

BEING CONSISTENT WITH REALITY: A GREAT CHALLENGE FOR CHEMISTRY LABORATORY REPORTS

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ABSTRACT– The experimental component has fundamental roles in chemists’ training, and laboratory reports provide evidence of critical aspects of students’ understanding. This paper focuses on a crucial understanding and interpretation aspect: students’ awareness of the nature, details and scope of the phenomena observed and their ability to distinguish them from apparently related descriptions available in textbooks or on the internet.

A study of laboratory reports for physical chemistry experiments across several years highlights a variety of statements included in reports and having nothing to do with the given experiment. The causes range from passive acceptance of pre-learnt paradigms, for which a student writes the same set of pieces whichever the nature of the experiment, to lack of confidence in one’s writing ability and consequent passive borrowing of sentences, patterns and entire sections from other sources, and to poor attention to the details of the experiment in question or actual failure to understand it. The paper considers examples from different components of laboratory reports, analyses the dichotomies between what students write and what could be called the ‘reality’ of the experiment, and outlines approaches to attract students’ attention to the importance of ‘sticking to reality’ in the description and interpretation of experimental work.

Keywords: Conceptual understanding; Description abilities; Interpretation abilities; Laboratory reports; Scientific method.

1. INTRODUCTION

The experimental component has fundamental roles in a chemist’s training, because it is a dominant component of a chemist’s professional activity. Students need to learn to perform practical operations correctly and also to understand the meaning of the operations, to be able to describe and interpret results and to link all these aspects with the theory presented and discussed within lectures. These features are well known and agreed upon among chemistry educators. Hofstein and Lunetta (1982), Lazarowitz and Tamir (1994), Hofstein (2004), Hofstein and Mamlok-Naaman (2007) include broad reviews of research on the educational significance of laboratory work in science education in their works about approaches to improve its quality and impact. A comprehensive review would require more than the space of this article and, therefore, the importance of the experimental component is taken as an acknowledged prerequisite, and references will be considered only in relation to specific aspects relevant to the focus of this paper.

Laboratory reports can be used to enhance students’ learning and stimulate reflection. Cacciatore and Sevan (2006) stress the importance that students become aware of why each part of a lab report is necessary, including the importance of reproducibility based on a lab report. Dawidowitz (2004) explores the role of lab-reports as part of the use of writing as a tool for chemistry learning. The analysis of lab-reports provides evidence on crucial aspects of students’ understanding of the nature of each experiment, thus providing precious inputs for interventions within lecturer-students contacts. It has been used as a tool to assess the outcomes of an inquiry-type laboratory aimed at placing the learner at the centre of the learning process (Hofstein, Shore and Kipnis, 2004). It has been included in an investigation to evaluate students’ metacognition in the chemistry laboratory (Davidowitz and

Rollnick, 2003) and in a study of the modelling abilities of non-major chemistry students taking the first year chemistry course (Chittleborough and Treagust, 2007).

Within a perspective considering students' works as the best sources of information about their understanding and perceptions (Mammino, 2005), lab-reports can be analysed with a variety of focuses, such as the understanding of aspects specific to a given experiment, students' ability to describe observations, to report data, to interpret results, or their ability to use language at an adequate level, or to relate an experiment to the corresponding theoretical components. This paper focuses on an aspect that has not yet being singled out specifically and that could be described as the ability to 'stick to reality', to identify the features of a given experiment in a clear-cut way (the term 'reality' is here used not in a philosophical sense, but simply to refer to what occurs in an experiment and what information and inferences can be reasonably derived from it).

2. METHOD AND OBJECTIVES

The study presented here pertains to a systematic study of students' works, with the objective of obtaining information for suitable in-class interventions. A study of this type is qualitative by its nature, because it responds to the questions "What are the problems?", "What is a realistic, evidence-based" description of each problem?" and "What can be designed to address each problem as effectively as possible?". The documentation that can be reported for this type of study consists of excerpts from students' works, viewed in their contexts. No *a-priori* hypothesis can be made, because the material itself (students' works) provides the evidence which leads to analysis criteria and to inferences.

Several problems may affect students' understanding and performance, often intertwining with each other and enhancing each other's impacts. It is necessary to identify each problem individually, recognizing as many details as possible as well as possible causes and overlaps (or enhancing interferences) with other problems, in order to design interventions. The identification of the individual problems is experimental. Once a problem appears with a certain frequency, it becomes object of study because it needs thought-out addressing. Then, lab-reports are analysed to identify the different circumstances and features with which the problem appears, until a sufficiently detailed picture is obtained to enable the design of focused interventions. The outcome of the interventions is analysed in a similar way and new interventions may be designed, repeating the process from year to year. Overall, this approach responds to the paradigms of action research as outlined in Levin (1947): ä recursion (iterative) process involving a series of three steps which can be repeated subsequently as long as needed, namely (Levin, 1947; reported in Girod):

Planning that involves reconnaissance;

Taking actions;

Fact-finding about the results of the action.

The analysis of the lab-reports highlights a variety of difficulties in the identification of the meaning of the given experiment and the operations involved, of the meaning and scope of the basic components of a lab-report, and also language related difficulties and difficulties with mathematics, with the chemical meaning of the working mathematical expressions used in the treatment of results and with graph-drawing. Recurrent types of errors may be grouped under suitable categories according to their nature and in view of the envisaged category of in-class interventions.

In the current study, lack of consistency with what can be considered 'reality' for a given experiment is identified as a suitable category because it is apt for interventions aimed at attracting students' attention to the concrete details of an experiment and the information that can be derived from it. In most cases, the aspects concerned are very basic and, therefore, the interventions aim at building basic foundations for the experimental work and its interpretation. The analysis highlights rather frequent occurrence of statements incompatible with reality in all the components of lab-reports, and with reference to a variety of features.

3. ILLUSTRATIONS OF INADEQUATE CONSISTENCY WITH REALITY

The results reported here derive from systematic analysis of student's lab-reports in the undergraduate physical chemistry courses at the University of Venda (UNIVEN, South Africa), during the past 19 years. All lab-reports are analysed as integral part of the marking, and statements or details highlighting specific problems are recorded. The courses comprise chemical thermodynamics in the second year and electrochemistry, chemical kinetics and surface chemistry in the third year. Incoming students at UNIVEN are largely underprepared – a fact which needs to be taken into account when designing teaching approaches, also beyond the first year. For the undergraduate physical chemistry courses, the experiments selected are technically simple, and their main objective is to train students to observe, to describe what they observe, to write sufficiently complete lab-reports and to relate experiments and theory. Because of this, lab-reports are not prepared on provided forms, but require articulate texts. In order to facilitate this task and to supplement for the inadequate training students might have received at pre-university instruction, detailed guidelines to each lab-report are provided, specifying what is expected in each of the major components (objectives, theoretical background, observations, treatment of results, conclusions, discussion) in form of issues to be addressed or (for the treatment of results) quantities to be calculated and graphs to be drawn. The design of detailed guidelines to lab-reports can be viewed in the perspective of what White (1996) considers a critical task for teachers. i.e. “establish significant and enduring links between episodes and declarative knowledge”. Since students' attitude in the laboratory closely resembles the one described by Berry, Mulhall, Gunstone, & Loughran (1999) – focusing on completing the required operations as fast as possible, without much attention to other aspects, the guidelines to the lab reports are the only tool that can stimulate reflections on all the aspects and details (including the meaning of the practical operations).

Despite this guidance, the adequate time given for the preparation of the lab-reports (at least 2-weeks) and the possibility of consulting literature and the lecturer during their preparation, lab-reports are often poor. It is not infrequent that half or more of the reports do not reach the passing mark (50%), with somewhat better proportions of passable reports in the third year. The most dominant reason is inadequate awareness (or acceptance) of the importance of the experimental part of the courses and of the corresponding reports, despite the fact that lab-reports contribute 40% to the semester mark. Students try to minimise the time devoted to lab-report, as if its value were lower than the time devoted to other activities. This leads to hurried-up presentation and treatment of results and to extensive copying from each other or from whichever source that might appear suitable. Both attitudes unavoidably lead to imprecisions and errors.

An experiment implies a set of operations, a set of observations, measurements which often need further treatment (graphs, calculations, identification of patterns) and interpretation. When something is not sufficiently clear or not sufficiently thought-out, the lab-report may contain things that have nothing to do with the given experiment, or statements that are impossible by their very nature. These errors are considered particularly serious, because they often suggest poor understanding of the nature of the experiment, of the operations involved, and of the type of knowledge that can be derived from it. Examples are reported and discussed in the next paragraphs, as illustrative documentation of frequent errors/problems. To facilitate concise references to the experiments considered, these experiments are denoted with acronyms, whose meaning is explained in table 1 (the acronyms starting with 2 refer to second year experiments, the acronyms starting with 3 refer to third year experiments). Students' statements reported as examples are numbered progressively throughout, to facilitate referencing; when mentioned in the text, they are preceded by 'st' for 'statement' (e.g., st-1, st-2, etc.). The examples are not grouped in terms of lab-report components because errors of similar nature may appear in different components, and it is considered more interesting to focus on the types of errors.

Table 1. Brief description of the experiments considered and acronyms utilized to denote them in the text.

Symbol	Brief description of experiment
exp-2-a	Determination of the heating curve of water. Three tests using different masses of water.
exp-2-b	Determination of the enthalpies of solution of sodium hydroxide and sodium thiosulphate in water. Five tests for each of them, resulting in different concentrations.
exp-2-c	Simple experiment on the Hess law
exp-2-d	Determination of the concentration (molality and then molarity) of a highly concentrated (nearly-saturated) table salt solution from the elevation of its boiling point. The solution is provided by the lecturer. The determination of the volume and mass of the solution are included in the procedure, to enable the calculation of its density.
exp-3-a	Determination of the relative tendencies of selected metals to be in an oxidized state (the selected metals are dipped in solutions containing ions of the other metals). The experiment is qualitative.
exp-3-b	Electrolysis. Five different tests, involving reactions that did not occur spontaneously in exp-3-a. The changes in mass of the anode and the cathode are measured.
exp-3-c	Determination of the dependence of the reaction rate on the concentration of permanganate ions using the isolation method (reaction of potassium permanganate with oxalic acid)
exp-3-d	Determination of the dependence of the reaction rate on temperature, performing the reaction at different temperatures (reaction of potassium permanganate with oxalic acid)

The simplest form of inconsistency with reality is conscious cheating on reporting values. Despite being generally advised to report truthful numerical values and warned that non-realistic values are detected easily on marking, several students write values that they consider more correct than their actual measurements. A typical example is the boiling temperature of water in exp-2-a. At least 20-30% of the students (varying from one year to another) write 100.00°C as the measured steady temperature when the water boils, expecting this to be more correct than the somewhat lower value which they actually measured and which is correct because of the altitude of the location. Other examples are the different values of the melting and boiling points for different masses of water (exp-2-a), which some students report because they are convinced that the values should be different, or graphs with points not corresponding to the tables of experimental values in the same report (which suggests that the graphs have been copied from other sources). Cases like this – although occurring with a certain frequency – will not be considered further, because they are voluntary deviations from reality. What is more interesting in view of in-class interventions, explanations and discussions are the cases where the inconsistency with reality is not intentional, and guidance is needed for students to recognize the inconsistencies.

The most typical example of unrealistic statements in the observation section is the description of what atoms, ions and molecules do – something that cannot be observed with our naked eyes. Descriptions of this type appear more frequently in the reports on exp-3-a, as in st-1 and st-2; sometimes the 'observation' concept is explicitly emphasized, as in st-3 and st-4.

Some of the copper atoms from the copper strip were oxidised to copper ions. Silver ions from the solution of silver nitrate were reduced to silver atoms, which were deposited on the surface of the copper strip.

Zinc releases electrons to copper in the beaker #5 and copper releases electron to silver in beaker #4.

Electrons were observed to move from the zinc atoms to the copper ions.

One can notice that there is an electron transfer from one element to the other.

Although less frequently, analogous statements appear also in the observations section of reports on other experiments, as st-5 (exp-2-a), st-6 (exp-3-b) and st-7 (exp-3-d):

Molecules were moving apart during melting,

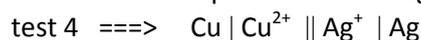
The ions were moving from an electrode of low potential to an electrode of higher potential.

We have observed that the increase in temperature increases the number of collisions of atoms and their velocity which as a result increases the rate of reaction.

Information that cannot be derived from a given experiment can also be viewed as inconsistency with reality. For instance, exp-3-a is purely qualitative, requiring observation and interpretation of any visible change (changes in colour, formation of deposits, etc.); it does not involve measurements. However, some reports contain information such as st-8, which is unrealistic because there was no mass-measurement and it is not possible to evaluate a mass change just by observing the copper strip (which gets rapidly coated with silver). The error is probably due to copying from some description of a quantitative experiment.

The copper metal strip becomes corroded and its mass reduces.

Symbolic descriptions like st-9 are also unrealistic for exp-3-a, because it does not involve galvanic cells; e.g., the system for test 4 involves a copper rod dipped in silver nitrate solution, and neither solid silver nor Cu^{2+} ions are present at the beginning.



The tendency to copy from some sources without checking whether they are compatible with the given experiment may be ascribed both to viewing it as a faster option and to lack of self-confidence about what they have actually observed and done. Consequently, several statements, descriptions or comparisons copied from other sources do not correspond to the experiment considered. A typical example is the comparison of exp-3-b with exp-3-a, which is part of the treatment of results for the report on exp-3-b. Textbooks and other learning materials frequently compare galvanic and electrolytic cells. Several students copy this comparison and end up referring to exp-3-a as an experiment involving galvanic cells (st-10 and st-11):

In practical 1 galvanic cell was in use and in practical 2 electrolytic cell was in use.

Experiment 1 was an example of galvanic cell where the reaction was not forced to occur, there was no intervention of technology.

Passive copying may extend to the description of practical details that did not pertain to the experiments, overcoming and cancelling what students have seen and experienced when performing them. St-12 refers to actual details of exp-3-a, but calls each 'metal+solution' system a galvanic cell (whereas a galvanic cell needs two electrodes and, in each electrode, the metal rod is dipped into a solution containing its ions, not the ions of another metal). St-13 describes the metal+solution systems as those expected in galvanic cells, although in exp-3-a each metal was dipped into solutions containing ions of a different metal. St-14 and st-15 refer to production of electric current, which was not true for exp-3-a. Some reports go so far as to describe the apparatus used in exp-3-a as having a salt bridge connecting two solutions.

In galvanic cell when copper is dipped in zinc sulphate solution nothing has happened. In galvanic cell when tin is dipped in zinc sulphate solution nothing has happened.

This is unlikely the previous experiment under galvanic where two metal rods were dipped into the solutions containing ions of that rod.

In experiment 2 electric current was supplied by the external technology but in experiment 1 electric current was produced by the reactants.

In experiment 1 the reaction was spontaneous because it generated current.

Exp-3-b involves only electrolysis of solutions of ionic compounds (not of molten ionic compounds) and only metal electrodes are used because of non-availability of other types. Passive copying may result in descriptions like st-16 and st-17.

Objective: to observe and analyse the phenomena that take place during electrolysis, when different metals are dipped in different melted ionic compounds.

Graphite rods were used to perform this experiment.

Lack of attention to the reality of an experiment, combined with passive copying, may affect many aspects of lab-reports. In exp-2-a, only the heating curve or water is determined; however, some reports state that the cooling curve was also determined (likely because the two curves are treated together in textbooks and despite the fact that the report does not contain data or the graph of the cooling curve). The conclusion expressed by st-18 would be legitimate only if both curves had been determined. Similarly, the conclusion expressed by st-19 cannot relate to exp-2-a because it did not involve the use of different substances (only water is used).

Conclusions: during phase change, temperature does not change, which can be observed as a flat part in the cooling or heating curve. The temperature of melting is the same as the temperature of freezing.

Conclusion: the shape of the graph when the substance had its temperature raised was related to the specific heat capacity of the substance.

Cases of this type are rather numerous. St-20 cannot relate to exp-2-c, because it did not involve decomposition and formation of a compound. St-21 cannot relate to exp-2-d, because it did not involve the determination of the freezing point of the solution. St-22 (besides being conceptually incorrect) cannot relate to exp-3-b because it did not involve tests in which the intensity of the current was varied, and st-23 cannot relate to exp-3-b because it did not involve metal ores. St-24 does not refer to operations included in exp-3-c. St-25 cannot relate to exp-2-d, because it involves only one solution (it would be correct only if solutions with different concentrations of solute were provided). St-26 (exp-2-a) gives expansion as the only outcome of supplying heat to a substance, whereas the experiment involves temperature increases and phase transitions. St-27 (exp-3-b) gives the decomposition of a compound as the only outcome of electrolysis, although exp-3-b involves only corrosion and deposition of metals.

Conclusion: the heat required to decompose a compound is equal to the heat evolved when the compound is formed.

Conclusion: the freezing point of the solution is lower than the freezing point of pure water.

Conclusion: it was seen that the current had no effect on the mass change and the time it takes the non-spontaneous reaction to occur.

Conclusion: electrolysis was found to be one of the good methods of producing pure elements from their ores.

Conclusion: the experimental data and calculated values show that if the concentration of one of the reactant is doubled, while the other reactant concentration is held constant, the reaction rate doubles.

Objective: to observe if the elevation in boiling point increases as the concentration of NaCl in the solvent increases.

When heat is supplied to a substance it is absorbed by that substance and the result of that absorption is expansion.

Electrolysis results to the decomposition of a compound to form its elements.

Statements containing logical contradictions are rather frequent, and their presence can be ascribed both to inadequate conceptual understanding and to language-mastery inadequacies, above all in terms of the ability to verify the internal logic of a statement, or to match statements with facts (Mammino, 2010). Sentences stating that temperature is constant or should be kept constant appear rather frequently with reference to experiments involving heating (like exp-2-a and 2-d) or processes which may cause heating or cooling (like exp-2-b), as an observation (st-28) or a recommendation to reduce imprecisions (st-29) or a source of imprecisions (st-30). The contradiction is not encountered only in lab-reports, but also in tests, with wordings like "heating isothermally".

An open beaker we used and temperature we keep constant.

We need to keep constant temperature.

Factors that might have affected the accuracy of our measurements: the temperature was not kept constant.

Similarly, several students write recommendations such as st-31–33 for exp-2-a and exp-2-d, where the nature of the experiment involves heat supply and, therefore, the system cannot be insulated or adiabatic.

I think we should have done the following: reduce error by using insulated container such as Styrofoam cup.

The experiment should be carried out in an adiabatic system.

We should conduct the experiment in a vessel completely surrounded by an adiabatic boundary.

Logical contradictions appear with a certain frequency also in the conclusions of exp-3-c, where the reaction is said to be both first order and second order with respect to the same reactant (e.g., st-34).

The first graph shows that the reaction is first order reaction. The second graph shows that the reaction is second order reaction.

Incorrect recording of numerical values may occur because of human errors. In some cases, not discarding the incorrect values shows inadequate understanding of relevant aspects of reality. For instance, st-35 refers to the time at which the concentration of MnO_4^- has been determined from the beginning of the reaction in exp-3-c. The second value is absurd, because it would mean that time has gone backwards, and should have been discarded. It might have simply be due to incorrect writing on recording values, but it was maintained and used in calculations and graphs, which can be ascribed either to a totally mechanical way of proceeding (using formulas without reflecting on the meaning of the results) or to actual lack of understanding that that value implies time going backward.

Time (s): 67.8 32.6 566.4 811.2

Recording of absurd values may concern various quantities. Errors like in st-36 (exp-2-a), where the mass of a “beaker + ice” is recorded as smaller than the mass of the empty beaker, may probably be ascribed to the haste with which many students prepare their lab-reports; on the other hand, the treatment of results is affected, leading to absurd calculated values.

test 1 mass of empty beaker = 143.7922 g

mass of beaker + ice = 140.6049 g

test 2 mass of beaker = 143.7922 g

mass of beaker + ice = 70.3582 g

The lack of self-confidence in what they do, combined with inadequate conceptual knowledge, may result in not-trusting measurements that are actually correct, as in st-37 (exp-3-b), in which the students correctly registered an increase in the mass of the cathodes, but does not consider it correct:

For each case of cathode masses were gained which is not true in reality but since it is an experiment it is possible, but theoretically it does not exist.

Calculations utilising experimental data need to yield realistic results. Incorrect measurements or incorrect calculation procedures lead to incorrect calculated values. The acceptance of absurd values in the treatment-of-results section is also part of inadequate consistency with reality, even if not related to practical operations. It relates to the understanding of what is possible and what is unrealistic. For instance, some lab-reports for exp-3-c give calculated values of the concentration of the reactant in the first three or four samplings which are greater than the initial value; yet, they are not discarded as unreasonable, which raises concern about students’ understanding of what happens during a chemical reaction (the concentration of a reactant cannot increase).

Frequent errors appear in the calculations of the molality and molarity for exp-2-d .The most common error is the calculation of the number of moles of NaCl by dividing the total mass of the solution by the molar mass of NaCl (largely due to the habit of not distinguishing between “NaCl” and “NaCl solution”

when talking or writing). When this combines with other errors in the series of calculations, students may find molarity values ranging between 1000 M and 16000 M. The fact that they accept these values shows inadequate awareness of what is possible in reality and what is absurd.

Procedural absurdities (st-38) appear with a certain frequency as answers to a question for the treatment of results of exp-2-b-, asking how they would proceed if they had to determine the enthalpy change when 1 mol solute dissolves in 1 dm³ water and the largest beakers available were 250 cm³ ones:

I would pour 1 dm³ water in a 250 cm³ ones beaker and

A variety of inconsistencies with reality appear in the discussion (the final section of a lab-report), where students are asked (among other things) to list the possible causes of imprecisions in the given experiment. St-39 and st-40 (exp-2-a) surprisingly express the concern that the same beaker may change its mass during an experiment. St-41 states that exp-2-b was conducted in a vacuum, what is not true. St-42 de facto considers that exp-3-b was not precise because of not having the set-up of a galvanic cell (in electrolysis, the flow of electrons is determined by the generator of direct current) Mass of the beaker, because it was measured once and used for all the tests.

The inconstant mass of the beaker may have affected the accuracy of the measurements.

Since the experiment was performed in a vacuum, the values we are determining will not always be correct, or we will not find the expected values.

The two halves of the electrodes had no porous partition to prevent electrons from transferring directly from the metal to the ions, instead of passing through the external circuit.

Inadequate understanding of theory combined with inadequate awareness of the conditions in which an experiment is performed may result in misinterpretations. St-42 refers to whether the conditions in which exp-2-b is performed enable us to consider the amount of heat involved as an enthalpy change. The answer should be positive, because the experiment was performed at atmospheric pressure and the duration of each test was too short for pressure fluctuations to be significant, so, the pressure can be considered constant (the temperature cannot be kept constant because the experiment concerns the heat involved in a process, but constant temperature is surely not a condition for the heat involved to be equal to the enthalpy change).

The conditions did not really apply as pressure was not constant and the temperature was not kept constant.

Confusion between physical reality and our representations are frequent and can be traced both to language-mastery inadequacies (for which students are often not aware of the actual meaning conveyed by the sentences they write, Mammino 2010) and to inadequate familiarity with the scientific method. For instance, st-44 (exp-2-a) considers that heat is supplied to a graph (which pertains to our representation, not to physical reality) and st-45 (exp-2-a) considers that a point in a graph has a phase and can undergo a phase transition.

If heat is added at a constant rate in the graph of the heating for water

Point A of the graph is solid, which melts at 1 °C as heat is supplied...

4. THE CHALLENGES OF INTERVENTIONS

The documentation in the previous section clearly shows the need for interventions. To be effective, interventions require effective communication, i.e., to attract the student's attention sufficiently to stimulate mental engagement and reflections. Some students remain largely passive during in-class activities (although these are carried out interactively and, therefore, aim at engaging students actively), and need individual stimulation. To take this into account, two options are widely utilised: in-class discussions for all the errors that appear in more than one report for a given experiment and

short written comments on the reports, meant as communication to the individual student. Experience shows that students read all the individual comments with great attention, probably because of a perceived value of individual communication.

Discussions and individual comments attempt to be as sharp as possible, to actually attract attention. For instance, in the briefing of exp-3-a, students are asked whether any of them can see atoms, molecules, ions or electrons and, when they answer “no” are invited to make sure that they will not state that they observe them in the lab-reports. Sometimes it is jokingly added that, if any of them could actually see those small particles, he/she would find high-salary employment in any chemistry enterprise. On marking lab-reports, a sentence like “Are you sure that you can see electrons (or atoms, ions, etc.) with your naked eyes?” is written near any statement like st-1–4, or like st-5–7 for other reports.

It is important to find short comments that convey the message to the point. In some cases it is easy. For instance, the comment near st-38 is of the type “Please, show me how you do it”. For sentences like st-31–33 the comment asks “How can you supply heat to an insulated system?”. Whenever a report states something that was not done (measuring masses in exp-3-a, using a salt-bridge in exp-3-a, determining the cooling curve of water in exp-2-a, etc.), the comments take the form of questions such as “are you sure that you have measured this?” or “are you sure that there was a salt bridge in your apparatus?” and the like. It is more difficult for aspects that involve greater reflection, as is the case with the conclusions. Then, the comment needs to point out how certain conclusions cannot be derived by the given experiment. When the conclusions are clearly copied from some source and have nothing to do with the experiment, the comments need to show that the given statements, although by itself expressing some true information, have no relationships with the observations or the calculated results of the given experiment. In most cases, students get the meaning of the individual comments and understand the errors. When this does not happen (mostly for conclusions and inferences), they contact the lecturer and this gives an opportunity for clarifications relevant to the given student.

Discussions on realistic values of physical quantities are given particular attention because of their relevance for any practical aspect of chemistry. They are also challenging, because the very concept of realistic values and absurd values for a given quantity is often not sufficiently developed. Analogies with quantities that are part of everyday experience can be useful. A convenient analogy refers to a hypothetical situation in which they should use a calculation to determine the height of a person. Students are asked what they would think if, e.g., someone gets a value of 12.5 m (or similar absurd values) and does not discard it. This conveys the message that some values may be absurd. However, more work is needed to foster the awareness of which values are unreasonable for quantities such as concentration, or other values that are measured in the lab.

5. DISCUSSION AND CONCLUSIONS

Physical chemistry is often considered particularly difficult by chemistry students, and this occurs even more in disadvantaged contexts (Mammìno, 2009). The perception of greater difficulties extends to the experimental part and to the lab reports, which require understanding of the meaning of an experiment and of the theory associated with it.

The combination of technically simple experiments and detailed guidelines to lab-reports considering all their descriptive and interpretation aspects has been particularly useful to train students to write sufficiently informative reports in the physical chemistry courses. The improvement observed from the second year to the third year courses shows that the training during the second year has some impact.

All the same, errors in the lab reports are frequent. Misinterpretations of the nature of an experiment and its related observations may affect all the components of students’ interpretation of what they did

and of what can be inferred from their observations. Errors involving lack of consistency with the reality of an experiment are particularly serious and need prompt and extensive addressing. A combination of in-class interactive discussions and comments on individual lab-reports appears to make interventions more effective than one of the two approaches alone. Search for further optimisation of the two approaches is still in progress.

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