LIVING WITH PRECONCEPTIONS. DOES MORE TEACHING AND LAB EXPERIMENTING HELP TO IMPROVE CHEMICAL PRINCIPLES ASSIMILATION?

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Abstract

A survey is carried out on first year students of Science Departments at a Greek university, in relation to knowledge of basic chemical principles, following a semester of lectures and tutorials within the General Chemistry class. The findings attempt to correlate the assimilation of information with the curriculum adopted by the school of study and the intensity of teaching both in lecture hours and in laboratory experiments carried out.

Key words: *chemical principles, university students, curriculum, preconceptions*

1. INTRODUCTION

As a follow up to our recent studies concerning the chemistry related misconceptions in the Greek high-school regarding their retention factors as well as their origin (Katsikis et al 2015, Vandoulaki et al 2016), we went on investigating the extent of preservation of such ideas at the higher level of education focusing on the period just after the initial semester which includes additional teaching and laboratory practice on specific topics related to the content of the introductory General Chemistry course.

In recent decades, we have established contact with a number of first year students who are required to study Chemistry to varying degrees, depending on their course objectives and the relative education they receive in the General Chemistry class taught during their first semester of study.

Chemistry and Geology departments require an introductory class in Chemistry, however the demands are slightly different as for the Chemistry students this forms a sort of basis for their future studies while it will be useful mainly as a prerequisite for the Geochemistry class to follow at a later stage in the Geology department curriculum.

It is generally accepted that students, even at an early age, try to modify aspects of science courses in order avoid contradiction with their previous ideas and perceptions rather than the opposite. Additionally, it is well documented that the task of conceptual change is never going to be easy, since such preconceptions have often been safely integrated into the cognitive structure at a relatively young age (Driver & Easley 1978, Gunstone et al., 1981). Intense and elaborate teaching at the level of primary and secondary education, which depends partly on the teacher's personality and the receptiveness of the young student and partly on the available textbooks and on the construction of the science educational program, can help towards drifting the early "Alternative ideas" into a group consisting mainly of scientifically accepted ideas and secondarily of persistent "preconceptions". These preconceptions are much more difficult to be dealt with, especially at a later age, since it has been argued and to a great extent proved that, in many cases, the time and the amount of teaching a particular subject do not provoke substantial advances (Ahtee & Varjola 1998, Bodner 1991), because the previous inherent models are going to be sustained and at the most, it will be possible to admit recently acquired facts into a self-made and self-explanatory model based on the existing preconceptions.

Students' conceptions which are generally different from the ones generally accepted by the scientific community can be assessed either by individual interviews or by questionnaires. Some multiple choice tests were related to specified and limited content structure. The multiple choices may be constructed

either to focus on a specific topic or to span over a wide range of subjects covering the breadth of a course (Treagust 1988). The construction of multiple choice test items is expected to contain a variety of distracters, which must not all be obvious to avoid. The best option for these distracters is to be built on the answers previously received by the students to essay questions and other open-ended questions and have dealt with the underlying conceptual knowledge about a limited range of content, in this case pH. Ideally, each multiple choice item could be followed by additional space for the reasoning provided by the student for the selection made in the previous question. Such ideas have already been advanced since the 1980s (Osborne 1980, Driver 1984). Of course, taking into account the implication resulting from the reluctance of Greek students to undertake the task of providing lengthy answers, this is not always possible; however we tried to use interconnected questions so as to check at least for the sustainability of lines of thought expressed through the answer to previous questions.

1.1 The Greek secondary educational system

At present, Greek students of ages between 12 and 18, are expected to attend consecutively three grades of Gymnasio (junior high-school) and three grades of Lyceio (senior high-school), before being eligible to attempt following an undergraduate course at some Higher level Education Institute through succeeding in an entrance examination. Junior high school constitutes a part of the compulsory educational program while up to the first grade of senior high school the curriculum is common for all students. The last two grades of senior high school provide the means by which the specific abilities of the students are tested and their intentions for undergraduate university studies are promoted accordingly. Admittance to higher education institutes is achieved through nationwide examinations following the end of the third and final grade at senior high school. For Science departments, exams must be taken on Essay, Physics, Chemistry and Mathematics and for the university departments considered in the present study, the lowest acceptable average in the written exams were 78.5% for Chemistry and 72.5% for Geology.

1.2 First year university studies involving General Chemistry

There are several undergraduate courses which require some introductory Chemistry classes, in most of the cases including a series of tutorials and light to medium complexity laboratory experiments. Among them, Chemistry is a demanding one, since its curriculum consists of several 3-hour laboratory periods, two of which are devoted to weak electrolytes and pH measurements, while an additional one is related to redox reactions. Both during the pre-lab introduction and in some of the traditional lectures, reference is made of the equilibrium in general, the equilibria related to the dissociation (practically hydrolysis) of weak electrolytes, to the simplification of using proton instead of hydronium ion and experiments are carried out for the determination of the dissociation constant, either as K_a or pK_a, of a weak acid (acetic acid) via either the measurement of the pH of successively more diluted solutions of the acid or of a series of buffer solutions with sodium acetate, in the course of which the theory and equations about buffers is explained. Furthermore, redox reactions are considered and studied in relation to their spontaneous character and besides revisiting the topic of writing a balanced redox reaction, including discussion of formal oxidation numbers, a metal reactivity series is constructed in a qualitative way by reacting metal foils with different aqueous salts. The curriculum for the Geology department consists of 2-hour laboratory periods, three of which are devoted to weak electrolytes and pH measurements. Indicators and their applications both individually and in the form of universal indicator are discussed, and theory and pH measurements related to buffer solutions and to the hydrolysis procedures in aqueous media are discussed and measurements made utilizing electric pH meters. Types of reactions and ways to identify them, homogeneous and heterogeneous equilibria principles as well as basic redox reactions, are also experimented upon.

2. DESCRIPTION OF THE STUDY

We carried out a survey on a wide variety of topics covered during the first semester of studies, both at the lecture hall and in the laboratory. The data presented and discussed in the manuscript were obtained in the opening semester of the 2016-17 academic year. The small sample size may preclude a straightforward generalization of the findings and the conclusions, however it can offer great insight into student alternative conceptions and how they can evolve over time in response to instruction (Horton 2007).

The topics investigated are common to all curriculae studied and also to have some connection with topics presented in the secondary school curriculum. Furthermore, we wanted to verify whether actual laboratory work plays a role in formulating new ideas or modifying existing ones.

The questionnaire constructed included mainly closed type questions since it has been established by previous investigations that the students in general avoid taking time to give lengthy descriptions even when it is evident that they can do so as inferred by their answers to related subjects presented in the form of yes-no or true-false type answers that only need checking the appropriate box. However, due to the fact that the topics of equilibrium and pH are related to concentration and to its special meaning and way of formulation and interpretation, questions requiring short discussion as well as ones that rely on the application of simple math skills. Subject consists of students attending Chemistry (n=34) and Geology departments (n=19) to both of which General Chemistry, including basic thermodynamics, equilibria in aqueous solutions, pH definition and measurement are taught. The first year students enter the schools following examinations taken on several topics, including Chemistry at the high school level, where the above topics are also taught to some extent.

A parameter for the study along with student sex (Cousins 2007, Zeyer & Wolf 2010) and type of high school of attended, in our opinion reflecting a mixture of socio-economic background of the students (Gorard & See 2009). Since the starting point is crucial for every achievement, we organized a couple of related tests, the first of which was taken during the introductory lesson in every course so as to precede any kind of teaching at the higher education level, and the second during the last period of tutorials, approximately a week or so from the termination of the teaching in the first semester.

3. RESULTS AND DISCUSSION

An overall study of the achievements is as follows: To the initial test taken just prior to any teaching at university level, Chemistry students averaged a 12.58 score on the 0-20 scale which is the one adopted throughout secondary education, i.e. an 62.9% assimilation of chemical concepts with a standard deviation of 1.92. In comparison, the preliminary test for the Geology students revealed an average score of 12.32 with a standard deviation of 2.40, indicating an overall assimilation of chemical principles of 61.6%, indicating that the two groups of students are originating from the same population, which is true since now they share a common background as of the extent to which Chemistry has been taught to them at senior high-school (not so until recently, see Katsikis et al 2017). This compares with the 42.0% observed in our recent study on secondary education students with a science orientation in their studies (Katsikis et al 2015, Vandoulaki et al 2016). Of course the current sample consists of the group of these students who succeeded in their entrance examinations and is expected to be higher than that of the whole group at the second of three years senior high school. Slightly encouraging for our efforts as teachers is the average of 13.89 of the same group of Chemistry students after a semester of teaching with a 2.75 standard deviation. For Geology students however, a considerable drop was observed in the motivation to study and understand chemical principles since their average achievement was evaluated as 7.40 with a standard deviation of 2.28. It should be noted at this point that the final test included two graph-based questions, which pose problems to Greek students because they are not extensively introduced into reading and understanding graphs; in the initial test there was only one such question. On average, a 6.6% elevation of chemical concept understanding is recorded for young chemists with a few examples of backwards movement and a few of tremendous improvement (as much as 27%) while a net drop of 22.2% is observed for their

geologist counterparts where a single person revealed positive "shift" and two more attained approximately the same level of achievement in both tests.

3.1 Preliminary test

3.1.1 Atomic structure

The related concepts are presented in questions 1-4 in the test.

It is expected that the atomic number is the pivotal atomic property on which periodicity is founded and this is so well established in the high school textbooks that only a 5.9% of Chemistry students is distracted by the mass number or the exact atomic mass. The students also have an overall view of the periodic table since and even smaller percentage (2.9%) fails to recognize that the main groups of the periodic table include S and P blocks only. Geology students present identical results for the first question, however, an 11.4% of them believe that D block elements belong to the main groups of the periodic table.

Further, within the Chemistry students just one (2.9%) did not know how to work out the electronic structure of the three elements presented, in the form of $_{11}$Na, $_{13}$Al and $_{19}$K, one (2.9%) got them all wrong and an additional (5.9%) made an error for potassium. Interestingly enough, none of the Geology students got any error in the above question. However, only 44.1% of the Chemistry students were able to predict the trend in the atomic radius of the above three elements, leaving 32.4% to argue in favor of the traditional misconception of "larger x gives larger y". Interestingly enough, nobody neglected answering the question, something that points to the fact that the students are sure about their knowledge of the topic and in this respect it is questionable why and 11.8% o the total was partitioned between the other two answers provided. Again the Geology students appear to do better since 71.4% located the right answer and all the rest were distracted by the trend of the atomic number of the elements.

3.1.2 Reaction kinetics and equilibria

The related concepts are presented in questions 9 and 17-20 in the test.

In addressing the equilibrium understanding, the question was set to describe what is happening in a closed vessel where equilibrium has been reached, the answers being

- No reaction occurs
- Two opposing reactions with equal rates occur
- The moles of the reactants and products are equal
- All the above

The 72.9% of future chemists (74.3% of future geologists) giving the right answer is fine however there is a 8.8% that believes in equality in the strict sense and another 8.8% (20.0% geologists) believing that all the statements are correct.

Regarding specific chemical reactions, the example of the Fehling test was set forward, which explicitly described in the textbooks and the question was about its utility to discriminate between alcohols, aldehydes, ketones and acids, all given in pairs. Just 64.7% of the chemists (and 77.1% geologists) give the answer out of the textbook, 5.9% (and 5.7% respectively) believe that alcohols are involved and an equal to the above percentage favors the pair aldeyhes-acids, probably remembering that the acids are posed as the oxidation terminus at these reactions.

Concerning redox reactions and the related topics of oxidation numbers, two questions were presented, the first provided the balanced oxidation of copper by nitric acid where it was required to define the atoms reduced/oxidized as well as their initial and final oxidation states, while in the second, three redox reactions were given requiring balancing and definition of the oxidant substance. Once again

geologist appear to do slightly better than chemists since for the first question they provide the full correct answer at 80.0% contrary to 76.5% being also more certain of their knowledge since 11.4% of their number avoided answering the question relative to 14.7% of the chemists. The second question lies along the same line since the geologists are more confident (25.7% not answering relative to 35.3% of the chemists) and they give the right answer (31.4% relative to 20.6%).

It is apparent that in the teaching of Chemistry at probably all levels, some distinctions between Organic and Inorganic Chemistry are made even unconsciously. For example, Organic Chemistry classes at the university are loaded with mechanisms, elucidations, intermediate trapping etc whereas Inorganic Chemistry is more descriptive or more physical, depending on the curriculum construction. However, it is almost common ground for graduating chemists to believe that inorganic reactions do not involve any mechanism at all. Of course, this is also promoted by several laboratory experiments which are designed to give a compound rather easily and involve mainly spectroscopic and other methods of its characterization. This deficiency in intercalating the two branches of Chemistry is obvious in the well-known haloform reaction which is described within the senior high school curriculum. When the two generally accepted steps of the reaction are given and the students are required to describe them as synthesis, decomposition, redox or metathesis, 68.6% of the geologists and 61.8% of the chemists do not attempt to do so and only 8.6% and 20.6% respectively provide the correct answer to both steps. It is true, of course, that in the redox chapter of the textbook a lot is described about oxidants and reductants, almost solely being inorganic compounds and only sporadic reference is given to the formal oxidation numbers in organic compounds, i.e. of carbon in a series of simple compounds.

3.1.3 Kinetics and thermodynamics

The related concepts are presented in questions 10-14 in the preliminary test.

There is only a single notable exception to the understanding that a "reaction that evolves 150 kJ per mole of reactant A" is exothermic and not endothermic or does not require heating to proceed or that it will proceed until 150 kJ are evolved. However there seems to be an ambiguity about the characterization of this amount of heat evolved as enthalpy change (64.7% for chemists and 62.9% for geologists), chemical energy in general (5.9% for chemists and 5.7% for geologists) or internal energy change (2.9% for chemists and 2.8% for geologists) the rest of the population studied just checking "enthalpy" without remembering that the notation in the thermochemical description of reactions is in the form of ΔH.

At practically every point of an educational system congruity is sought between topics theoretically described in lectures and even experimentally checked on the laboratory bench with processes occurring in the natural environment, making the well-documented useful approach of the metaphor more accessible and more efficient for the teacher. To check the ability of the students to make such a connection with a known simple process, the question was put forward of why the flame blossoms once we poke the wood burning in a hearthstone. The distribution of the answers among the provided ones was observed to be as follows:

- The CO_2 produced is driven away (20.6% for chemistry and 28.6% for geology students)
- A suitable airstream is formed (17.6% for chemistry and 11.4% for geology students)
- The active surface between wood and air is enhanced (32.4% for chemistry and 20.0% for geology students)
- The kinetic energy of wood molecules is enhanced (17.6% for chemistry and 31.4% for geology students)

A number did not answer, 11.8% for chemistry and 8.6% for geology students respectively.

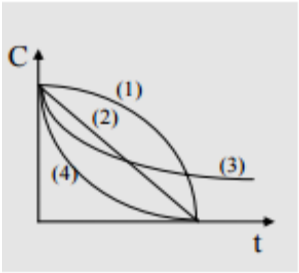
The formulation and results of the next related question are as follows:

The rate of the reaction $A + B \rightarrow C$ describes:

- The rate at which the mass of C increases (2.9% for chemists and 2.9% for geologists)
- The rate at which the moles of C increase (14.7% for chemists and 34.3% for geologists)
- The quotient of the change of the moles of a reactant or product versus the respective time period (11.8% for chemists and 11.4% for geologists)
- The absolute value of the rate of change of the concentration of a reactant or product (68.6% for chemists and 51.4% for geologists)

It is fairly obvious that a considerable percentage either is confusing mass with concentration or has read the question superficially, while it is notable that a 5.9% of the chemists failed to think of an appropriate answer to the question.

In an effort to exploit the extent to which Greek students are accustomed to reading and understanding graphs the following one was given and the question was asked about which of the lines represents the change of the concentration of the reactant in a reaction of the type A(g) → B(g).



82.4% of the chemistry students and 68.6% of their geology counterparts interpreted correctly the graph, while 8.8% and 5.7% respectively were misled by the general similarity of graphs 3 and 4 and probably drew on their background of studying equilibria in giving a wrong answer. In a scarce situation, nobody declined giving an answer which leaves a rather small percentage of students who seem to adopt the straightforward approach to the problems, i.e. supposing that the concentration of the reactant drops linearly with time following graph 2.

3.1.4 Solutions and electrolytes

The related concepts are presented in questions 5-8, 15, 16 and 22 of the test.

Basic understanding is required, even in departments where deep and/or wide knowledge of chemical principles is not required, of the composition and properties of specific solutions. The background knowledge of the students should be adequate enough for them to define the amount of water needed to prepare a 10% w/w given a quantity of 20 g sugar.

Nobody was so careless as to be distracted by the first provided choice of 20 g. The other possibilities are ranked in order of preference as follows:

200 g	70.6% (chemistry students)	77.1% (geology students)
180 g	17.6% (chemistry students)	17.1% (geology students)
100 g	2.9% (chemistry students)	2.9% (geology students)
80 g	2.9% (chemistry students)	0% (geology students)

Confused and therefore not providing any answer is a 5.8% and 2.9% respectively. It is obvious that the students in general have not been able to distinguish between solution and solvent.

Some of the tasks performed with solutions at high school involve the theoretical treatment of the dilution process. The concept is similar in its basic idea with that of condensation and in order to reveal the possibility of the students to identify this similarity we set up the problem dealing with a 40

mL solution of $NaNO_3$ with a concentration of 0.4 M which is boiled until 8 mL evaporate and we require the molarity of the resulting solution. Obviously there is a series of thoughts to be made such as that the inorganic compound will not evaporate and that its amount, given by the product volume x molarity should remain the same at the end of the process. The answers provided, besides the right one (58.8% for chemistry students and 54.3% for geology ones), were

0.80 M	8.8% (chemistry students)	0% (geology students)
0.44 M	8.8% (chemistry students)	8.6% (geology students)
0.55 M	8.8% (chemistry students)	5.7% (geology students)
0.10 M	5.9% (chemistry students)	2.9% (geology students)

8.8% of the chemistry students and 28.6% of the geology students failed to provide any answer.

A series of simple true-false questions followed stating that

- All acids possess H atoms
- Dissolving a covalent compound in H_2O causes its crystal lattice to decompose and form ions.
- Pure water does not possess electric conductivity.
- An aqueous solution with pH = 6 is acidic.
- An aqueous solution with pH = 6 is divided into three vessels; in each of them the solution has pH = 2.

Equal (38.2%) percentages of the two departments' students give wrong answer to the first question, 31.4% geology and 41.2% chemistry students are wrong in the second, 51.4% and 42.9% respectively are wrong in the third, only 22.9%and 8.8% get the wrong idea in the fourth, probably distracted by the non-temperature specific form of the statement, overlooking or forgetting the limits within which pure water pH may vary and finally 22.8% of geology students believe in the partition of the pH with the partition of the solution, therefore making it clear that they have not understood in principle that pH is related to concentration and not amount of hydronium (or the equivalent) ions. Very few were the cases where no answer was provided, in each case being just a single person and in this respect we may conclude that the population subjected to the study is particularly sure of their background on the subject.

A rather simple but tricky question was the one where it was required to make an estimate of the pH of aqueous HCl solutions at 25 °C, their concentrations given as 10^{-3} M, 10^{-6} M and 10^{-9} M. 31.4% of geology students were wrong in estimating the pH of the very dilute solution, for obvious reasons, while another 17.1% expressed their uncertainty by avoiding to answer, the corresponding percentages being 29.4% and 24.5% for chemistry students. Those who did not provide an answer may be categorized among those who have a basic understanding or average memorizing ability to conclude that a concentration of 10^{-9} M of H^+ would mean a solution with basic reaction, something contradictory to the use of an acid to prepare it but could not make the appropriate connection with the water autoionization process which is known. In our opinion and since the question was put as of "estimate" rather than "calculate" we considered as correct verbal answers of the type "water ionization must be taken into consideration" or "cannot be above 7".

An interesting topic provoking expected and unexpected responses to questions is related to the behavior of typical salts in aqueous solutions. A part of the traditional neutralization topic teaching, it is made clear at every level of teaching, that neutralization occurs when there exist in solution equal amounts of acid and base, or alternatively, that in the solution there are no acid or base entities but only salt. The examples presented, in almost all cases, involve a couple of strong electrolytes, since in that case the process can obviously be connected to macroscopically produced data, i.e. pH measurement. Almost globally and timeless in occurrence, the next topic taught involves the hydrolysis of various salts, in fact their majority, which makes the above generalization about neutralization almost obsolete, since in most cases the students are encouraged to work out

mathematical formulae in order to determine the pH value of a specific solution where no excess acid or base should be present. In line with the above general observations a rather simple question was put forward in the form of requesting the identity of an aqueous solution at 25 °C which is acidic in nature and may contain NaCl, NaClO, NH_4NO_3 or NH_3 respectively. Only 10.5% of geology students, and, interestingly enough 14,5% of chemistry students were confused by the presence of ClO^- in the corresponding sodium salt, probably believing it stood for Cl^-, while all the rest gave the right answer.

Finally, concerning inorganic compound nomenclature, which again is a subject not taught to extend contrary to the several hours provided for the basic organic compounds nomenclature, when the question was set to name the four compounds appearing in a previous question, almost everybody (a single person in either group did not answer this question, a mere 2.9%) identified ammonia (NH_3), sodium chloride (NaCl), ammonium nitrate (NH_4NO_3) but 77.1% of the geologists and 64.7% of the chemists were not able to provide a name for NaClO although it is a compound referred to in relation to redox reactions.

3.2 Final test

3.2.1 Atomic structure and periodic properties

The relevant questions are 1, 2, 12 and 16.

In the introductory question requires the electronic configuration of three elements, namely $_{12}Mg$, $_{20}Ca$ and $_{30}Zn$. A single member from each department did not attempt to answer the question, both being girls. All the rest were able to give the right answer. This is considered an advance relative to the knowledge of constructing atomic configurations since at high school the rules and exceptions are applied only to atoms with Z as high as 20. However, when required to assign reported ionization energies (given in eV) to the above atoms, only 10.5 and 8.8% of the geology and chemistry students respectively were completely right, while another 5.3 and 8.8% failed to provide any answer at all. Having this result at hand, we did not expect large percentages in the question where reasoning for the above answer was requested. 63.2% geologist gave no answer and the rest provided irrelevant ones, while interestingly enough, 35.3% of chemistry students gave the right reasoning and 41.2% failed to produce an answer, which is puzzling in view of the great failure in the previous question. This important finding can only be related to the failure to recognize that two of the given elements belong to the same period and this reflects a misunderstanding in the construction of the periodic table and the definition of valence shell in a form different from the traditionally discussed in high school textbooks (described in the form of K,L,M… rather than 1s,2s2p,…). Seeking further evidence for the understanding of periodic table construction we proposed a mini-problem in which bond distances and bond energies are intercalated, in the form of "For the molecules Cl_2, Br_2 and I_2 dissociation energies and bond distances were collected from differing bibliographic sources. The values are, at random order, 228 pm, 198 pm, 267 pm, 150 kJ/mol, 232 kJ/mol and 185 kJ/mol. Pair them in the right way".

For geology students 5.3% gave completely wrong pairing and another 5.3% succeeded whereas 52.6% failed to provide any answer at all. For chemistry students the corresponding percentages are 50.0%, 2.9% and 47.1%. This leaves us wondering why several geology students attempted only in part to give some correlation between the two observables.

3.2.2 Reaction equilibria and kinetics

The relevant questions are 5, 6, 17 and 18.

The first question of this group consisted of several true-false statements as follows: In every case we report the right answer and no answer percentage for geology and chemistry students respectively, in parenthesis.

- Equilibrium is a static state since there is no change in masses of the reactants or the products (63.2%, 21.1% – 29.4%, 2.9%).

- Equilibrium is dynamic, reaction are occurring towards both directions (78.9%, 21.1% – 100%, 0%)

It appears that the traditional "stick to the theory" process which is adopted continuously and extensively in the Greek educational system pays back in such cases where the citation of a passage of the textbook is made or repetition of a definition is required. In this respect the general failure to the previous question has to be ascribed to a cause-effect mixing up which is commonplace in several cases. We are driven to the assumption that the students believe that the achievement of a set reactant or product mass drives the equilibrium at a halt point and therefore did not read and did not comprehend the question in the way they were supposed to do.

- At equilibrium the moles of reactants and products are equal (52.6%, 21.1% – 76.5%, 5.9%).

About 20% of the students adopt the common misconception that when referring to an "in between" position this has to be exactly halfway between the extremes. In the laboratory lectures at least, mention is made to the equilibrium position which has to be where it is predicted to be following the equilibrium constant determination and given some initial state of the reaction. Of course, in most cases the simplest example discussed is the oversimplified and generalized A + B $\rightleftharpoons$ C + D and the most common starting position is one where equimolar amounts of the two reactants are brought under reaction conditions, therefore playing an important role in retaining the "in between" preconception.

- Equilibrium represents the most stable state for the reactant-product system (31.6%, 36.8% – 85.3%, 5.9%).

The thermodynamics part of the course is not taught to a great extent in either curriculum since a full semester of thermodynamics will follow, however the basic ideas are described, the key definitions and formulae given and the relation of ΔG° with K, the reaction equilibrium constant is presented.

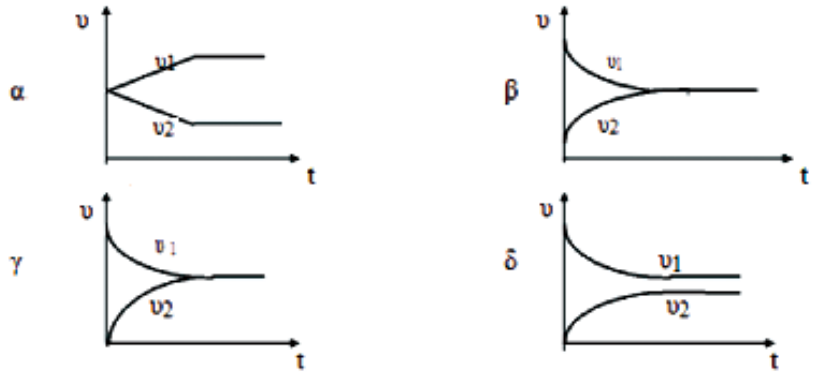
- At equilibrium the moles of reactants and products can be calculated from the value of the equilibrium constant K of the reaction (5.3%, 26.3% – 76.5%, 0%).

The significant reluctance of geology students to answer the above set of questions, relative to the chemistry students make it difficult to accept the percentages of correct answers as being true and only point at a need for a better presentation of the equilibrium topic during the lectures and possibly laboratory experimentation.

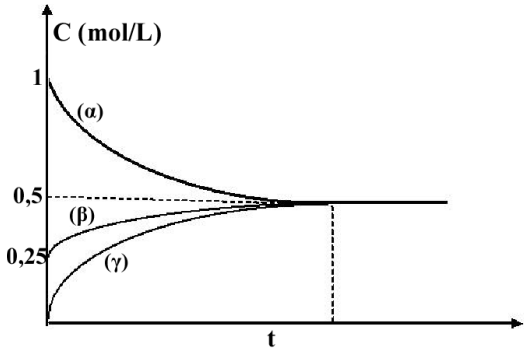
A tricky question was set in the form of "For a reaction A + B $\rightleftharpoons$ C + D, done stoicheiometrically, the equilibrium constant was found to be equal to 1. What is the yield of the reaction?". Although this is the traditionally discussed general form of a reaction, students are instructed to care about the stoicheiometry and to form the quotient for a reaction before trying to get insight into its equilibrium state or not. None of the geology students gave the right answer, 42.1% failing to answer altogether. Just one (2.9% overall) chemist gave wrong answer and another 17.6% did not answer the question confirming again that there is really a better assimilation of the related concepts among them.

In a diagrammatic question quantities of two reactants were supposed to be placed in a previously empty vessel whereupon the reaction A(g) + B(g) $\rightleftharpoons$ C(g) + D(g) occurred. In the four diagrams given the students were asked to identify the one representing the trajectories of the two reactions' rates, defines as u_1 to the right and u_2 to the left respectively.

None of the geologists was distracted by the last graph indicating that probably they understand that at equilibrium the two reactions possess identical values, however one (5.3%) gave the first answer probably driven by the fact that the two reactions are described or understood as opposing each other. Another 10.6% most probably did not have a closer look at the second graph, believing that the trajectory of u_2 has a zero starting point. Three chemists (8.8%) were distracted by the convergence of the two trajectories in the final graph and none from the first one and just one (2.9%) from the second one.



In the final question of the test the following graph was presented with the description that accompanies it:



In a 2 L vessel the equilibrium described by the reaction $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$, $\Delta H > 0$ has been reached. The diagram shows the change of the concentrations of the three gases involved.

The questions put forward were:

- Identify the graph for the concentration change of each compound.
- How many moles of each compound were introduced initially into the vessel.
- Calculate the value of the equilibrium constant of the reaction.
- To which way would the equilibrium shift upon heating the vessel.

Although the last question is merely a copy-paste answer derived from the theory about equilibria, 26.3% of geology students gave the wrong answer and another 52.6% did not provide an answer at all, while still substantial but considerably lower percentages of 5.9% and 41.2% were obtained for chemistry students. Equally straightforward is the third question given the apparent equilibrium concentrations and the stoicheiometry of the reaction, however 5.3% of wrong answers and 57.9% of non-answers were collected from the geology questionnaires relative to 20.6% and 47.1% from the chemistry ones.

Totally unexpected was the null wrong answers provided for the first question, since it involves a series of calculations and reasoning, accompanied by 36.8% and 14.7% percentages for non-answers for students of the two departments. However, and since it was not required to present the calculations performed, we cannot be very optimistic about the above results as the percentages avoiding answer to the second question, which is a simple algebraic treatment of the numbers provided in the graph and furthermore directly related to the first answer, rise to 52.6% and 47.1% respectively.

3.2.3 Solutions and electrolytes

Questions 3, 4, 7, 10, 11 comprise this essential part of the test. It starts with the reaction

$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$ for which the Brønsted acids and bases are to be identified.

As expected, the memory control of the students works perfectly and complete success was recorded.

A question similar but a little more demanding than an analogous one in the preliminary test required the sorting of 1 M solutions of NaCl, HCl, NH_4NO_3, NH_3 and CH_3COONa in order of increasing pH.

Difficulties start appearing at this point since 21.1% of the geology students provided wrong sorting and 26.3% none, while only one (2.9%) of the chemistry students failed to provide an answer and the rest were right.

Given that in the laboratory work is done with weak electrolytes it seemed reasonable to inquire about the change in the pH value of an acid solution at 25 °C which has an initial value of 4 and is diluted tenfold with water, the answers provided being 3, 5, 4, between 3 and 4 and between 4 and 5.

Just 10.5% of the geologists took into consideration that the acid is not identified as strong or weak and projected to their answer the known change of the pH of weak acid solutions. Fortunately and happily for us, none checked the first answer but the vast majority was distributed among the other answers. Among the chemists 29.4% gave wrong answers, again nobody checking the first one.

Hydrolysis reactions in aqueous salt solutions take a considerable part of the laboratory and therefore it was expected to be reasonable to inquire as of which are the reactions occurring in aqueous solutions of NH_4NO_3 and CH_3COONa.

21.1% geologists neglected answering and 42.1% gave wrong equations, the corresponding percentages for chemists being 2.9% and 11.8%.

Finally a more demanding question was put forward describing the reaction of 80 mL of a 0.25 M HA solution with 50 mL of a 0.5M NaOH solution. The data given was that the reaction released 3,2 kJ and requested was the constitution of the final solution and the calculation of the ΔH value for the neutralization reaction.

None of the geologists gave the right answer and 63.2% did not attempt to do so, while 42.1% of the chemists avoided working out or did not come to a result of the problem and only 8.8% were correct in their predictions.

3.2.4 Thermochemistry and electrochemistry

Relevant questions are 8, 9, 13, 14 and 15.

Quite similar to the initial test, the role of Cu in the reaction $2Cu + O_2 \rightarrow 2CuO$ was requested, and 15.8% geology and 5.9% chemistry students are not sure what the answer should be while 5.3% and 8.8% believe it is reduced or acts as oxidant and fortunately everybody recognized the reaction as a redox one avoiding the last offered answer of “is not oxidized”.

Then the negative charge of Cl in HCl had to be interpreted in terms of: ability to attract an electron, possession of a -1 net charge, being more electronegative than H, possession of oxidation number -1 in all its compounds.

Of course, one of the cornerstones of teaching oxidation numbers is the memorizing of some standard numbers as +1 for H and -1 for the halogens and in this respect the 78.9% and 29.4% of geology and chemistry students respectively stick to it and consider it to be a theorem. Electronegativity was introduced by 21.1% of geologists and 50,0% of chemists while only 5.3% and 2.9% are those who did not give any of the selected answers.

Galvanic cells are not taught extensively, however they are mentioned with relation to spontaneity of reactions and to redox reaction prediction. A set of three statements was set and the results obtained are summarized as follows:

42.1% geology students and 64.7% chemistry students believe that positive E° for a galvanic cell indicates a spontaneous reaction and that the cathode has a lower potential than the anode. 47.4% and 5.9% are those who did not provide an answer. The electric conductivity of metals is attributed to the free electrons of the metal lattice according to 47.4% and 79.4% of geologists and chemists respectively, while 31.6% and 8.8% are those who did not respond.

Finally, 26.3% geologists and 47.1% hold the opinion that the metallic bond is due to electrostatic forces between free electrons and cations of the metal lattice, however 26.3% and 8.8% respectively did not know anything for sure.

The test was concluded with two interrelated questions about thermochemistry, which is still a mitigated topic at this level of the curriculum. The first one required the writing of two thermochemical equations which are described verbally and for which some data are provided. More precisely, the enthalpies of formation of SO_2 and SO_3 are given as -297 and -396 kJ/mol and the corresponding thermochemical equations have to be written. The second question is about the exo- or endothermal nature of the "burning" of SO_2 to SO_3. The equations appear to be difficult to handle, as the 26.3% of geologists who tried to get involved were all in error, relative to only 14.7% chemists, of whom a mere 11.8% were able to work them out. Similarly, combining the two equations was difficult and only 5.3% geologists and 11.8% were able to conclude about the nature of the oxidation of SO_2 to SO_3. Interestingly enough none of the chemistry students responded in the right way to both questions.

4. CONCLUSIONS

The introductory level of students in different Science departments facilitated through common exams and through following a common high school curriculum provides grounds for the assessment of the teaching, both in the lecture hall and in the lab during their first year studies, in the field of General Chemistry. Despite minor differences, the two sub-groups of students, following a chemical or a geological university curriculum appear to be members of a common population. In this respect, a recent amendment of the Greek educational system where students following a certain course termed "technical direction" are not allowed into Science departments seems to have been right, as previous studies revealed a significant differentiation of their population relative to that of the students who had followed the "positive direction" (Katsikis et al 2017).

Upon completing the first semester of studies where the topics incorporated into the General Chemistry course are presented, there appears a significant differentiation among the students of various Science departments. This can be attributed, in part, to the different extent of teaching they have been subjected to, as viewed by the 2 vs. 3 hours of lecturing and 2 vs. 4 hours of lab work per week.

Some common characteristics between students of different Science departments still persist, namely the difficulty to handle even simple and straightforward chemical reactions as well as graphs and the facile assimilation of ideas added to and completing the existing ones, like those related to atomic structure and bonding. Another common point is the difficulty in unravelling the underlying principle and applying the known relations or reasoning, when the formulation of a question does not match exactly the one memorized during the study. This is apparently an inheritance from the secondary level of education and cannot be dealt with in simple and straightforward steps.

On the other hand, motivation to follow the specific course within the complete educational program seems to take over as the students of the Geology department which is not as highly esteemed as the Chemistry one, tend to not commit themselves to attending lectures or trying to understand principles discussed in the lab. Therefore, although chemical equilibrium and properties of electrolyte solutions (mainly related to pH) are taught and discussed in detail, students of the Geology department are more

reluctant to work out answers and generally provide the right ones to a lesser degree than their Chemistry counterparts.

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