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Concepts

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CHEMICAL PHENOMENA VERSUS CHEMICAL REACTIONS: DO STUDENTS MAKE THE CONNECTION?

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ABSTRACT: In this work, we examine whether tenth-grade high school students (*N* = 197, age 15-16) as well as first-year university chemistry students (*N* = 77, age 18-19) can make the connection between chemical reactions and chemical phenomena. We used nineteen physical and chemical phenomena, and asked the students at one stage to distinguish physical from chemical phenomena, and at another stage to state in which cases one or more reactions occur. Students can be categorised into two distinct groups. One group includes those who do not always identify chemical phenomena with reaction(s), while the other group includes those who are successful in that distinction. Further, the students of the first group can be divided into two subgroups: (a) those who perform better in identifying the chemical phenomena; (b) those who perform better in identifying the reactions. A differentiation of chemical changes into natural and man-caused processes seems to be operating, at least with Greek students. On the other hand, students may be intuitively viewing chemical reactions as fairly simple processes, which can be expressed by means of chemical equations. Finally, it might be preferable to group (i) changes of physical state and phase, and (ii) solutions, in a separate category (physicochemical changes). [*Chem. Educ. Res. Pract.*: 2003, *4*, 31-43]

KEY WORDS: *misconceptions; students' conceptions; physical phenomena/changes/processes; chemical phenomena/changes/processes; chemical reactions; Greece; chemistry/science education programmes of study*

INTRODUCTION

Early in every introductory chemistry book (and often physics too) attempts are made to categorise phenomena or changes into physical and chemical. Physical phenomena (PP) or physical changes are defined as those in which there is a change in form or state of a substance (or a material in general), but no new substance or substances are produced. Chemical phenomena (CP) or chemical changes are defined as those in which one or more new substances are produced (Gensler, 1970). Examples of PP normally include: boiling, melting, and other changes of physical state; breaking or deformation of a material; thermal expansion and contraction; solvation; recrystallisation; magnetic action; electric phenomena (except electrolysis). Examples of CP include: burning; rusting of iron; action of an acid on a material.

According to Nelson (2003), substances can undergo three kind of changes: physical, physicochemical, and chemical. "In a physical change (e.g. compression of air) there is no change in substance or form; in a physicochemical change (e.g. melting of lead, dissolution of chlorine in water) there is a change in form but not of substance; in a chemical change (e.g. rusting of iron, boiling of mercury, dissolution of chlorine in alkali) there is a change of substance. Properties relating to the three kinds of change are likewise called physical, physicochemical, and chemical. The first two categories are usually conflated, but it helps to distinguish them. Substances can also undergo a fourth kind of change: *radiochemical*. In this there is a change of substance and absorption or emission of high-energy radiation."

The placing of such definitions and examples, as well as their deeper meaning, at the start of a course may not be helpful. In point of fact, the concept of substance is central in these definitions. Also, "there is no virtue in trying to define these changes more precisely at this stage" (Nelson, 2003). Further analysis and deeper understanding has to wait until molecules and atoms have been introduced. But plunging beginners into the world of molecules and atoms goes against the psychology of learning (Johnstone, 1991; Tsaparlis, 1997; Johnstone 2000). There is, then, great concern among science educators about the distinction of phenomena/changes into physical and chemical, as well as about students' ability to make that distinction. A number of studies have demonstrated that there is poor understanding of chemical changes, and confusion between PC and CP (Garnett, Garnett, & Hackling, 1995). The topic has been the subject of skepticism with chemical educators too (Gensler, 1970; Jensen, 1998) (see also Conclusions and Implications). In the case of Greece, an added problem comes from the different use of the term 'physical phenomena' in everyday language as phenomena that occur on their own in nature (natural phenomena).

The phenomena of burning and rusting have been most studied. Driver (1985) found that students use intuitive everyday ideas to explain such chemical changes; in addition they maintain that something is conserved, despite change in appearance. For instance, they assume that the mass of steel wool does not change during its burning; in addition, they consider that the change is physical ("melting"). On the other hand, they fail to include in the system gaseous reactants and/or products. Burning has been studied also by Meheut, Saltier, and Tiberghien (1985), while similar to the findings of Driver were those by Hesse and Anderson (1992), whose students treated changes such as rusting as physical changes in form or state, and at the same time failed to understand the role of invisible gaseous reactants and/or products. In addition, they had a preference for superficial analogies, for instance they considered rusting as something like decay. Finally, most students did not invoke atoms and molecules in their explanations (even though they had been emphasised in the chemistry course), a finding similar to that of Andersson (1986). Abraham et al. (1992, 1994) studied the problem of burning of a candle, as well as that of formation of a black film on the end of a glass rod which is held in the yellow part of the flame of the candle, and found that over 70% of students held misconceptions. The change was assumed to be physical, because no chemicals were involved or because the candle underwent a change of shape or form. According to Johnson (2000), the difficulties in understanding chemical changes are due to the specification of the curriculum, and in particular to failure to deal properly with the relevant concepts. The curriculum "does not directly address key ideas that students do not have and need to develop in order to understand 'standard' chemistry content".

This work constitutes an extension of the work of Stavridou and Solomonidou, who have carried out two relevant studies. In their first study (Stavridou & Solomonidou, 1989), they asked 15 Greek pupils (ages 8-17) to group nine familiar (everyday) PP and nine familiar CP on the basis of common criteria. It was found that students could be divided into two major categories, with regard to the criteria they used: (a) criteria used for describing change; (b) criteria used for making the change. In the first category, common features did not refer to a change, but to a static-external view of the phenomenon: human actions on the objects, action of heat, necessary conditions (e.g. enzymes, air, time); in the second category, changes were realised, while the criteria could be classified into: natural change as opposed to artificial (man-caused) change; simple change versus complicated change; change of matter (modification of form, destruction, CP); reversible versus irreversible changes. For some students, in a PP we simply have a one-material change, while in a CP we have a change of a material in the presence of another material. On the other hand, the use of the criterion of reversible and irreversible change appeared to help students to distinguish physical from chemical changes: physical changes are reversible, but chemical ones are not. (However, this criterion is not general: for instance, when dinitrogen tetroxide is heated, it changes into nitrogen dioxide, but cooling reverses the process.) None of the students was able to distinguish the described phenomena on the basis of the identity conservation or change of identity of substance entering the phenomena. Noteworthy is also the lack of criteria invoking microscopic aspects of matter.

In the second study (Stavridou & Solomonidou, 1998), nineteen phenomena were used, almost the same with those of the first study. These are divided into nine PP and ten CP (see Table 1). In the study, four groups of French students participated, of ages 12, 14, 16, and 18 respectively. Each group consisted of ten students. The students were asked to recognise the occurrence of PP or chemical reactions (CR) in the ten examples of CP (see Table 1). If the ten students in each group had made correct choices, they should have recognised zero PP and ($10 \times 10 =$) 100 CR in the ten CP. An increase of correct choices was noted with the increase of age, with younger pupils having many failures, while the older ones had substantial improvement: the 14-years-olds recognised 42 PP and 54 CR; the 16-years-olds recognised 33 PP and 66 CR; finally, the 18-years-olds recognised 17 PP and 90 CR. According to the authors, the concept of substance is a prerequisite for the proper acquisition of the concept of chemical reaction.

In this work, we will examine if tenth-grade Greek students can make the connection between chemical phenomena and chemical reactions. In addition, we will include in our sample first-year university chemistry students. At the outset, it must be pointed out that the author is aware that, in some countries, the distinction between physical and chemical changes/processes is no longer dealt with in science education programmes. The justification for the study reported here arises not only because in many school chemistry programmes the topic of physical versus chemical changes is still discussed; but also because these concepts are considered as basic in chemistry (Nelson, 2003).

METHOD

The research was carried out at the beginning of school year 1996-97, with 197 tenth-grade students (age 15-16) from three upper-secondary schools (*lykeion*) of the *Epirus* region of Greece, as well as 77 first-year chemistry students (age 18-19) from the *University of Ioannina*. They were given the same paper test, including the nineteen everyday physical phenomena (PP) and chemical phenomena (CP), which were used by Stavridou and Solomonidou (see Table 1). The test included two parts. About half of the students had first to distinguish PP from CP, and then (after completion and collection of the first part of the test) to state in which cases one or more chemical reactions (CR) occur. The other half of the students had first to make the distinction between PP and CP, and then to identify CR. The whole test (parts 1 and 2) took less than half an hour for students to complete. Four alternative forms of the test were used with the aim of avoiding student interaction. All forms presented the same phenomena, but in a different order.

TABLE 1. *Everyday phenomena used in the study (after Stavridou & Solomonidou, 1998).*

Physical phenomena	Chemical phenomena
1. A falling stone	1. A nail rusting
2. A breaking glass	2. Meat being cooked (burnt) in the oven
3. Water boiling	3. Wood burning
4. Wax melting	4. An apple ripening
5. Water freezing	5. A tree's leaves decaying
6. Eau de cologne evaporating	6. Grape juice becoming wine
7. Salt being added to soup	7. Milk turning sour
8. Sugar being added to tea	8. Chlorine bleaching a dress
9. Beer frothing	9. Lemon juice acting on marble
	10. 'Boiling' of an egg

In the 'Results and Discussion' section, we provide detailed data for the performance of both high school and university students. In addition, we look in more detail at the particular choices of the university students. Our findings can then easily be generalised.

Finally, although this study was basically quantitative (it had not been designed to include a qualitative component), we asked a limited number (twelve) of university students to provide explanations about certain of their answers to the test. The importance of the integration of quantitative with qualitative methods in science-education research has been recognised in the literature (e.g. Tobin, 1993; Yeany, 1992).

RESULTS AND DISCUSSION

Physical phenomena

Tables 2 and 3 provide mean achievement levels of both tenth-grade and first-year chemistry students in identifying physical phenomena (PP). [In there tables (as well as in further analysis of data), the students are separated into two groups: those with satisfactory performance (up to 2 errors) and those with poor performance (more than 3 errors): the latter had on the average about 4 errors in identifying the PP (out of the nine items).] In Table 2 we observe that 36% of tenth-grade students performed satisfactorily (maximum 2 errors); on the other hand, the remaining 64% made many wrong choices. The pattern is reversed with first-year chemistry students: 61% versus 39%. Note however that the differences in performance in selecting the *correct* answers (that is, not taking into account the *wrong* answers) between the two cohorts of students were very small and statistically insignificant (t = 0.61). However, the younger students made more *wrong* choices ($t = 4.69$, $p < 0.01$). As a result, the difference between correct and wrong answers was larger for the chemistry students ($t = 2.13$, $p < 0.05$).

Physical phenomena that cause difficulties

Table 4 lists the percentages of first-year chemistry students who *failed* to categorise correctly the various PP. (Alternative data are included in Table 10: percentages of students who wrongly assumed as CP the various PP.) We observe that with the exception of the breaking glass and the falling stone, there were large proportions of students (mostly over 40%) who failed to recognise the other phenomena. Gaseous materials (in beer, eau de cologne, and in boiling water) caused serious problems. (Beer was justifiably the hardest item - see below). In the case of water freezing, the change of physical state was less of a trouble

TABLE 2. *Mean achievement levels of tenth-grade students in identifying physical phenomena (PP) (maximum correct: 10*).*

	N	PP correct	PP wrong	Difference
All tenth-grade students	197	6.64 (1.97)	3.64 (1.85)	3.00 (3.53)
Students with a maximum of 2 errors	71 (36.0%)	7.36 (2.17)	1.69 (0.70)	5.67 (2.22)
Remaining students (with 3 or more errors)	126 (64.0%)	6.22 (1.72)	4.74 (1.31)	1.48 (3.23)

* For the sake of comparison, achievement is referred to ten items (while the actual number of items with physical phenomena was nine).

TABLE 3. *Mean achievement levels of first-year chemistry students in identifying physical phenomena (PP) (maximum correct: 10*).*

	N	PP correct	PP wrong	Difference
All first-year chemistry students	77	6.47 (2.34)	2.46 (1.93)	4.01 (3.53)
Students with a maximum of 2 errors	47 (61.0%)	7.07 (2.36)	1.09 (0.82)	5.98 (2.52)
Remaining students (with 3 or more errors)	30 (39.0%)	5.52 (2.01)	4.59 (1.00)	0.92 (2.53)

* See note in Table 2.

TABLE 4. *First-year chemistry students: Percentages of students who FAILED to categorise correctly the various physical phenomena.*

	All first-year chemistry students	Students with a maximum of 2 errors	Students with 3 or more errors
	N = 77	*N* = 47	*N* = 30
Beer frothing	67.5	63.8	73.3
Eau de cologne evaporating	49.4	38.3	66.7
Salt being added to soup	46.8	36.2	63.3
Water boiling	40.3	36.2	46.7
Sugar being added to tea	40.2	31.9	53.3
Wax melting	39.0	27.7	56.7
Water freezing	26.0	27.7	23.3
A breaking glass	3.9	2.1	6.7
A falling stone	1.3	0.0	3.3

because of absence of gas. In general, errors are caused by the radical change in the form of substance in the change in physical state. The solvation process is problematic too. This is particularly the case if the student has a certain degree of 'sophistication' in chemical matters: solvation processes usually result in (chemical) species that are different from the original ones. If students have some notion of this, they may regard solvation processes as chemical processes, rather than physical phenomena. In the case of beer, we must take into account, on the one hand, the fermentation reactions that occur in the production process, and, on the other hand, the fact that many students associate gas evolution with chemical reaction(s). Finally, the case of wax melting is an ambiguous one, because of the associated burning of the candle.

Chemical phenomena and chemical reactions

Tables 5 and 6 give mean achievement levels of both tenth-grade and first-year students in identifying chemical phenomena (CP) and chemical reactions (CR). In Table 5 we observe that 38% of tenth-grade students performed satisfactorily (maximum 2 errors) in both tests (CP and CR); on the other hand, the remaining 62% made many wrong choices. Again the pattern is reversed with first-year chemistry students: 44% versus 56%. It is noteworthy that the differences in performance in selecting the *correct* answers between the two cohorts of students were significant in favour of the chemistry students ($t = 5.08$ for CP and 5.70 for CR, $p < 0.01$). On the other hand, no differences are observed in the case of wrong choices. Significant also are the differences of the *differences* between correct and wrong choices ($t = 2.68$ for CP and 3.55 for CR, $p < 0.01$). Students with a poor performance (more than three errors) had on the average about 4 errors (out of the ten items).

TABLE 5. *Mean achievement levels of tenth-grade students in identifying chemical phenomena (CP) and chemical reactions (CR) (maximum correct: 10).*

	N	CP correct	CP wrong	Difference	CR correct	CR wrong	Difference
All first-year chemistry students	197	6.39 (1.79)	2.65 (1.61)	3.74 (2.79)	6.54 (1.69)	2.45 (1.76)	4.09 (2.63)
Students with a maximum of 2 errors in both tests*	75 (38.1%)	7.00 (1.72)	1.20 (0.81)	5.80 (2.10)	6.96 (1.61)	0.96 (0.83)	6.00 (1.91)
Remaining students (with 3 or more errors in one or both tests*)	122 (61.9%)	6.02 (1.74)	3.54 (1.30)	2.47 (2.38)	6.28 (1.69)	3.37 (1.54)	2.90 (2.30)

* Chemical phenomena / Chemical reactions.

TABLE 6. *Mean achievement levels of first-year chemistry students in identifying chemical phenomena (CP) and chemical reactions (CR) (maximum correct: 10).*

	N	CP correct	CP wrong	Difference	CR correct	CR wrong	Difference
All first-year chemistry students	77	7.62 (1.83)	2.85 (1.96)	4.77 (3.03)	7.83 (1.67)	2.48 (1.82)	5.35 (2.66)
Students with a maximum of 2 errors in both tests*	34 (44.2%)	8.24 (1.58)	1.12 (0.69)	7.12 (1.68)	8.44 (1.37)	1.12 (0.77)	7.32 (1.63)
Remaining students (with 3 or more errors in one or both tests*)	43 (55.8%)	7.14 (1.88)	4.23 (1.48)	2.91 (2.51)	7.35 (1.74)	3.56 (1.69)	3.79 (2.26)

* Chemical phenomena / Chemical reactions.

Chemical phenomena that cause difficulties

Table 7 has the proportions of students (expressed as percentages) who categorised wrongly various CP as PP. (Alternative data are included in Table 11: percentages of students who failed to categorise the various CP as CP.) 'Boiling' of an egg and an apple ripening were in the lead of failures (both with over 55% failures), with tree's leaves decaying coming

TABLE 7. *First-year chemistry students: Percentages of students who categorised WRONGLY various chemical phenomena as physical phenomena.*

	All first-year chemistry students	Students with a maximum of 2 errors	Students with 3 or more errors
	N = 77	*N* = 47	*N* = 30
'Boiling' of an egg	58.4	48.9	73.3
An apple ripening	55.8	29.8	96.7
A tree's leaves decaying	35.1	6.4	80.0
Meat being cooked (burnt) in the oven	24.7	4.3	56.7
A nail rusting	16.9	0.0	43.3
Milk turning sour	11.7	2.1	26.7
Lemon juice acting on marble	5.2	0.0	13.3
Wood burning	5.2	0.0	10.0
Grape juice becoming wine	3.9	2.1	6.7
Chlorine bleaching a dress	1.3	0.0	3.3

in third place (35%). The corresponding figures for the students with 3 or more errors are very bad: 73, 97, and 80% (contrast the last figure for tree's leaves with that of students with up to 2 errors: 6.4%). At the other end, lemon juice acting on marble, wood burning, grape juice becoming wine, and chlorine bleaching a dress caused no serious problems. In the middle lie: meat being cooked, a nail rusting, and milk turning sour, which proved very easy for good students, but considerably harder for the weak students.

The non-problematic cases shed light on the causes of difficulties that students experience in distinguishing very involved chemical process, such as cooking of food, ripening of fruit, etc. The action of lemon juice can be interpreted as action of an acid on a salt (calcium carbonate); wood burning is connected with organic combustion reactions; and grape juice becoming wine has a chemical equation associated with it. The case then might be that a number of students may intuitively view CP as processes that are fairly simple (and can be expressed by means of chemical equations).

Chemical phenomena versus chemical reactions: Patterns of students' approaches

Tables 8 and 9 contain the results for the tenth-grade and the chemistry students respectively. Performance is judged through the difference *D* of number of correct items of chemical phenomena minus number of correct items of chemical reactions.

Students fall into two distinct groups. One group includes those (75.7% for high school, 72.8% for university) who in most of the examples failed to identify CP with CR, while the other group includes those (24.4% / 27.3%) who identified CP and CR. Further, the students of the first group fall into two subgroups:

I. those (44.2% / 46.8%) who had more successes in recognizing examples of CR; for these students, there were examples of CR which they failed to see as also CP;
II. those (31.5% / 26.0%) who had more successes in recognizing examples of CP; for these students, there were examples of CP which they did not recognize as CR also.

We observe that the emerging pattern is the same for both high school and university students. In all cases, university students had higher achievement levels than high school students, and this is reasonable. What is, however, more interesting is the fact that

TABLE 8. *Mean achievement levels of tenth-grade students in the tests on physical and chemical phenomena (CP) and on chemical reactions (CR).**

	N	CP	CR	*D*	*t* statistic
All grade-10 students	197	3.74 (2.79)	4.09 (2.63)	-0.35	-1.28 (p = 0.200)
Students with higher performance in CR	87 (44.2%)	2.70 (2.72)	5.00 (2.30)	-2.30	-6.02 (p = 0.000)
Students with higher performance in CP	62 (31.5%)	4.94 (2.60)	2.82 (2.69)	2.11	4.45 (p = 0.005)
Students with equal performance in CP & CR	48 (24.4%)	4.06 (2.47)	4.06 (2.47)	0.00	0.00 (p = 1.000)
Students with a maximum of two errors in both parts of the test	75 (38.1%)	5.80 (2.10)	6.00 (1.91)	-0.20	-0.61 (p = 0.543)
Remaining students (with 3 or more errors in one or both tests**)	122 (61.9%)	2.47 (2.38)	2.90 (2.30)	-0.43	-1.57 (p = 0.117)

* Performance is judged through the difference *D* of number of correct items of chemical phenomena minus number of correct items of chemical reactions. Standard deviations are given in parentheses, under CP and CR.
** Chemical phenomena / chemical reactions.

TABLE 9. *Mean achievement levels of first-year chemistry students.**

	N	CP	CR	*D*	*t* statistic
All first-year chemistry students	77	4.74 (3.04)	5.35 (2.66)	-0.61	-1.32 (p = 0.187)
Students with higher performance in CR	36 (46.8%)	2.81 (2.65)	5.39 (2.70)	-2.58	-4.10 (p = 0.000)
Students with higher performance in CP	20 (26.0%)	5.60 (2.26)	4.05 (2.35)	1.55	2.13 (p = 0.04)
Students with equal performance in CP & CR	21 (27.3%)	6.90 (2.23)	6.90 (2.23)	0.00	0.00 (p = 1.000)
Students with a maximum of two errors in both tests	34 (44.2%)	7.12 (1.68)	7.32 (1.63)	-0.21	-0.61 (p = 0.543)
Remaining students (with 3 or more errors in one or both tests**)	43 (55.8%)	2.91 (2.51)	3.79 (2.26)	-0.88	-1.71 (p = 0.090)

*, ** See footnotes to Table 8.

achievement in the various groups and subgroups is not much different between university and high school, that is, the observed grouping persists in university. Remarkable also is the fact that the students who achieved higher in the CR than the CP outnumber those who achieved the other way round.

Searching further the pattern

Table 10 gives further data about the wrong categorisation of the PP studied as CE and/or CR. All data refer to the sample of first-year chemistry students. In agreement with the general pattern that the students who achieved higher in the CR than the CP outnumber those who achieved the other way round, we observe that in all particular cases, more students

TABLE 10. *First-year chemistry students: Percentages of students who WRONGLY assumed that various physical phenomena are chemical or that chemical reaction(s) occur in them.*

	All first-year chemistry students		Students with a maximum of 2 errors*		Students with 3 or more errors*	
	$N = 77$		$N = 34$		$N = 43$	
	CP	CR	CP	CR	CP	CR
Beer frothing	64.9	58.4	38.3	38.3	86.1	74.4
Eau de cologne evaporating	44.2	39.0	23.5	14.7	60.5	58.2
Salt being added to soup	41.6	28.6	20.6	14.7	58.1	39.5
Water boiling	36.4	31.2	11.8	14.7	55.8	44.2
Sugar being added to tea	33.8	29.9	8.8	11.8	53.5	44.2
Wax melting	28.6	27.3	2.9	8.8	48.9	41.9
Water freezing	28.6	26.0	5.8	5.8	46.5	41.9
A breaking glass	3.9	0.0	0.0	0.0	7.0	0.0
A falling stone	0.0	0.0	0.0	0.0	0.0	0.0
None**	3.9	3.9	8.8	8.8	0.0	0.0

* In both tests: Chemical phenomena / Chemical reactions.

** Three students who did not make any such errors are categorised here.

chose the various PP as CP than as CR. The problems appearing are the same as those discussed in connection with PP. We argued above that many students may intuitively view CP as processes that are fairly simple (and can be expressed by means of chemical equations). In addition, there are some students who assume that CR are simple processes, expressed by means of chemical equations. This ties in with the comment by one interviewee who associated the writing of equations as a characteristic of CR (as opposed to CP) (see below).

Table 11 gives detailed data about the proportion of the chemistry students in our sample who failed to identify the various chemical phenomena and chemical reactions in the lists. It follows from the Table that we can group CP into two broad groups. The first group involves natural phenomena, such as: ripening of fruit, trees' leaves decaying, rusting of iron, milk turning sour. The second group includes man-caused processes, such as: cooking of food, action of acids, burning of organic matter, action of chemicals such as chlorine bleach. (The fermentation of grape juice can be considered as both a natural and a man-caused process.) The interference of everyday language is in operation here: recall that in colloquial Greek 'physical phenomenon' means 'natural phenomenon'. Our data seem to support this argument. In all items with natural phenomena, we had more students omitting them from the list of CP than from the list of CR. On the other hand, the items dealing with man-caused CP do not show a clear-cut pattern: for some ('boiling' of egg, action of chlorine bleach) we had more students omitting them from the list of CR, while for the others (meat cooked/burnt, lemon juice acting on marble, wood burning, fermentation of grape juice) we had no difference. The association of the term 'chemical' with human activity may also play a role.

Apart from the natural versus man-caused processes (which may be idiosyncratic of the Greek students), few criteria seem to apply that cause the consideration of a change as CP but not as CR or the other way around. As we argued above, one such criterion might be that CR are simple processes, expressed by means of chemical equations. This may then induce them to reserve the term CP or 'chemical change' or 'chemical process' for those chemical events that they cannot describe by means of straightforward reactions.

Finally, we will consider a number of students' papers, which demonstrate to the

TABLE 11. *First-year chemistry students: Percentages of students who FAILED to identify the various chemical phenomena and chemical reactions.*

	All first-year chemistry students		Students with a maximum of 2 errors*		Students with 3 or more errors*	
	N = 77		*N* = 34		*N* = 43	
	CP	CR	CP	CR	CP	CR
‘Boiling’ of an egg	62.3	81.8	64.7	70.6	60.5	90.7
An apple ripening	57.1	46.8	44.1	32.4	67.4	58.1
A tree’s leaves decaying	36.4	24.7	17.6	8.8	51.2	37.2
Meat being cooked (burnt) in the oven	27.3	27.3	17.6	26.5	34.9	27.9
A nail rusting	16.9	5.2	5.9	0.0	25.6	9.3
Milk turning sour	10.4	2.6	2.9	0.0	16.3	4.7
Lemon juice acting on marble	9.1	9.1	8.8	5.9	9.3	11.6
Wood burning	7.8	6.5	2.9	2.9	11.6	9.3
Chlorine bleaching a dress	5.2	9.1	8.8	5.9	2.3	11.6
Grape juice becoming wine	3.9	3.9	2.9	2.9	4.7	4.7

* In both tests: Chemical phenomena / Chemical reactions.

extreme some of the problems involved. A chemistry student had spotted all CP and all but one (action of lemon juice on marble) CR; on the other hand, while the student had only one failure with CP (beer), he had included seven of the nine PP (leaving out only the falling stone and the breaking glass) as involving CR. The opposite picture emerged from the answers of two other chemistry students. While they included nearly all CP/CR, and at the same time had not included any PP as involving a CR, they assumed a number of PP as CP: one student included seven PP (the same as the previous student); the other student four PP (beer frothing, sugar dissolving in tea, salt dissolving in soup, and wax melting). A high school student had only three correct choices (chlorine bleach, ‘boiling’ egg, fermentation of grape juice) of CP, but all ten CR. Another high school student had included six PP in the list of CP, but only one (eau de cologne) in her list of CR. Finally, another high school student had five successes and five failures in his list of CP, but nine successes and no failures in his list of CR.

Findings from the interviews

One student assumed that CP and CR are different in that "*for CR we also write chemical equations*". In this spirit, boiling of water is assumed rightly as a PP, but wrongly as CR, "*since we right down a chemical equation for boiling* [$H_2O(l) \rightarrow H_2O(g)$].” The same student assumed that CP cannot be reversed, while CR can.

Many students take the evolution of a gas and frothing as indicators of chemical reaction(s). For instance, in the case of evaporation of eau de cologne, a student assumed that "*vapour is the result of a CR*". Further, “*when we remove the cap of the bottle [containing eau de cologne], its composition changes, and then it evaporates*”. In the case of the frothing of beer, the same student suggested that "*alcohol comes into contact with the air, and this caused frothing*". The student stated that she did not know that the froth contains carbon dioxide. Another student, who stated that «the froth did not exist before opening the bottle», invoked similar reasoning. On the other hand, another student did not accept that a gas was involved in the froth.

Two students who had assumed that chemical reactions occur in the case of evaporation of eau de cologne (one student) and of boiling of water (both students) justified it by stating that "*a reaction occurs in the case of change of physical state*". On the other hand, "*no reaction was assumed in the case of freezing of water*" (where no evolution of gas occurs).

Another student accepted frothing of beer as both CP and CR, with the justification that "*it was the froth that led me to think of reaction, precisely as in carbonic acid in beverages* ($H_2CO_3 \rightarrow CO_2 + H_2O$)". For the same phenomenon, another student thought that "*during frothing, hydrogen gas could be evolved too*". The same student considered that "*CR are made to happen by man*."

It must be added that some students justified their errors by invoking hastiness or carelessness ("it was stupid of me!").

CONCLUSIONS AND IMPLICATIONS

This work has added evidence that demonstrates that problems exist in connection with the concepts of physical and chemical phenomena/changes, as well as of chemical reactions.

A number of students do not always identify chemical phenomena with reaction(s). One cause may be the differentiation of chemical changes into natural and man-caused processes, which seem to be operating, at least with Greek students. On the other hand, students may be intuitively viewing chemical reactions as fairly simple processes, which can be expressed by means of chemical equations.

Two concepts that need attention are (i) changes of physical state and/or phase, and (ii) solutions. According to Gensler (1970), the idea of a physical state or phase change as 'physical' change, based on the identity of 'chemical composition', is problematic: it is either the beginning of "an unproductive circular argument" or "forces the introduction of terms that at this [beginning] stage have little meaning". Even from a more sophisticated point of view (in terms of changes in intermolececular 'chemical' bonding), it is not clear why such changes are non-chemical. Differentiation between inter- and intramolecular bonding can pose problems too (Gensler, 1970). The process of solvation, or its converse, crystallisation from solution, also involves changes in 'chemical' bonding between submicroscopic particles (Gensler, 1970). Even the non-problematic physical changes of breaking or deforming a solid have chemical connections (Gensler, 1970; Jensen, 1998).

Though understanding of chemistry at the submicroscopic level (molecules, atoms) is a prerequisite for a clearer understanding and distinction of the various changes, it is argued that this understanding is very demanding, so the problems will persist for beginning chemistry students. Jensen (1998) attributes the inability of chemists to get right the distinction between chemical and physical changes after over 200 years of practice to the dramatic change of our level of description of chemistry from the molar to the molecular, and finally, to the electrical level.

In conclusion, we propose that the terms physical and chemical phenomena should not be used any longer. The terms physical and chemical change may be preferable, but they pose problems too. According to Gensler (1970), the distinction between 'physical' and 'chemical' processes involve "concepts of model systems, submicroscopic particles, interatomic bonds, intermolecular bonds, etc. whose understanding and appreciation call for more than a few introductory pages in a general chemistry text". He then goes on to propose that "we should leave the distinction out altogether".

Understanding and identifying chemical changes presupposes the acquisition of the 'chemical reaction' concept. This in turn presupposes understanding of the 'chemical substance' concept (Stavridou & Solomonidou, 1998; Johnson, 2000). We stress the need for the proper understanding of this concept at the macroscopic, experimental level. At the same level should and can be introduced the concept of chemical reaction (Strong, 1970; De Vos & Verdonk, 1985). The concepts of 'substance' and of 'reaction' can and should form the basis for a definition of the science of chemistry, which seems/is essential to begin a chemistry course: the study of substances and their properties, with at the centre the interaction of substances that lead to formation of other substances (chemical reactions). One should also bear in mind that, as a rule, chemical changes/chemical reactions are accompanied by physical changes too. Finally, there are a number of processes and properties (such as changes of state/phase, and solvation) that "do not exhibit all the features that are central to chemical systems", but are of central interest to chemists too (Strong, 1970). The latter changes are sometimes termed 'physicochemical' (see also Nelson, 2003).

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