)
Working hours	⇔	Volume (in litres) of solutions	Dance	⇔	Chemical reaction
Income	⇔	Moles of solute	Dancing couples	⇔	Moles of ammonium chloride (NH_4Cl)
			'Yield' of dance	⇔	Yield (extent) of reaction

Chemical questions set to both experimental and control groups immediately after each analogy was presented in class

For the comparison between the experimental and control groups, we used five chemical questions that were set to both groups after the relevant topic had been introduced (in the case of the experimental group, after the corresponding analogy had been studied). It was hypothesised that the answer to each question could be facilitated (for the experimental group) by a corresponding analogy, while the control group had to invoke only their directly relevant chemical knowledge. The Appendix gives the five chemical questions under consideration. Four of these questions were numerical problems, and one was a conceptual question. The first three questions were set in tenth grade, and the remaining two in eleventh grade. We assumed that all five questions were moderately demanding, hence the comparison of the performances of the experimental and the control groups could inform us about the cognitive effect of the analogies.

The end-of-year final examinations

If the longitudinal use of analogies has a measurable effect, it must surely show up in the end-of-year examinations. Three mean marks from the end-of-year examinations will be considered: Examination 1 will represent the mean mark in all subjects except chemistry; examination 2 will represent the mean mark in mathematics and physics, taken together; and examination 3 is the chemistry examination. The end-of-year examinations took two hours for each subject, with the chemistry examination containing three items that were mainly knowledge questions, plus two numerical problems (exercises). Students had to answer two knowledge questions and one problem. The marking in all subjects except chemistry was made by one teacher; chemistry papers were marked by two teachers as previously. Pearson's r value was 0.80 for the tenth-grade chemistry examination, and 0.77 for the eleventh grade ($p < 0.01$).

In making the comparisons of the end-of-year examinations, we must take into account that apart from the analogies, a number of 'chemical games' as well as some pieces of historical information on some chemical concepts were used with the experimental group.

Of necessity, their effect on the student achievement was integrated with that of the analogies. However, the following facts must also be considered: (i) Analogies were incorporated in most games; (ii) the number of games, as well as of pieces of historical information was much smaller than the number of analogies; and (iii) analogies alone made a considerably higher single contribution (28.3%) to the attainment of cognitive aims than games alone (5.8%) or historical information alone (11.1%), as was found from students' responses to a relevant questionnaire.

Psychometric factors: developmental level and motivational style

Finally, the effect of two psychometric factors was examined in this work; developmental level in the Piaget sense, and student motivational style according to the four Adar categories (Adar, 1969; Hofstein & Kempa, 1985; Kempa & Diaz, 1990a).

Developmental level was judged by means of the Lawson paper-and-pencil test of formal reasoning (Lawson, 1978). The test consists of 15 items that examine the following cognitive abilities: weight conservation, volume conservation, numerical analogies, control of variables, combinations, and probabilities. Students had to justify their answers. One to five points were allocated, but only to correct answers, as follows: 5 points were allocated to completely justified answers; 4 points to justified answers, but with errors in calculations; 3 points to answers with insufficient justification; 2 points to answers with unclear justification; and 1 point to unjustified answers. Subjects with 0-25 points were classified as concrete; with 21-50 points as transitional (2B/3A), and with 51-75 points as formal. The marking of the answers to the Lawson test was made by two teachers, and Pearson's r values were 0.69 ($p < 0.01$) for the tenth-grade sample, and 0.62 ($p < 0.01$) for the eleventh-grade sample. In tenth grade, 24.3% of the students were classified as late concrete (2B), 56.1% as transitional (2B/3A), and 19.6% as early formal (3A). In eleventh grade, 22.4% were 2B, 51.7% were 2B/3A, and 25.9% were 3A. Note that all concrete students of our sample were late concrete (2B), while almost all formal subjects were early formal (3A); the only two late formal students (3B) were grouped with 3A. The above figures are within or close to the ranges reported by Shayer (1991).

Tenth-grade students' motivational styles were judged by means of a simplified version of Adar's test material questionnaire (Johnstone & Al-Naeme, 1995) that included 16 statements, four for each category of motivational style. The 16 items were partitioned equally into four subject areas: (a) work in classroom; (b) work that requires information gathering from sources outside the school-books, as well as group-work in the laboratory; (c) discovery learning; and (d) social life. Students had to mark on the relevant sheet, the dominant view that was more relevant to them. The classification of each subject into one of the Adar categories was made according to the dominant view that was relevant to him or her, which resulted from summing his/her preferences for all four subject areas (Johnstone & Al-Naeme, 1995). In the few cases with no trait prevailing, students were asked to mark a secondary view. According to Kempa & Diaz (1990a), the classification of students in terms of the four motivational patterns does not imply that the patterns should be fully independent of each other; actually, a certain degree of overlap between the traits was found, and in particular a very strong link between 'curiosity' and 'consciousness'. Consequently, the motivation to learn of many students stems from more than one source. The reliability of the answers was judged by having the subjects fill the same questionnaire twice, one at the start of the school year, the other after six months (test-retest method). Ninety-one point two percent of the students were classified in the same category in both cases. Those who differed in the two cases, were deleted from the analysis. From the 148 tenth-grade students, 135 were sorted into distinct categories, of which 31.8% were classified as conscientious, 45.9% as curious, 19.3% as sociable, and only 3.0% (4 students) as achievers. The distribution of these students into the experimental ($N = 73$) and the control group ($N = 62$) was as follows: conscientious, 24 (32.9%) versus 19 (30.6%); curious, 33 (45.2%) versus 29 (46.8%); sociable, 14 (19.2%) versus 12 (19.4%); and achievers, 2 (2.7%) versus 2 (3.2%).

All open answers were classified as either correct or wrong by two secondary teacher-chemists, according to: (i) their clarity, (ii) sufficient justification (Zoller, 1995), and (iii) correct calculations wherever they were required. For 89.9% of the correct open answers of the tenth-grade experimental group and for 85.2% of the correct open answers of the eleventh grade experimental group, there was agreement between the two markers. All answers for which there was disagreement between the two markers as to whether they were correct or wrong were discarded from the analysis.

RESULTS AND DISCUSSION

Comparison of experimental and control group in chemical questions set immediately after each analogy was presented in class

Table 3 has the data for this comparison. As a rule, formal students scored higher than transitional, and transitional students scored higher than concrete students. This is an expected result, since chemistry is a demanding subject with abstract concepts (Herron, 1975; Shayer & Adey, 1981). Now, in all five comparisons, there was an apparent outperformance of the experimental concrete students over the control concrete students. In addition, by comparing the answers of concrete students to the questions on the analogue and on the target domains, we have found a phrasal similarity, showing that concrete students of the experimental group did make use of the analogies. The effective use of analogies by the concrete students can be deduced also from their positive opinion with respect to the help offered by the analogies (see below).

From Table 3, it is also obvious that there was a statistically significant difference in favour of the whole experimental group in four out of the five questions, with a similar trend for the fifth question. Some trend in favour of the experimental group was observed with the transitional students, while in the case of formal students there was neither a statistical significant difference nor a general trend.

Although the results with formal students are not surprising, and demonstrate that these students were capable of functioning without the analogies, in accordance with the findings of Gabel and Sherwood (1980), the very positive effect of the analogies in the case of concrete students is impressive and very encouraging.

Achievement in the end-of-year final examinations

(i) Comparison between the whole experimental and the whole control groups

Table 4 has the mean percentage achievement in the end-of-year examinations of the whole experimental and control groups for both the tenth- and eleventh-grade samples. Although the differences on examinations 1 and 2 (final examinations in all subjects except chemistry, and in mathematics plus physics, respectively) were not statistically significant, for comparing the chemistry examinations we have carried out an analysis of covariance with examinations 1 and 2 as covariates. The differences in the chemistry examination was statistically significant for the tenth but not for the eleventh grade.

TABLE 3. *Comparison of mean percentage achievement*[1] *of experimental and control groups, in total and according to developmental level, in a number of chemical questions set immediately after each analogy was presented in class.*[2]

analogy #	Concrete		Transitional		Formal		Total	
	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control
15	57.1 (14)	22.2 (18)	73.7 (38)	73.0 (37)	100.0 (12)	100.0 (6)	75.0 (64)	60.6 (61)
t	2.10*		0.07 (N.S.)		0.00 (N.S.)		1.73^{+}	
16	53.3 (15)	20.0 (20)	65.8 (38)	56.8 (37)	100.0 (29)	100.0 (6)	72.6 (73)	49.2 (63)
t	2.13*		0.79 (N.S.)		0.00 (N.S.)		2.86***	
19	84.6 (13)	53.8 (13)	70.6 (34)	56.0 (25)	95.0 (20)	77.8 (9)	80.6 (67)	59,6 (47)
t	1.73^{+}		1.15 (N.S.)		1.41(N.S.)		2.50**	
23	69.2 (13)	23.1 (13)	78.1 (32)	76.0 (25)	85.0 (20)	80.0 (10)	78.5 (65)	62.5 (48)
t	2.55**		0.18 (N.S.)		0.34 (N.S.)		1.88^{+}	
24	46.2 (13)	15.4 (13)	78.1 (32)	68.0 (25)	80.0 (20)	90.0 (10)	72.3 (65)	58.3 (48)
t	1.73^{+}		0.85 (N.S.)		-0.67 (N.S.)		1.56 (N.S.)	

[1] For each entry, percentage performance appears first, followed by the number of students in parentheses, and the value of the *t* statistic. Note that the questions concerned are of success or fail type, so variances can be calculated by means of the formula $[N/(N-1)]s(100-s)$, where s is the success percentage rate.

[2] The titles of the analogies, together with relevant references and the corresponding questions are given in the Appendix.

* $p<0.05$; ** $p<0.02$; ***$p<0.01$ (two-tailed *t* test); $^{+}p<0.10$ (two-tailed test), $p<0.05$ (one-tailed test).

N.S. : Not (statistically) significant.

To see whether the above trends and findings characterize separately each of the two years of data collection, we examined the mean achievement in the three examinations for the two separate tenth-grade years. The same pattern was revealed.

(ii) The effect of developmental level

Table 5 gives details of the student achievement in the end-of-year examinations 1 to 3 of the three Piagetian groups - late concrete (2B), transitional (2B/3A), and early formal (3A) - of the tenth grade. We concentrate on the tenth grade because it provides a clearer case. In almost all examinations in both the experimental and the control group, formal students had higher achievement than transitional students; similarly, transitional students outperformed concrete students. This finding was expected of course. On the other hand, the

TABLE 4. *Mean percentage achievement*[1] *of the experimental and control groups of the tenth and eleventh grades, in the end-of-year examinations and statistical comparison through analysis of covariance.*[2]

	Tenth grade (N=148)		Eleventh grade (N=116)	
	Experim. group (N=82)	Control group (N=66)	Experim. group (N=68)	Control group (N=48)
Exam. 1*	69.3	65.8	66.2	63.1
	(14.1)	(14.1)	(15.2)	(14.5)
F	2.23 (p=0.14)		1.19 (p=0.28)	
Exam. 2**	54.8	49.8	47.9	42.5
	(23.1)	(18.5)	(22.6)	(18.9)
F	2.11 (p=0.15)		1.83 (p=0.18)	
Exam. 3***	60.5	50.4	51.9	49.7
	(18.4)	(18.0)	(23.3)	(20.4)
	11.6$^{\&}$ (p=0.00)$^{\&}$		0.45 (p=0.51)	

[1] Standard deviations in parentheses.

[2] Note that the content of each examination was different for the tenth and eleventh grades.

* Mean achievement in all subjects except chemistry. No covariates, analysis of variance.

** Mean achievement in mathematics and physics. No covariates, analysis of variance.

*** Mean achievement in chemistry. With examinations 1 and 2 as covariates.

[&] Statistically significant difference.

TABLE 5. *Comparison of tenth-grade student mean percentage achievement in the end-of-year examinations, according to developmental level of the experimental and the control groups, through analysis of covariance.*[1]

	late concrete, 2B (N=36)		transitional 2B/3A (N=83)		early formal, 3A (N=29)	
	exp. (N=16)	control (N=20)	exp. (N=44)	control (N=39)	exp. (N=22)	control (N=7)
Exam. 1	57.6	56.0	68.5	68.4	79.2	79.1
	(7.8)	(7.9)	(13.1)	(13.9)	(12.7)	(12.5)
F	0.33 (p=0.58)		0.00 (p=0.96)		0.00 (p=0.99)	
Exam. 2	39.9	41.0	52.2	50.4	70.9	71.6
	(16.9)	(12.1)	(20.1)	(17.8)	(23.8)	(21.0)
F	0.04 (p=0.84)		0.20 (p=0.66)		0.00 (p=0.95)	
Exam. 3	50.6	44.0	58.5	51.0	71.6	65.0
	(18.0)	(13.1)	(17.7)	(18.0)	(15.1)	(22.4)
F	2.30 (p=0.14)		6.59$^{\&}$ (p=0.01)		2.51 (p=0.13)	

[1] See footnotes of Table 4.

[&] Statistically significant difference.

lack of difference of the performance in examinations 1 and 2 demonstrates the equivalence of the experimental and the control groups. In all cases, students of the experimental group had superior achievement in the chemistry examination, although only in the case of transitional students the difference was statistically significant.

In the case of the eleventh-grade sample (data are not shown), the data were somehow obscure. To explain this, one could think of both negative (discouraging) and justifying reasons. On the negative side, students in eleventh grade might have become indifferent or even been worn out by the long use of analogies, so that the analogies became ineffective. On the other hand, a possible justification might be the fact that in eleventh grade, students as a rule, made a choice with respect to their future post-school careers. This preference was rather weak in tenth grade, but took a definite shape in eleventh grade. Thus, in the case of the concrete students of the eleventh grade, from the 13 concrete students of the control group, 6 students (46.2%) followed in the twelfth grade science-related study cycles, compared to only 2 out of 13 students (15.4%) of the experimental group.

Affective factors

It seems that apart from the positive effect that was traced above in connection with the cognitive objectives of teaching, analogies appealed to students from the affective perspective, especially towards satisfaction of the objectives of attendance and response. This conclusion derives firstly from the in-class observations of the teacher, where an active student participation in all stages of the educational process was realized; and secondly from the students' answers to the relevant item of the opinion questionnaire which was distributed in the end of the school year, with the students expressing on a five-point Lickert-type scale their positive or negative views about the used methodology.[&] In fact, for about half the students (52.2%) the reasons for their preference for the use of analogies were nearly evenly distributed into cognitive only (28.3%) and affective only (23.9%), while the other half (47.8%) invoked mixed reasons (cognitive and affective).

Table 6 gives the percentage of positive opinions with respect to the help offered by analogies in the whole of the experimental group, as well as according to developmental level and motivational trait. It appears that concrete students were more positively disposed towards analogies.

Turning now to the motivational styles, we note from Table 6 that curious students were more positive towards analogies than conscientious and sociable students. This is an expected finding, demonstrating the importance for the curious student of the constructivist learning environment, such as that offered in this work through the use of analogies. Note that as has been reported (Kempa & Diaz, 1990b), curious students prefer to engage actively in their educational process through various activities (for example, discovery learning), while they do not like to be passive receivers or listeners (as in formal teaching).

[&] Among cognitive reasons were assumed answers like "(the methodology/the analogies) helped me understand the difficult chemistry concepts, or helped in chemistry problem solving". Among affective reasons were assumed answers like "(the methodology/the analogies) made the lesson interesting, or made the lesson amusing, or provided a break to the monotonous flow of chemical concepts."

TABLE 6. *Percentage of positive opinions with respect to the help offered by analogies in the whole of the experimental group, as well as according to developmental level and personality trait.*

Whole sample (N = 73)	Late concrete, 2B (N = 15)	Transitional, 2B/3A (N = 36)	Early formal, 3A (N = 22)
63.0	86.7	52.8	63.6
Achievers	**Conscientious (N = 24)**	**Curious (N = 33)**	**Social (N = 14)**
*	58.3	75.8	50.0

* Because of their small number (only two), achievers were not taken into account.

Attitude of students

Here are representative positive and negative comments from students on the teaching methodology.

Positive comments

- "Despite the fact that I had never had difficulty in understanding anything from any teacher, I am convinced that through this methodology many students are getting help. In addition, I was provided with the chance to understand and remember everything, by invoking the analogies." (male student, formal, sociable)
- "The methodology helped me a lot. It was quite unusual for me, and I feel sorry that such a methodology had not been used in my earlier chemistry courses." (male student, formal, curious).
- "The methodology has succeeded in turning a difficult and boring subject into an entertaining and understandable one. Carry on, we have a lot to benefit." (female student, formal, curious)
- "The lessons were delivered in a very unusual and constructive way, and have helped me to understand chemistry, more than in any previous year." (female student, transitional, sociable)
- "The teaching methodology has made me love chemistry. My performance was higher than previous years." (female student, transitional, curious)
- "During all years I was taught chemistry, I had never understood anything. That was the reason I was not interested in chemistry. This year, however, thanks to the methodology and the way the lessons were manipulated, I feel that I have learnt, if not many, at least some elements of chemistry." (female student, transitional, conscientious).
- "I think that the methodology was very good and unusual, and helped students understand chemistry. Even for those who did not like chemistry, I think that the methodology had changed them, because the lessons were interesting and never boring." (female student, transitional, conscientious).
- "Despite the fact that chemistry is not among the subjects that will be useful in my post-school studies, this method has helped me to keep in my mind certain things that otherwise it is likely that I would not remember." (female student, concrete, curious)
- "I always had a problem with chemistry because I could not recall formulas, valences,

symbols, etc. Nevertheless, with the analogies I managed to overcome this problem, and as result I don't run the risk of failing this subject." (male student, concrete, sociable)
- "The teaching methodology has made me think seriously about choosing chemistry instead of mathematics." (female student, concrete, curious)

Negative comments

- "I did not like the way lessons were made. I believe that the lectures should be carried out only with purely chemical terms, not with analogies, because only chemical questions are given in the examinations." (female student, concrete, conscientious).
- "I should have preferred the lessons to be the standard ones, for the methodology confused me at some times." (male student, transitional, curious)
- "I think that the lecture should follow the way it is written in the book, for it is the book that I have to study at home." (female student, transitional, curious)
- "The analogies made us lose time from the standard lessons." (male student, transitional, sociable)

CONCLUSIONS AND IMPLICATIONS FOR INSTRUCTION

This paper has summarised a longitudinal study involving the use of socially-related analogies in the teaching of school chemistry, and its relationship to performance and student attitude. It was demonstrated that gains were observed. However, at the outset, we should issue a cautionary warning. A problem which characterises all this kind of work is being able to control variables tightly, and then being able to attribute outcomes to specific inputs; that is, it is difficult to isolate clearly the effect of the analogies from the social and the student enjoyment factors. A counter-argument to this is that the social and enjoyment factors constitute an integral part of using analogies such as those employed in this study.

Social relevance is a very important factor, suggesting that there must be educational gains from this on its own, without any specific use of analogies. It is possible then that this is at least part of the effect we are observing. On the other hand, the analogies were often fun for the students, turning the lessons into "interesting and never boring" sessions. Enjoyment is a very important factor in effective learning, and this may be a major contributor too. It is possible then that the observed gains are not simply and directly attributable to the use of analogies. Some of the quoted student comments would certainly favor the analogies, while some would support the increased enjoyment argument, and some would support the social relevance aspect.

Relevant to the above discussion is the *Award Address* by *Zafra M. Lerman*, published in the November 2003 issue of the *Journal of Chemical Education* (Lerman, 2003). The author describes how she communicates chemistry effectively, and gives arguments and evidence that support the efficiency of her method. According to Lerman, the arts (music, dance, drama, and fine arts) are excellent vehicles for enhancing understanding:

> "For example, most people are not interested in the concept of the ionic bond, but when presented as a love story between Sodium and Chlorine like Shakespeare's Romeo and Juliet, people enjoy learning about the bonding relationship… The same is true for students who … "danced 'The Three States of Matter'." (p. 1234)

There is no doubt that Lerman uses a multitude of instructional tools, and that the social and enjoyment factors play a dominant role. Equally, there is no doubt that analogies play a central role in her methodology.

The most important finding of this work was that analogies can be more effective for lower cognitive development students. Concrete students who were taught the analogies scored much higher than control-group concrete students on demanding questions (four problems and a conceptual question - see the Appendix). The opinion of Sutala and Krajcik (1988) is thus confirmed that students of low cognitive ability benefit from the analogies and have good results when they enjoy the help of the teacher in making the analogical connection. On the other hand, we have provided evidence that formal students (in the Piaget sense) can be successful without the need of analogies, in agreement with Gabel and Sherwood (1980). However, the usefulness of the analogies to both transitional and formal students cannot be ruled out, as can be judged from both the wording of their answers and their positive views towards analogies.

The above finding seems to come into conflict with the view of Enyeart (cited in Duit, 1991) that there is no connection between the use of analogies and developmental level. We must take into account, however, that Enyeart refers to the personal analogies used by students, not to the instructional use of analogies. On the other hand, the fact that concrete students can benefit from analogies seems to come into conflict with Piagetian theory, according to which these students are not capable of using analogical reasoning. However, Piaget is referring to spontaneous and personal analogies. We had instructional use of analogies, whereby we enforced students to see and examine new knowledge through the correspondences; at the same time, we provided allusions as to how to think, and showed the path to the answer, so important to the concrete student. Note that the one-to-one correspondence is an ability that has been established with concrete operations. In addition, the importance of allusions that contribute to the effective instructional use of analogies has been pointed by a number of workers (Reed, Ernst & Banerji, 1974; Hays & Tierney 1982; Tenney & Gentner, 1985; Glyn et al., 1989, p. 392). Thus, while the spontaneous use of analogies is common in everyday life and in problem solving, the fruitful use of analogies by teachers and learning media requires considerable guidance (Duit, 1991).

From the affective perspective, we have demonstrated that analogies have a positive effect for most students. Developmental level, as well as motivational trait, both play a definitive role here, with the concrete students on the one hand, and the curious students on the other being more favourably disposed towards the use of analogies in teaching.

Considering the implications for instruction, analogies should be used only when they contribute significantly to acquiring new concepts and processes. Thus the use of analogies is linked with the difficulty of the target domain for the learner. Analogies should be, and are used as an aid to understanding when the target is difficult to understand (Royer & Cable, 1976). Similarly, in the case of problem solving, the target problem must be sufficiently novel and challenging (Gick & Holyoak, 1983).

Needless to add that time constraints make it difficult to advocate a massive use of chemical analogies, as was done in this work. A careful selection of analogies has then to be made. We must check each analogy for both its effectiveness and its limitations. The analogies should meet all requirements for an effective analogy. Most importantly, the analogue domain has to be familiar to the students. It is this fundamental requirement that is met by analogies with a social content. It is further desirable to use analogies in a constructivist manner (Black & Solomon, 1987), through the provision to the students, for instance, of the structural correspondences between the analogue and the target, a method used here. The information-processing demand of the analogies should also be carefully controlled. Last but not least, we must warn students about the possible misconceptions associated with each analogy. Although multiple analogies may help avoid the misconceptions caused by a single analogy, and so function as “antidotes for analogy-induced misconceptions” (Spiro et al., 1989), we must take into account that multiple analogies demand multiple teaching (and learning) time.

NOTE: Preliminary results of this work have been previously presented in two European conferences (Tsaparlis & Sarantopoulos, 1993, 1995).

NOTE ADDED IN PROOF: A paper published in the current issue of this journal (Orgill & Bodner, 2004) deals with the use of analogies in chemistry teaching and reviews the relevant literature. In addition, the authors interviewed biochemistry students about the analogies that were used in their classes, and found that most students liked, paid particular attention to, and remembered the analogies their instructors provided. The paper includes students’ suggestions for improving the use of analogies in class.

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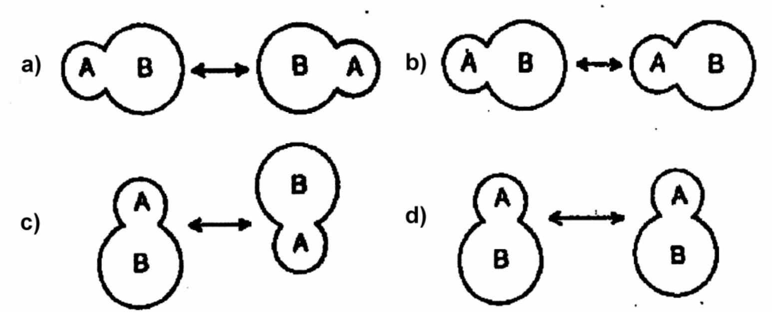
APPENDIX: Chemical questions used for comparison of the experimental and the control groups

The following five questions were set, to both the experimental and the control groups, immediately after the corresponding analogy was presented in the experimental class. Performances on these questions are reported in Table 2.

Question after analogy # 15 (Determining the density at a rally of a political party)
In 250 mL of solution ‘A’ 60 g of NaCl are contained, while in 150 mL of solution ‘B’ 42 g of NaCl are contained. Which solution is more concentrated?

Question after analogy # 16 [Concentration calculations (the calculation of the monthly income of a married couple): Lubeck, 1983]
11.2 L of a 0.5 M glucose solution were mixed with 0.8 L of a 0.45 M glucose solution. Calculate the total number of moles of glucose that were present in the final solution.

Question after analogy # 19 (A bloody nose: Last, 1983)
Consider the reaction $2AB \rightleftharpoons A_2 + B_2$. Which of the following collisions can lead to the formation of products?



Question after analogy # 23 (Dancing couples: Last, 1983)
11 mol HCl plus 9 mol NH_3 were brought inside a closed reaction vessel. After chemical equilibrium was established, 3 mol NH_3 were found to be present in the vessel. What was the yield of the chemical reaction?

Question after analogy # 24 (A hypothetical coffee vending machine: McMinn, 1984)
In a reaction vessel, 2.5 moles of carbon plus 7 moles of hydrogen were placed. After the chemical equilibrium $C + 2H_2 \rightleftharpoons CH_4$ was established, it was found that 1.5 moles of methane were produced. What was the reaction yield? How many moles of carbon or/and hydrogen remained in the vessel?