

A Titration Experiment as an Example for a Coordinated Approach in Science Teaching at High School Level

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Why a co-ordinated approach in science teaching?

Last year, a work-group comprising teachers of biology, chemistry and physics⁴² was instituted at the Alta Scuola Pedagogica in Locarno with the aim of realising didactic materials for the *teaching of thermodynamics* at the upper-secondary level. The work-group had the following remit: the production, for colleagues, of complete didactic sequences (texts, model experiments, exercises and evaluation tests) based on the introduction of the concepts of *entropy* and *chemical potential*.

This project came to life within a vaster undertaking aimed at co-ordinating the teaching of the three science subjects using an experimental approach. Quite apart from the structural circumstances leading to this initiative⁴³, we believe that a rethinking on these lines is overdue at a general level. In fact, science-teaching suffers, in our opinion, from excessive fragmentation. The pupils are often called upon to learn a large number of facts, which often are presented in ways that differ from one subject to another and are seemingly disconnected, even contradictory.

We, however, believe that pupils should be provided, explicitly and more directly, with the means for conceiving and appreciating science as a vast, collective construct, both unifying and logical. They must have the feeling of mastering, little by little, those basic tools necessary for the gradual building-up of a framework which will enable them to interpret the various processes which occur in nature or which are used in the field of technology. They must become aware of being actively engaged in the building-up of their own knowledge and understanding in this sector, rather than being mere passive spectators, effectively barred from assimilating what is presented in class. We should also like to point out that co-ordination of the kind envisaged should be an objective throughout the whole period of schooling: in general, there is a lack of continuity when pupils move from one level of school to the next.

Biology, chemistry and physics have each their own specificities: these must be acknowledged, maintained and highlighted. However, these specificities also refer to a common core of knowledge, to a sort of *transversal, conceptual scaffolding* which gives shape and substance to all the various contexts. Thus, when considering a given school

⁴² The group consists of twelve upper-secondary school teachers of biology, chemistry and physics in the Canton Ticino (in the Italian-speaking part of Switzerland), who meet regularly about once a fortnight, together with the methodology teachers of the respective subjects at the *Alta Scuola Pedagogica* in Locarno.

⁴³ This problem became particularly immediate for us with the recent reform of the Federal Ordinance of the Swiss “*Maturità*” (ORR/M), which introduced, inter alia, a “*basic course*” in the experimental sciences, to be taken by all pupils for two years, and which takes the form of separate teaching in the three subjects but which leads to a common final mark in the “*Maturità*”.

system, rather than focussing on an evaluation of the teaching of the single subjects, one should verify what has been offered on the whole. It is not, therefore, a question of the supremacy of one subject over the others or the defence of a single “territory”, but rather a question of reflecting on the complex demands of the pupil who, at an upper-secondary level, should still have the possibility of being confronted with a sufficiently vast, non-specialist offer which will enable him to acquire a solid, basic grounding. The teaching of the three science subjects should, therefore, be conceived in such a way as to take this consideration into account. Seen from this point of view, an effective co-ordination between these subjects becomes an indispensable requirement.

A (new?) model for a co-ordinated approach

All attempts to arrive at forms of co-ordination based on the chronological ordering of the contents of the subjects involved, on the basis of a presumed propaedeutical or hierarchical relationship, have failed to meet expectations: there are too many practical difficulties connected both with curricular structure and with teaching conditions⁴⁴. Nevertheless, as we shall see shortly, such an approach, fortunately, is perhaps not the only one possible, nor is it desirable either from a pedagogical or from a purely subject-oriented point of view.

In fact, the path we have followed is founded on another principle: the selection of a small number of basic nuclei which are significant for the three science subjects concerned and which can act as *cognitive organisers*⁴⁵. We have opted for the following three cognitive organisers: *energy*, *structure of matter* and the *concept of system*. For each of these, we intend to elaborate a common frame of reference, agreed upon by all three subjects (knowledge and skills) demanded of the pupils by the end of the *basic course*⁴⁶. In this way, the time factor and restrictions resulting from the (supposed) hierarchical relationship of one subject with respect to another can be avoided: on the other hand, what is expected is that the consistency with the agreed general model be guaranteed by all subjects in each, single didactic operation. Needless to say, the individual subject content must be dealt with in one or more of the subjects concerned as and when is deemed fitting.

Over and above subject-specific considerations, particular importance is attached to the methodological aspects which, by their very nature, are common to the three subjects concerned. Amongst these methodological aspects, we attach considerable importance to the maintaining of a strong experimental component and the introduction of modelling activities. As far as the experimental aspects are concerned, we have at our disposal today particularly versatile apparatus which enable pupils to acquire a high number of physical quantities on-line, the use of which is easy and rapid and certainly effective from a pedagogical point of

⁴⁴ With increasing frequency, the introductory courses in the three experimental sciences are of brief duration and present two or three of the subjects in parallel: this, in fact, renders impossible the simultaneous timetabling of contents specific to the individual subjects. Another practical obstacle consists in the fact that a single teacher finds himself working with a number of parallel classes and a number colleagues from the other science subjects: in the resultant intertwining of the interests of the single teachers and of the single classes, the chances of real agreement are reduced to a minimum.

⁴⁵ For a more precise definition of the concept, see, for example, the chapter *Contre le savoir en miettes: les concepts organisateurs* in Giordan [1].

⁴⁶ At the moment, a concrete proposal for an energy model is given in the document *L'energia nel corso di base delle scienze sperimentali del liceo: riflessioni e proposte* which was written in the Spring of 2003 by the corresponding *Gruppo per il coordinamento degli insegnamenti in biologia, chimica e fisica* and approved by the UIMS/DECS [2].

view. Modelling activities, as other contributors have illustrated, constitute both an important instrument for the building of scientific knowledge and an intrinsically interdisciplinary device [3], [4]: the cognitive performances realised by the pupils are particularly interesting – especially if use is made of a working environment offering a graphic interface - since they are called upon to explain a network of connections as opposed to single facts, a kind of conceptual map, the connections of which nevertheless express the quantitative aspects.

A simple example from thermodynamics: a titration experiment

The teaching of thermodynamics is an area particularly in need of intervention of the kind described above: conventions which are not very consistent, a multitude of quantities introduced *ad hoc* and a particularly complex terminology make the science of heat unnecessarily difficult and scarcely transparent for pupils. On the other hand, thermodynamic aspects are important in physics, chemistry and biology. So our attention focused on the examination of this field of study, particularly linked to the cognitive organiser *energy*, with the specific objective of producing concrete didactic proposals.

As an example of a possible practical activity with pupils, we present here a calorimetric titration experiment, underlining in particular the experimental and modelling aspects.

The experimental apparatus comprises (v. fig.1), in essence, a calorimeter containing initially a certain quantity of an aqueous solution of sodium hydroxide, into which an aqueous solution of hydrochloric acid is introduced drop by drop. The exothermic reaction which ensues leads to a rise in temperature which is recorded on a thermometric sensor connected to an on-line data acquisition system. A magnetic stirrer sees to it that, as far as possible, the temperature distribution is kept homogeneous. A drop-counter is connected to the data acquisition system in such a way as to record how much acid is introduced and at what intervals. The neutralisation reaction



Figure 1: The experimental set up.



is distinguished by two aspects: on the one hand, it occurs practically instantaneously (that is, the resistance to the reaction is particularly low) and on the other hand it is distinguished by an equilibrium which is (almost) entirely shifted to the side of the products. As already noted by others [5], such experimental situations allow a semi-quantitative description of the thermal aspects accompanying chemical reactions.

In fact, as we see from the data referring to temperature readings plotted versus time (v. fig. 2), three phases are easily recognisable: in the first phase, the exothermic aspect of the reaction predominates and the temperature of the system rises.

At a certain point, there is no further reaction: in this second phase, the introduction of the acid solution – which is at room temperature - has the sole effect of causing the temperature of the system to fall. In the third phase, the tap of the burette is closed: from now on the fall in temperature is the result only of the recipient's outward loss of heat.

On the basis of the values which can be read directly from the graph, it is possible, with a simple calorimetric calculation, to determine the value of the molar enthalpy ΔH of the

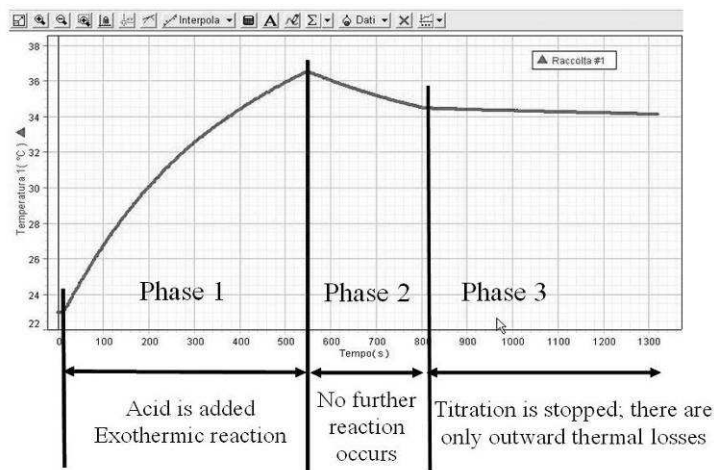
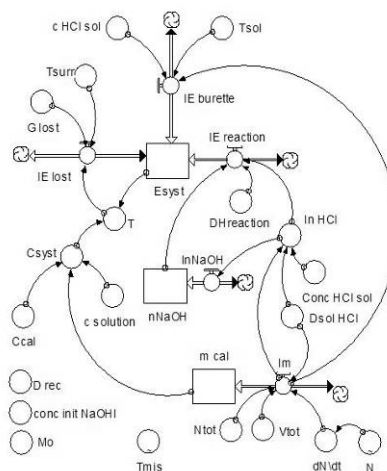


Figure 2 : Temperature vs. Time.

must recognise and be able to represent mathematically the relations involved in the various thermal exchanges encountered but he does not necessarily have to be able to perform the integration explicitly: the latter is, in fact, carried out numerically thanks to a process of iteration.

In the case under examination, we must consider the release of heat in the reaction, the cooling effect of the solution which is introduced drop by drop into the recipient as well as outward losses. If we know the various experimental quantities (mass and concentration of the solutions, outside temperature, thermal capacity of the water), it is possible to use the recorded temperature data to determine the various parameters which have not yet been defined, amongst which is the molar reaction enthalpy. Figure 3 reports a version of the model in which the specific heat of water was used for determining the heat capacity of the whole system.

Figure 3: Simplified dynamical model: notice the three thermal exchanges intervening in the energy balance of the system, as well as the capacitive and conductive laws describing the thermal properties of the system. The change of the mass of the system as a function of time is obtained via the experimental data collected using the drop-counter. The temperature is calculated with the usual calorimetric relations. The temperature registered on-line is also represented in order to make it possible to compare the model output with the collected data.



reaction: it is with the data collected from the drop-counter that it is possible to determine the amount of acid added to the solution during the titration.

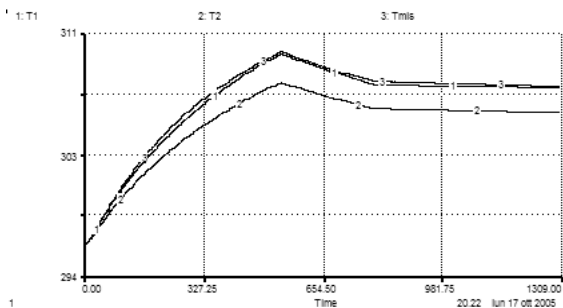
A further step consists in the description of the time evolution of the whole observed process.

Seen in this light, the dynamic modelling assumes major significance: it enables us to face the whole problem in terms of *instantaneous balance* for the energy of the system. The learner

Figure 4 shows a comparison of the experimental data with the data generated by the model under the assumption illustrated above: in order to get a better fit to the experimental data it is necessary to employ a value of the molar reaction enthalpy about 20 % greater (absolute value) than the standard molar enthalpy reported on thermodynamic tables. Alternatively, using this latter value for the molar reaction enthalpy, it is possible to get a similar fit using for the solution a heat capacity about 20 % less than that of water.

Figure 4: Comparison between measured data and model output.

1. Model output for the temperature using for the reaction enthalpy a value about 20 % greater (absolute value) than the standard molar enthalpy.
2. Model output for the temperature using the standard molar enthalpy for the reaction.
3. Measured temperature.



Conclusion and perspectives

The construction of a co-ordinated conceptual basis enables us to tackle fields of study in which the components of the various subjects involved intersect naturally. In this way, the pupils receive an initial but significant introduction to the complexity of the study of natural systems without, however, losing the specificity of the contributions of the single subjects.

The use of transversal instruments such as dynamic modelling enables us to pinpoint one of the fundamental aspects of scientific activity, that is to say the constant dialectical relationship between theory and experiment. In this way the pupil sees directly what it means to be confronted with the necessity to simplify the description of the system under scrutiny and is encouraged to seek solutions of an ever more general and unifying amplitude. In the case in point, for example, the next step could take the form of the introduction to a real dynamic mechanism for the chemical transformation being considered on the basis of the explicit use of the concept of entropy and of the differences in chemical potential as *driving force* for the reaction. As well as being more consistent with the proposed energy model, this approach would enable us to highlight the origin of the two contributions which determine the value of the reaction enthalpy: on the one hand, the variation in free energy, on the other the variation in the entropy accumulated in the system.

References

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