CHEMISTRY EDUCATION:
RESEARCH AND PRACTICE
2003, Vol. 4, No. 3, pp. 319-333

RESEARCH REPORT (EMPIRICAL STUDY)
Problem solving and other
higher-order cognitive skills (HOCS)/
Experiments and practical work

Constantinos KAMPOURAKIS and Georgios TSAPARLIS
University of Ioannina, Department of Chemistry

A STUDY OF THE EFFECT OF A PRACTICAL ACTIVITY ON PROBLEM SOLVING IN CHEMISTRY

Received 6 December 2002; revised 9 May 2003; in final form/accepted 11 June 2003

ABSTRACT: A practical activity on the well-known ammonia fountain experiment was used in order to find out if it can contribute to the solution of a demanding chemistry problem on the gas laws. Three different cohorts of Greek students from tenth and eleventh grade (16-17 year olds) were studied. It was found that students of experimental groups achieved higher scores than control groups, and the differences were in many cases statistically significant. The differences were not, however, very large. As the school process moved on, from tenth to late eleventh grade, a general improvement was observed. On the other hand, only a small proportion of the students found the practical activity relevant/useful to the solution of the problem, and these students had a much higher achievement than the rest of the students. Furthermore, students experienced difficulties in providing in writing a proper interpretation of the experiment. Finally, the common misconceptions and false interpretations are reported. The conclusion is that laboratory/practical activities and theory may constitute two non- or not strongly-overlapping 'spaces', at least when we use experiments such as the chosen one, which is both conceptually and practically very complicated. [*Chem. Educ. Res. Pract.*: 2003, *4*, 319-333]

KEYWORDS: *problem solving; laboratory/practical activities; theory vs. practical work; ammonia; ammonia fountain experiment; ideal-gas equation; concentration of solutions*

INTRODUCTION

It is well known that problem solving is a composite activity that involves various cognitive functions. It depends on the one hand on the number and quality of available operative schemata in long-term memory (see below); on the other hand, on working memory capacity (Roth, 1988; Johnstone, Hogg, & Ziane, 1993; Tsaparlis, 1998; Niaz, de Nunez, & de Piheda, 2000; Tsaparlis & Angelopoulos, 2000; Stamovlasis & Tsaparlis, 2001, 2003).

At the outset, a distinction must be made between problems and exercises, with the latter requiring for their solution only the application of well-known and practised procedures (*algorithms*). The skills that are necessary for the solution of exercises are as a rule *lower-order cognitive skills* (LOCS). On the other hand, a real/novel problem requires that the solver must be able to use what has been described as higher-order cognitive skills (HOCS) (Zoller, 1993; Zoller & Tsaparlis, 1997). However, the degree to which a problem is a novel problem or an exercise depends on the student background and the teaching (Niaz, 1995). Thus, a problem that requires HOCS for some students may require LOCS for others in a different context. A more thorough classification of problem types has been made by Johnstone (1993, 2001).

A number of researchers (Simon & Simon, 1978; Larkin & Reif, 1979; Larkin, 1980; Reif, 1981) have studied the differences between expert and novice problem solvers. The basic differences were: (a) the comprehensive and complete schemata of the experts, in contrast to the sketchy one of the novices; and (b) the extra step of the qualitative analysis taken by the experts, before they move into detailed and quantitative means of solution. Relevant to this work is the lack of experience on the part of secondary students of realistic chemical and physicochemical systems, such as those involved in chemistry problems.

An important property of a problem is its *logical structure*. According to Niaz and Robinson (1992) (see also Tsaparlis, Kousathana, & Niaz, 1998), the logical structure of a problem represents the degree to which it requires formal operational reasoning. The logical structure of a problem 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 this work, a laboratory/practical activity, involving the well-known ammonia-fountain experiment, is used in order to find out if it can contribute to the solution of a demanding chemistry problem on the gas laws. Furthermore, we explore the extent to which the practical activity (which was performed by the students working in small groups), together with the follow-up discussion/interpretation in the classroom, could contribute to the improvement of the problem-solving ability of the students. In addition, we compare the performance of various subgroup of students to find out which of them were affected most by the practical activity. Finally, the main conceptual obstacles in the solution process are discussed.

Practical activities in teaching

We know that there is the widely held idea that laboratory/practical activities are necessary, contributing to the understanding and learning of the concepts of science. In addition, the literature of science education provides empirical evidence that favours practical activities. Johnstone and Shuaili (2001) have recently carried out a review of educational research on the use of laboratory activities in chemistry teaching. These activities have both cognitive and affective aims and objectives. Buckley and Kempa (1971, cited in Johnstone & Al-Shuaili, 2001) stated that laboratory work should aim to encourage students to gain, among others, observational skills, as well as the ability to interpret experimental data. On the side of affective aims, one should distinguish (Johnstone & Al-Shuaili, 2001) between attitudes to science and scientific attitudes (Gardner & Gauld, 1990, cited in Johnstone & Al-Shuaili, 2001). Attitudes to science include interest, enjoyment, satisfaction, confidence, and motivation. Scientific attitudes apply to styles of thinking such as objectivity, critical-mindedness, scepticism, and willingness to consider the evidence (Garnett & Hackling, 1995, cited in Johnstone & Al-Shuaili, 2001).

It is well known that there are various laboratory instruction types (Domin, 1999): expository, inquiry, discovery, and more recently, problem-based. An analysis of these types has been made by Domin (1999). Expository instruction is criticised for placing little emphasis on thinking. On the other hand, content knowledge is crucial for the proper interpretation of observations (Johnstone & Al-Shuaili, 2001).

Turning to the relation of laboratory activities to problem solving, we note first that among the aims for practical work listed by Kerr (1963, cited in Johnstone & Al-Shuaili, 2001) is that of giving training in problem solving. Roth (1994) reported very positive conclusions with regard to physics problem solving at upper secondary level by means of practical work. Using demonstrations (and laboratory experiences in general) as an assessment tool, Bowen and Phelps (1997) reported that demonstrations not only orient students' attention toward learning from them because they know that they will be assessed, but also they improve the problem-solving capabilities of the students because they help them switch between various forms of representing problems dealing with chemical phenomena (for instance, symbolic and macroscopic). Along the same line, Deese et al. (2000) found that demonstration assessments promote critical thinking and deeper conceptual understanding of important chemical principles. Finally, Welzel (1999) maintains that problems are interesting to students when they can connect them to their experiences from everyday life.

METHOD

The sample

Three cohorts of students were the subjects of our study. The three cohorts correspond to three different points of the educational process of these students' dealing with chemical problems involving the ideal-gas state equation. A common feature of the majority of the students of our sample was that they lacked concrete experiences that would result from contact and experience with chemicals and equipment. They even lacked experience of chemistry and physics demonstrations. There was a small sample of students, however, who had practical experience.

- Cohort A consisted of 180 tenth-grade students at the end of school year 1998-99, from three different public schools, one from an urban area, and two from semi-urban areas.
- Cohort B consisted of two groups of students:
    - Group B1 consisted of 188 eleventh-grade students at the end of term 1 (winter term), of school year 1998-99, from seven public schools, two from an urban area, and six from semi-urban areas.
    - Group B2 consisted of 46 eleventh-grade students at the end of term 1, of school year 1998-99, from one prestigious private urban school. A common feature of these students was that they, in contrast to all other students of our study, had practical experience, performing since ninth grade in pairs experiments in a well-equipped school lab. The practical activities were carried out on the basis of distributed notes, written by the class teacher, while the students kept a notebook in which they reported their experiments.
- Cohort C consisted of 105 eleventh-grade students at the end of school year 1999-00 from three public schools, two from urban areas, and one from a semi-urban area.

An experimental-control group design was adopted for the study. For Cohort A, the same students acted as control and experimental group: The students first made an attempt at solving the problem. After that attempt, the practical activity took place, and then the same students made a second attempt at the same problem. Though such a research design has the advantage of monitoring the progress of the same students, hence the effect of the intervention, it has the drawback that the additional time that students had in their second attempt to solve the problem may have contributed itself to an improvement in performance.

With Cohorts B and C we had different students as experimental and control groups. The allocation of students to the two groups was made after consultation with their teachers. Equivalence between experimental and control groups was checked through their achievement in the final, end-of-year exam of the chemistry course: For B1, $t = 1.22$; for B2

TABLE 1. *The distribution of three cohorts of students into experimental and control groups.*

Cohort	Description	Practical experience	Experimental group	Control group
A	Tenth-grade students at the end of school year 1998-99	No	90*	90*
B1	Eleventh-grade students at the end of term 1, of school year 1998-99.	No	96	92
B2	Eleventh-grade students at the end of term 1, of school year 1998-99	Yes	23	23
C	Eleventh-grade students at the end of school year 1999-00	No	54	51
Total			263	256

* The same students acted here as both experimental and control group.

$t = 0.70$. For Cohort C, equivalence was judged on the basis of achievement in chemistry ($t = 0.43$), physics ($t = 0.29$), as well as of the sum of all tested courses ($t = 0.97$). All differences are statistically non significant. Table 1 shows the distribution of the three cohorts of students into experimental and control groups.

Students of Cohort A had been taught, just one week before the treatment, basic stoichiometry concepts, the ideal-gas equation, and concentration of solutions. Those of Cohort B had in addition been taught colligative properties of non-electrolyte solutions, including solution of demanding problems, involving the ideal-gas equation, and various ways of expressing concentration of solutions. Finally, students of Cohort C had further covered organic chemistry, thermochemistry, chemical kinetics and chemical equilibrium.

The problem

A vessel contained gaseous ammonia (NH_3) at a pressure $p_1 = 2$ atm, and a temperature of 27^oC. Part of the ammonia gas was transferred to a flask with water, when ammonia completely dissolved, providing 2 L of a 0.1 M ammonia aqueous solution. If the pressure in the vessel reduced to 1.18 atm, find the volume of the vessel.

The logical structure of the problem involves two main schemata: the ideal gas equation and concentration of aqueous solutions (molarity). The problem caused various difficulties to the students. In particular, they failed to connect the fall in the gas pressure with the ammonia solution that was formed. To make the problem as close as possible to a real problem (and not a traditional exercise), no further comments about the problem were made, nor the value of the gas constant was given, so they had to know or should be able to calculate the value of the gas constant in the proper units.

Most successful solvers applied the ideal-gas equation twice, for the initial and the final state of the ammonia gas in the vessel: $p_1V = n_1RT$ (1) and $p_2V = n_2RT$ (2). From these two equations, they arrived at the relation $n_1/p_1 = n_2/p_2$ (3). If n_s are the moles of ammonia dissolved in water, then $n_2 = n_1 - n_s$. Replacing this relation in (3), allows for solution of the resulting equation for n_1. Finally, replacement of the expression for n_1 in eq. (1) leads to the calculation of V. A much smaller proportion of students did not use the ideal-gas equation, but instead started with the relation $p_1/p_2 = n_1/n_2$ (at constant V and T), and went on as above. Finally, just four students of Cohort B wrote directly the equation $(p_1 - p_2)\ V = n_sRT$.

Two marks were given for each solution, one for the total achievement in the problem, and one for the solution procedure only (75% percent of the total mark). Partial marks were allocated to the various steps in the solution procedure as follows: 10.0 + 2.5 = 12.5 marks for calculation of moles of ammonia gas dissolved in water; 11.25 marks each for equations (1) and (2) (total 22.5 marks); 2.5 marks for conversion of degrees Celsius to degrees Kelvin and an additional 2.5 marks for knowing or estimating the value of R; 20.0 marks for the relation $n_2 = n_1 - n_s$; 22.5 marks for the algebraic manipulations that lead to a final expression for V; 10.0 marks for intermediate numerical calculations; finally, an additional 7.5 marks for correct numerical result with proper units. Four experienced markers marked independently, according to the agreed marking scheme, fifteen randomly selected papers. The Pearson correlation coefficients between the four markers varied between 0.94 and 0.99.

Practical activity: The ammonia fountain

Because the Cohort A students had weaker background, the practical activity started for them with a number of experiments that aimed to clarify the concept and the effects of the pressure of a gas, as well as of the atmospheric pressure, through the operation of a straw in drinking water from a cup. Then the action of acid-base indicators was discussed, through the practical example of phenolphthalein, in connection with the ammonia producing reaction between ammonium chloride and sodium hydroxide.

All students worked in groups of four (Alexopoulou & Driver, 1996) and carried out the ammonia-fountain experiment under the supervision of the instructor.

> *Into a spherical flask 25 mL, we place about 15 g NH_4Cl plus a small quantity of water, and the mixture is shaken until a pelt is formed. Following that, we add about 8 g NaOH and the flask is stoppered with a cork through which a thin glass tube of a length about 35 cm passes. Then, holding the open end of the tube closed with a fingertip, we turn over the flask and dip the open end of the tube into a beaker filled with water, to which a few drops of phenolophlalein had been dropped. At the same time, we fasten the neck of the flask onto a stand. Then we observe what is going on until the ammonia fountain forms.* (Figure 1 shows three stages of the experiment.)

The experiment is strongly related to the above problem in the following ways:

a. the ammonia gas dissolving in water causes the fall in the pressure in the vessel, hence;
b. the amount of ammonia dissolved is the same as the ammonia gas which was removed from the vessel, causing the fall in pressure.

After the experiment, a discussion followed between the instructor and the students, concerning the elucidation of the concepts that enter the experiment. Though the instructor emphasised to the students of Cohorts A and C that *the experiment was relevant to the problem*, no other special statement was made that could bias the data. This is also supported by the fact that only a small proportion of students actually found the experiment useful in the solution of the problem (see results below).

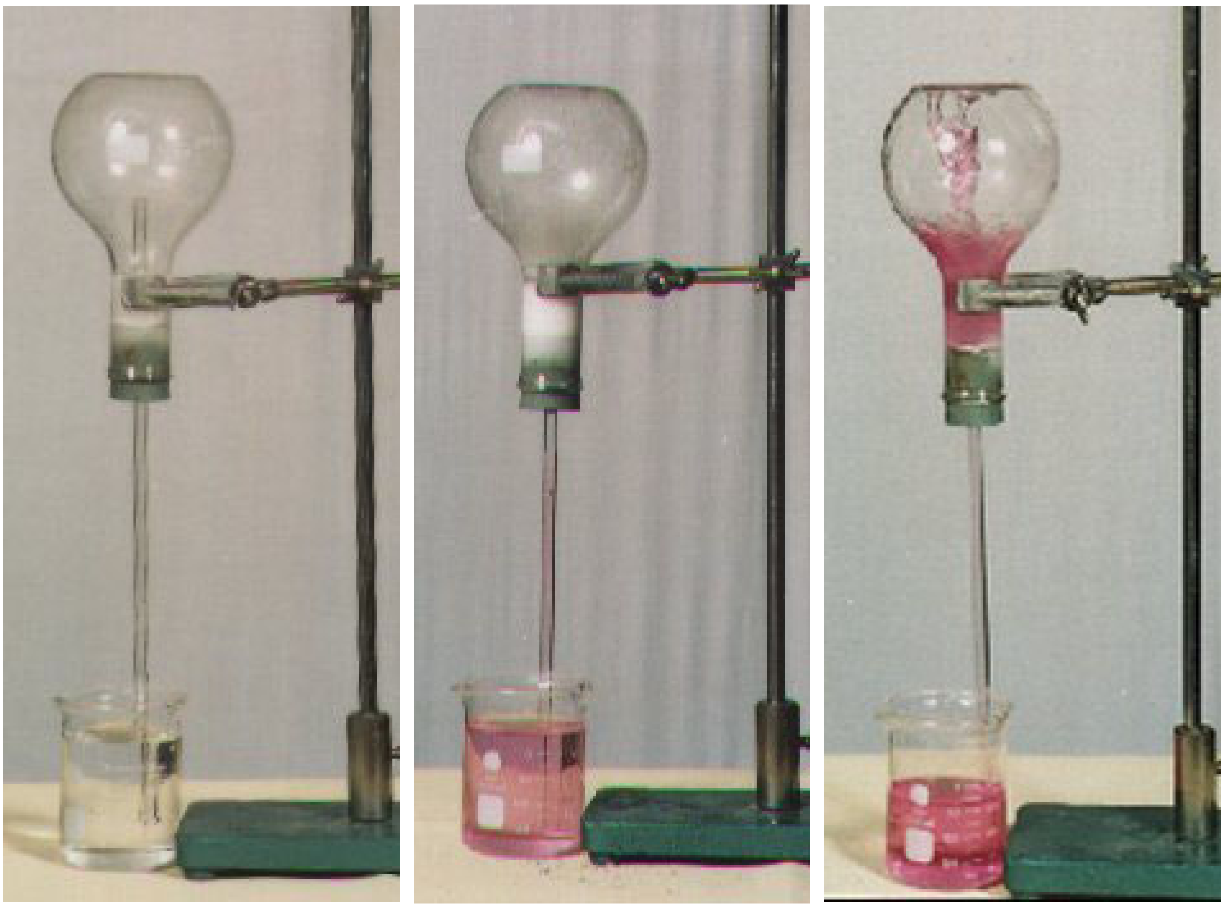

FIGURE 1. *Experimental set-up, and three instances of the ammonia-fountain experiment.*

Problem-solving procedure

For students of Cohort A, the whole procedure took place the same day, and lasted two teaching periods of forty-five minutes each, without intermediate break. Twenty five minutes were provided for the first, plus twenty minutes for the second attempt at solving the problem, while the rest of the time (just over forty-five minutes) was taken by the practical activity. We repeat that students of Cohorts A and C were warned before the activity that it was connected with the problem, and that they would have to deal with the same problem again later.

For Cohorts B and C, a teaching period of forty-five minutes was used with the experimental groups for the practical activity. One to three days after the activity, students of both the experimental and control groups were given the problem and allowed to work on it for 25 minutes. No hint about the connection of the activity and the problem was made in the case of the Cohort-B students.

Written questionnaire

A written questionnaire was distributed to students of the experimental Cohort-B group, after they dealt with solving the problem. It consisted of the following two questions:

A) *Did you use your experience from the practical activity in the solution of the problem? If yes, at which point or points in the solution was the activity useful to you?*

B) Describe in your own words the ammonia fountain experiment and try to explain it as best as you can.

For the evaluation of students' responses to the second question, the responses were divided into those dealing with descriptions and those attempting to interpret the observed events. For each description and interpretation, a maximum number of marks was assigned, with explanations being assigned more marks. Thus, mentioning of the bubbles observed in the beaker at the beginning of the experiment was given 5 marks, while explaining their origin (ammonia gas produced in the reaction) was given 10 marks. On the other hand, explaining that the liquid rose gradually inside the tube because of the fall in pressure in the flask (caused by dissolving of ammonia gas into water) got 25 marks. A total performance mark was thus estimated (maximum 100). In addition, for each description/interpretation, a percentage mark was defined as the ratio of marks gained to the maximum number of marks allocated to the description/interpretation (multiplied by 100).

Statistical analyses

For Cohort A, where the same students acted as control and experimental group (matched pairs of subjects), the appropriate statistic is the *Wilcoxon signed-ranks test*, which calculates *Z* scores. For Cohorts B and C (independent samples), because of deviation of the distribution of achievement scores form the normal curve (with increased frequencies of the low scores), we have used the *Mann-Whitney statistic* which calculates *U*-values (or *Z scores* for large samples: one or both larger than 20-25). All statistical calculations were made using the *SPSS* software.

RESULTS AND COMMENTS

Achievement in solving the problem

Tables 2 and 3, and Figure 2 show the achievement of experimental and control groups for each cohort. The following conclusions can be drawn from the data:

TABLE 2. *Total percentage achievement (standard deviations in parentheses) in solving the problem for the various experimental and control groups.*

Cohort	Experimental group	Control group
A	18.6 (21.2)	12.2 (14.9)
	$Z = 6.79, p < 0.001$	
B1	33.5 (31.0)	26.6 (27.8)
	$Z = 2.61, p < 0.01$	
B2	37.0 (30.5)	25.7 (26.4)
	$U = 199.5, p > 0.05$	
C	46.9 (31.7)	35.2 (29.0)
	$Z = 2.43, p < 0.05$	

TABLE 3. *Percentage achievement (standard deviations in parentheses) in the solution procedure only* in solving the problem for the various experimental and control groups.*

Cohort	Experimental group		Control group
A	19.3 (22.1)		12.9 (16.0)
		$Z = 5.00, p < 0.001$	
B1	35.5 (35.1)		30.1 (32.7)
		$Z = 1.46, p > 0.1$	
B2	40.4 (35.1)		27.1 (30.7)
		$U = 198.5, p > 0.05$	
C	50.8 (35.5)		39.7 (33.9)
		$Z = 1.94, p < 0.10$	

*Excluding numerical computations (see text). Percentage change of achievement according to level of achievement.

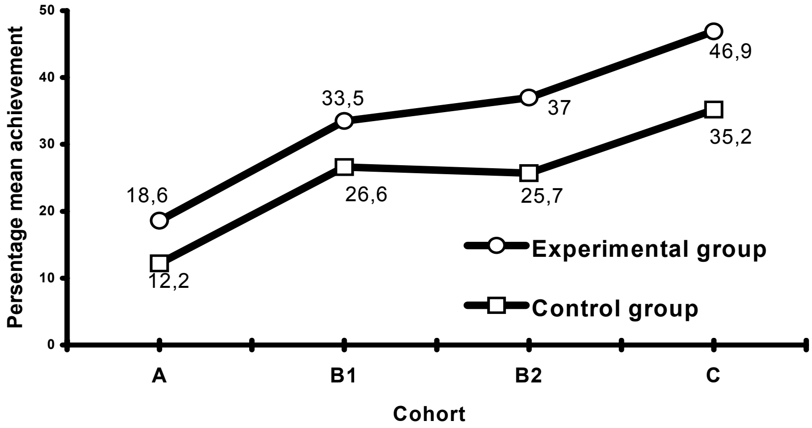

FIGURE 2. *Graph of experimental versus control-group mean achievement in solving the problem for the various cohorts studied. (The lines connecting the data points have been drawn for illustration purpose only.)*

- The achievement of the tenth-grade cohort A was very low. This should mainly be attributed to the limited contact of these students with chemical calculations. As time went past in the school process, an overall improvement was natural to occur, and this is reflected in the increase of mean scores, so about one year later (Cohort C) the 50% mean mark was approached.
- In all cases, the experimental groups had higher achievement than control groups, and in many cases this superiority is statistically significant. The differences were not however very large.
- As expected, when we consider achievement in the solution procedure only, achievement was a little higher, and higher were the standard deviations too.

Percentage change of achievement according to level of achievement

Table 4 shows a separation of the Cohort-A students into three distinct groups, according to the improvement they made between their first and second attempt to solve the problem. Note that just over 20% of the students had substantial improvement.

TABLE 4. *Separation of the Cohort-A students (N = 90) into three distinct groups.*

	N	Mean achievement (%) (standard deviation) Before the activity	 After the activity
GROUP 1 Improvement ≥ 10%	20 (22.2%)	15.1 (15.2)	41.2 (26.4)
GROUP 2 No improvement < 10%	68 (75.6%)	10.9 (14.4)	12.0 (14.1)
GROUP 3 Deterioration	2 (2.2%)	28.1 (25.7)	15.0 (8.8)

In the case of Cohorts B and C, we distinguished students into various levels of achievement: as high achievers, those with achievement higher than 65.0%; as moderate achievers, those with achievement from 35.0% up to 65.0%; and, as poor achievers, those with achievement lower than 35%. Table 5 has the data for the distribution of students into the three performance groups. We observe that, in all cases, we had a larger proportion of high achievers and a smaller proportion of poor achievers in the experimental group, while, in Cohorts B1 and C, moderate achievers were about the same in the experimental and control groups. This demonstrates a shift of a number of low achievers into a higher achievement group (most likely the moderate group), and a simultaneous shift of an about equal number of moderate achievers into the high achievement group.

TABLE 5. *Division and distribution of students (end of eleventh grade) into subgroups according to their level of achievement.*

	Cohort B1		**Cohort B2**		**Cohort C**	
	Experim. group ($N = 96$)	**Control group** ($N = 92$)	**Experim. group** ($N = 23$)	**Control group** ($N = 23$)	**Experim. group** ($N = 54$)	**Control group** ($N = 51$)
High achievers	20.8%	16.3%	21.7%	13.0%	35.2%	23.5%
Moderate achievers	5.2%	4.3%	17.4%	4.3%	9.3%	9.8%
Poor achievers	74.0%	79.3%	60.8%	82.6%	55.5%	66.7

Answers to written questionnaire: Use of the experiment for the solution of the problem

Table 6 has the division of students of Cohort B into those who found and those who did not find the practical activity useful in the solution of the problem, and their respective achievement. It is observed that while only a small proportion of the students used the experiment, these students had considerably higher achievement than the remaining students. Also, it is noteworthy that the combination of the students who did not use the experiment, or did not answer if they used it, had no difference in achievement compared to the students of the corresponding control groups. This is strong evidence about the reliability of the study.

Twenty answers from students of group (1) in Table 6 were noted and these show that facts from the practical activity and their explanation had indeed played a part in decisive steps into the solution process. The answers were as follows (translated from Greek):

TABLE 6. *Division of experimental group students of Cohort B according to actual use of the experiment in the solution of the problem, and corresponding percentage achievement (standard deviations in parentheses) in the solution procedure. For comparison, the achievement of control group students is repeated from Table 3.*

	Cohort B1	**Cohort B2**
1) Experimental group students who used the experiment in the solution of the problem	*N* = 17 (17.7%) 55.7 (38.0)	*N* = 3 (13.0%) 84.9 (26.0)
2) Experimental group students who did not use the experiment in the solution of the problem	*N* = 35 (36.5%) 29.9 (33.3)	*N* = 11 (47.8%) 31.2 (28.3)
3) Experimental group students who did not answer if they used the experiment in the solution of the problem	*N* = 44 (45.8%) 31.6 (31.5)	*N* = 9 (39.1%) 24.4 (37.9)
4) Combination of experimental group students (2) and (3) above	*N* = 79 (82.3%) 30.8 (32.1)	*N* = 20 (87.0%) 28.1 (32.2)
5) Control group students	*N* = 92 (100.0%) 30.1 (32.7)	*N* = 23 (100.0%) 27.1 (30.7)

- *"To realise that some ammonia that was passed from the flask into the solution, and this caused the drop in pressure."* (4 students)
- *"To find the difference in pressure in the flask."* (4 students)
- *"It helped me at the point where ammonia was passed into the flask and we have a change in pressure."* (3 students)
- *"It helped me realise the instance at which the pressures were balanced."* (2 students)
- *"Because of the pressure, sucking up took place, thus we realise that there was a difference in pressure; this leads us to the gas state law."* (2 students)
- *"To realise that there was an excess of ammonia, so that part of it dissolved."* (2 students)
- *"In the difference in pressure, that caused the solution in the beaker."* (1 student)
- *"The activity was relevant at the point where ammonia dissolved in the water."* (2 students)

We repeat that the above students had higher achievement than those who stated that the practical activity was of no help to them. Of interest were also some of the answers of the latter students:

- *"The experiment did not help me with the problem - yet it was impressive, it was a good experience for me."* (12 students)
- *"We had never done a similar experiment at school; what is the connection of the experiment with the problem?"* (10 students)
- *"I used my knowledge from the course as well the properties of gases."* (6 students)
- *"I knew the gas-state equation - the only information I got form the experiment was the physical state of reactants and products."* (3 students)

Indeed, the experience from the activity, that part of the ammonia gas dissolves in the water in the beaker and this caused the fall of pressure in the flask is decisive for the solution of the problem. This is the connection that most students failed to make.

The description and interpretation of the practical activity

Cohort B1 achieved an average mark of 36.6% in the description and interpretation of the practical activity, while Cohort B2 achieved 44.5%. The difference may partially be attributed to B2 students having an experience with practical activities. The results showed that descriptive elements gained more marks than interpretative. The following events received the highest marks: mention of reactants (78%); mention of the action of phenolophthalein (75%); mention of bubbles formed at the edge of the tube (dipped in the solution in the beaker) at the beginning of the reaction (39%); interpretation of change in colour of solution on dissolving of ammonia gas into water (34%); mention of reaction products (26%). Production of gaseous ammonia and formation of ammonia solution (not obvious events) gained lower marks (22% and 3% respectively). The interpretation of the nature and origin of the bubbles, as well as the solution rising received the smallest marks.

Central to proper interpretation of the experiment is the concept of the gaseous pressure, as well as the fact that the difference in pressure is the cause for movement of fluids. Here are some representative interpretations provided by Cohort-B students:

- *"This (the phenomenon) is due to equalisation of pressures, the external pressure became equal to the internal pressure in the flask."*
- *"Because of difference in pressure caused by gaseous ammonia, the liquid started to rise» (partially acceptable answer)."*
- *"Because of the hydrostatic pressure that is exerted at the tube, the liquid rises through the tube, and the fountain forms."*

Students' misconceptions and false interpretations

In the discussion that followed the practical activity, students experienced difficulty in explaining why the liquid rose gradually up from the beaker into the tube. The lack of the atmospheric pressure concept in our students' minds was evident, in agreement with previous findings (diSessa, 1993; Tytler, 1993). The following main misconceptions and false interpretations were detected:

1. *Nature detests vacuum*. Some students hold this Aristotelian conception, so they explain the experiment in terms of creation of a vacuum which has to be filled by the liquid solution. Of course, this is a reasonable description from the student perspective, even if a wrong explanation:

- *"Ammonia dissolves a lot in water, a vacuum forms in the flask, and this has to be filled by sucking up of water."*

2. *Conservation of volume of liquids*:

- *"As ammonia gas goes down into the tube, water from the beaker rises up in the tube."*
- *"On dissolving, ammonia occupies some space, and this space is compensated for by the rising of the solution."*

3. *Lightness of the ammonia gas*:

- *"Gaseous ammonia is lighter than air, hence it pushed at a large speed the solution into the spherical flask through the tube."*
- *"Gaseous ammonia is lighter than air, hence a pressure difference was formed, pushing the solution into the tube."*

DISCUSSION AND IMPLICATIONS FOR INSTRUCTION

The low achievement in the solution of the problem was primarily due to its complexity, complexity being defined in terms of the information overload implicit in the problem. Indeed, one could argue that, by mixing the gas-law equation with volumetric analysis, and by denying the value of the gas constant, the problem was doomed to cause gross working memory space overload. However, we must point out that the problem was taken from an official book for tenth-grade students, supplied by the Ministry of Education. Our choice not to supply the value of the gas constant certainly added to the difficulty, but that choice was guided by the rationale to have a problem and not an exercise. On the other hand, the small differences (despite many of them being statistically significant) between experimental and control groups could be attributed to the failure of many students to connect the practical activity with theory.

At the outset, we also admit that the chosen practical activity was very involved. The fountain experiment is indeed a spectacular and impressive one, but this feature may be the cause of the failure of most students to pay attention to the stimuli relevant to the problem. Indeed, one could argue that they were not the dominant stimuli of the experiment. In particular, the generation of ammonia in the flask was also producing working memory space overload. In any case, it was our intention to check if a spectacular experiment could benefit students in many of the involved concepts and aspects.

To introduce the concept of chemical reaction, de Vos and Verdonk (1985) suggested that experiments are needed that “could intrigue purely by the change of substances to other substances and that would not display any distracting phenomena. (On the contrary), fascinated (and blinded) by the bright light of burning magnesium, students fail to notice the white powder that is left behind by the process.”

Kempa and Ward (1988) reported that students failed to notice or record one in every three observations: “As the intensity or magnitude of an observational stimulus is reduced, it becomes more difficult to detect. Moreover, when there are multi-stimuli, the 'detectability' of one stimulus can be seriously affected by the presence of another; the dominant stimulus obscuring, or masking completely, the less dominant ones.” Al-Shuaili (2000, cited in Johnstone & Al-Shuaili, 2001) showed that:

> “Visual observational changes, which might go unnoticed in a normal laboratory, could be made to appear well above the detection threshold. Therefore, whilst demonstrating a particular task, the instructor can highlight the kind of things learners should be looking for in order to fulfill the task's aim of focusing on 'signals' and suppressing 'noise' (Johnstone & Letton, 1990). Teachers also have to ensure that 'signals' offered to students should have enough observational magnitude and intensity as to be above the threshold. They should also be aware of the dominant observation in situations of multi-stimuli and manage them accordingly. The dominant stimulus may have to be played down if it is in danger of masking other important observations. This does not imply that the teacher should give all the answers before the laboratory, but rather prepare the observational faculties for what is to come. There may well be occasions when demonstration, rather than individual laboratory work, may be the best procedure when there is a danger of vital observations being obscured by powerful, but less important stimuli. In a demonstration the teacher has control and can focus attention on the salient observations.”

A further complication to observation is that apparatus often masks a phenomenon. According to Johnstone & Al-Shuaili (2001), “people's memories of their school science often relate more to the dramatic equipment than to its significance for scientific ideas. Because of this, it is important to take some time to explain a piece of apparatus, with the intention of making it sufficiently familiar so that the class can forget it and focus attention on the phenomenon.”

Finally, of paramount importance for the proper interpretation of laboratory observations is the knowledge of the relevant theory. “Students who lack the requisite theoretical framework will not know where to look, or how to look, in order to make observations appropriate to the task in hand, or how to interpret what they see. Consequently, much of the activity will be unproductive" (Johnstone & Al-Shuaili, 2001). "Knowing what to observe, knowing how to observe it, observing it and describing the observations are all theory-dependent and therefore fallible and biased" (Hodson, 1986). On the other hand, we repeat that there is a need to actually assessing practical experiences of all kinds, because if the students know that they will be tested on these, they will pay more attention (Bowen & Phelps, 1997; Deese, Ramsey, Walczyk, & Edy, 2000).

The low mean achievements make it obvious that the students of our samples had not a good understanding of the concepts that related to the ideal-gas equation. This agrees with Kautz et al. (1999) who pointed out that first- and second-year undergraduate students who attended traditional lectures had not developed functional understanding of the ideal gas and the ideal-gas law. In addition, as is the case with most Greek students, our students had not previous experience in working with chemicals and carrying out, or even watching, experiments. It may then be the case that this contact with chemical experiments had so much attracted their attention that little opportunity, during the experiments, was left for a mental processing of what was going on and why. In addition, the particular experiment chosen involved so many details, as well as so many physics and chemistry concepts, that an overload of many students' working memory took place (see discussion above, as well as Johnstone & Wham, 1982), and this explains the lack of spectacular improvement.

In conclusion, it has been demonstrated that it may be the case that science problems and the concepts that enter the problems may constitute two unconnected, non-overlapping spaces. Extending this, we can state that the theory of chemistry and chemistry experiments *may* constitute two minimally overlapping spaces. Coupled with a recent similar research finding (Hart et al., 2000), it suggests that it MAY BE that *the theory of chemistry and chemistry experiments constitute two minimally overlapping spaces.* In our special case, it MAY BE that *science problems and the concepts that enter the problems may constitute two minimally inter-connected/overlapping spaces,* especially in the case of complicated experiments. This finding reinforces the argument of Gabel et al. (1984) that students who do not understand a concept qualitatively are likely to handle thoughtlessly the mathematical equations.

We must, however, keep in mind the limitations of our particular research situation (see above), that prevent us from committing ourselves: apparently, our above statement constitutes for the moment just a *working hypothesis* that needs to be studied further. Simplifying the experimental setting, by using ready liquefied ammonia (from a lecture bottle, with a manometer attached to it) may help reduce the 'noise' and make students concentrate on the actual relevant phenomena. On the other hand, the use of computer simulations is promising with such problems. We have carried out an investigation along the latter direction, and will report the findings in due course. In any case, chemical educators must take into account the available possibilities, and carefully choose their experiments, so that they first use simple experiments that involve few concepts.

The choice of the fountain experiment with its potential for working memory space overload and its quite dramatic visual impact may have not permitted students to make too much sense of the underlying physical and chemical events. This may explain the relatively low improvement in performance for many students. It is certainly open to question to what extent experimental work will contribute easily to the ability in solving conceptually demanding problems. This is an area which merits further research.

NOTE: Part of this work (a preliminary study), using data from students of Cohort A only (tenth-grade students), was included in the 6th ECRICE (Tsaparlis & Kampourakis, 2001).

ACKNOWLEDGMENT: We thank the following colleagues who contributed to carrying out this work: A. Bakolis, D. Demsias, D. Papathanakos, D. Stamovlasis, and I. Chronis. We also thank Dr. N. Reid for handling editorially our submission, and the two reviewers for their comments and helpful suggestions.

CORRESPONDENCE: *Georgios TSAPARLIS, University of Ioannina, Department of Chemistry, GR-451 10 Ioannina, Greece; fax: +30 2651 098798; e-mail: gtseper@cc.uoi.gr*

REFERENCES

Alexopoulou, E. & Driver, R. (1996). Small-group discussion in physics: Peer interaction models in pairs and fours. *Journal of Research in Science Teaching*, *33*, 1099-1114.

Deese, W., Ramsey, L.L, Walczyk, J., & Eddy, D. (2000). Using demonstration assessments to improve learning. *Journal of Chemisty Education, 77*, 1511-1516.

de Vos, W. & Verdonk, A.H. (1985). A new road to reactions, Part I. *Journal of Chemical Education, 62*, 238-240.

di Sessa, A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, *10*, 105-226.

Domin, D.S. (1999). Review of laboratory instructional styles. *Journal of Chemical Education, 76*, 543-547.

Dowen, C. W. & Phelps, A. J. (1997). Demonstration-based cooperative testing in general chemistry: A broader assessment-of-learning technique *Journal of Chemical Education, 74*, 715-719.

Gabel, D.L., Sherwood, R.D., & Enochs, L. (1984). Problem-solving skills of high school chemistry students. *Journal of Research in Science Teaching*, *21*, 211-233.

Gabel, D. (1999). Improving teacher and learning through chemistry. Education research: A look to the future. *Journal of Chemistry Education, 76*, 548-554.

Genya, J. (1983). Improving student's problem-solving skills – A methodological approach for a preparatory chemistry course. *Journal of Chemical Education*, *60*, 478-482.

Gil-Perez, D. & Martinez-Torregrosa, J. (1983). A model for problem solving in accordance with scientific methodology. *European Journal of Science Education, 5*, 447-455.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). What is the purpose of this experiment? Or can students learn something from doing experiments? *Journal of Research in Science Teaching*, *37*, 655-675.

Johnstone, A.H. (1993). Introduction. In C. Wood & R. Sleet, *Creative problem solving in chemistry* (pp. iv-vi). London: The Royal Society of Chemistry.

Johnstone, A.H. (1997). Chemistry teaching - Science or alchemy? (1996 Brasted Lecture). *Journal of Chemical Education, 74*, 262-268.

Johnstone, A.H. (2001). Can problem solving be taught? *University Chemistry Education*, *5*, 69-73.

Johnstone, A.H.& Al-Shuaili, A. (2001). Learning in the laboratory: Some thoughts from the literature. *University Chemistry Education*, *5*, 42-51.

Johnstone, A. H., Hogg, W., Ziane, M. (1993). A working memory model applied to physics problem solving. *International Journal of Science Education*, *15*, 663-672.

Johnstone, A. H. & Letton, K. M. (1990). Investigating undergraduate laboratory work. *Education in Chemistry*, *27* (1), 9-11.

Johnstone, A.H. & Wham, A.J.B. (1982). The demands of practical work. *Education in Chemistry*, *19* (3), 71-73.

Kautz, C. H., Lovrude, M.E., Herron, P.R.L., & McDermott, L.C. (1999). Research on student understanding of the ideal gaw law. In R. Duit et al. (eds.), *Research in science education – Past, present, and future*: Proceedings, 2nd International Conference of ESERA, Vol. 1. 83-85. Kiel, Germany: IPN.

Kerr, J. F. (1963). *Practical work in school science: An account of an inquiry into the nature and purpose of practical work in school science teaching in England and Wales*. Leicester: Leicester University Press.

Larkin, J.H. (1980). Teaching problem solving in physics: Issues in teaching and research. In *Problem solving and education: Issues in teaching and research,* D.T. Tuma & F. Reif (eds.). New York.

MacRae, S. (1996). *Drawing inferences from statistical data*. The British Psychological Society. Open Learning Units-Research Design and Statistics.

Mettes, C. T. C. W., Pilot, A., Roossink, J. H. & Kramers-Pals, H. (1981). Teaching and learning problem solving in science. Part II: Learning problem solving in a thermodynamics course, *Journal of Chemical Education*, *58*, 51-55.

Niaz, M. (1995). Relationship between student performance on conceptual and computational problems of chemical equilibrium. *International Journal of Science Education, 17*, 343-355.

Niaz, M., & Robinson, W.R. (1992). Manipulation of logical structure of chemistry problems and its effect on student performance. *Journal of Research in Science Teaching, 29*, 211-226.

Niaz, M., de Nunez, S. G., & de Pineda, R.I. (2000). Academic performance of high school students as a function of mental capacity, cognitive style, mobility-fixity dimension, and creativity. *Journal of Creative Behaviour*, *34*, 18-29.

Reif, F. (1981). Teaching problem solving – A scientific approach. *The Physics Teacher*, *19*, 329-363.

Roth, W. M. (1988). *Short-term memory and problem solving in physics education*. Dept. of Science, Appleby College Oakville, Ontario Canada.

Roth, W.-M. (1994) Experimenting in a constructivist high school physics laboratory. *Journal of Research in Science Teaching*, *31*,197-223.

Sanger, M. J., Phelps, A. J. & Fienhold, J. (2000). Using a computer animation to improve students' conceptual understanding of a can-crushing demonstration. *Journal of Chemical Education*, *77*, 1517-1520.

Simon, D.P. & Simon H.A. (1978). In R.S. Siegler (ed.), *Childrens' thinking: What develops.* Lawrence Erlbraum Associates, Hillstate NJ.

Stamovlasis, D. & Tsaparlis, G. (2001). Application of complexity theory to an information processing model in science education. *Nonlinear Dynamics, Psychology and Life Sciences*, *5*, 267-286.

Stamovlasis, D, & Tsaparlis, G. (2003). A complexity theory model in science education problem solving: random walks for working memory and mental capacit. *Nonlinear Dynamics, Psychology and Life Sciences*, *7*, 221-244.

Tsaparlis, G. (1998). Dimensional analysis and predictive models in problem solving. *International Journal of Science Education,* 20, 335-350.

Tsaparlis, G. & Kampourakis, K. (2001). A preliminary study of the effect of a practical activity on problem solving in chemistry. *Proceedings of 6th ECRICE/2nd ECCE* (on CD-ROM). A.F. Cachapuz (ed.). Aveiro, Portugal: University of Aveiro.

Tsaparlis, G., Kousathana, M., & Niaz, M. (1998). Molecular-equilibrium problems: Manipulation of logical structure and of *M*-demand, and their effect on student performance. *Science Education*, *82*, 437-454.

Tytler, R. (1993). Children's conceptions of air pressure: Exploring the nature of conceptual change. *Internatiomal Journal of Science Education*, *20*, 929-958.

Welzel, M. (1999) A study of factors determining the difficulty and interestingness of physics problems. In R. Duit et al. (eds.), *Research in science education – Past, present, and future*: Proceedings, 2nd International Conference of ESERA, Vol. 2. 369–371. Kiel, Germany: IPN.

White, R. T. (1996). The link between the laboratory and learning. *International Journal of Science Education, 18*, 761-774.

Woolnough, B. E. (1991). *Practical science*. Milton Keynes, Open University Press: UK.

Zoller, U. (1993). Are lecture and learning compatible? Maybe for LOCS: Unlikely for HOCS. *Journal of Chemical Education, 70,* 195-197.

Zoller, U. & Tsaparlis, G. (1997). HOCS and LOCS students: The case of chemistry. *Research in Science Education, 27, 117-130.*