REFLECTING ON CONCEPTUAL LANGUAGE AND SYMBOLIC REPRESENTATIONS IN CHEMISTRY TEXTBOOKS

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SCHOOL SCIENCE AND SCIENCE EDUCATION RESEARCH

Traditional school science is presented and dealt with for its own sake, with little relation (or none) with societal and technological issues. As these are expected to be more interesting contexts for science learning, interrelations Science-Technology-Society (STS) have been explicitly considered as important in school science, by many educational authorities worldwide. The increasing importance given to such a contextual component is portrayed in many school science reforms wherever STS interrelations are emphasized and incorporated, to a different extent and in different ways, in school science curricula. The need to incorporate this component in school science appears related with evidence that most students construct and assimilate poor understanding of school science (Gamble *et al.*, 1985; Adams *et al.*, 1991; Garnett *et al.*, 1995). Research programmes on students' alternative conceptions in science have been particularly illuminating in this respect and their findings, in addition, have often shown that school science instruction does not take into account students' prior knowledge, much related to common sense knowledge (Osborne and Freyberg, 1985; Driver and Oldham, 1986). Traditional school science often stresses neat definitions, the carrying out of investigations following a pre-determined set of procedures, as well as resolving exercises following well known and previously trained applications of definitions and laws, often reduced to algorithms (de Berg, 1992). In traditional teaching approaches there is little room to look at and care about the different conceptualizations constructed by students involving interactions between prior knowledge, scientific concepts and their application to observable phenomena (Novak, 1988). Moreover, the construction of plural conceptual schemes by the learner in dealing with particular aspects of science within different contexts is ignored (Solomon, 1983). It is unlikely that such approaches help students improve their scientific understanding by constructing views closer to those shared by scientific communities.

PROBLEMATIC DISCOURSES IN SCHOOL CHEMISTRY

Chemistry, in addition, uses common words with specific meanings, that is, words that have certain meanings in common language, for example dissolve, or in maths, for example equation, have different, precise and theory-laden meanings in chemistry (Ebenezer and Gaskell, 1995). Furthermore, communication in chemistry relies much on symbolic language and discourses full of assumptions linked to accepted models and theories, where description and interpretation of phenomena are often entangled and shifts from approaches based on macroscopic properties of substances and materials to others based on sub-microscopic characteristics are frequent. In general, science textbooks are structured and built following similar trends to meet science education needs, especially by helping students to succeed in assessment tasks. While such specific discourses appear appropriate among chemists they may be inappropriate for quality chemistry learning (White, 1994). It may be necessary to "translate" them into language still accurate and meaningful to students (de Jong, 1996). This may require desintangling description and interpretation and making shifts between approaches and contexts explict. In other words, breaking tradition by making implicit assumptions common in chemistry discourses explict so that they appear meaningful and fruitful to learners. If teaching and assessment in Chemistry do not challenge and address students' views dissonant from those of the scientific communities, the students are bound to hold them throughout their schooling, while being, in spite of that, simultaneously, successful in their academic lives (Fensham, 1994). In the long run, ignoring and bypassing such views, will have additional negative effects in the quality of science education due to the influence and repercussions in the knowledge and skills science teachers require.

REFLECTING ON EXCERPTS FROM CHEMISTRY TEXTBOOKS: A PROGRAMME FOR TEACHER PROFESSIONAL DEVELOPMENT

Metacognition seems powerful for science teacher professional development within these fairly novel demands, which mean teaching for better science learning (Gunstone, 1994). This communication will report on a chemistry teachers' development programme focussed on analysis and discussion of conceptual language and symbolic representations widely used in school chemistry resources, particularly in textbooks. This activity was chosen to help teachers become more aware of learning problems related to specific and widely used language in school chemistry. It was also intended to help them develop metacognitive strategies by questioning and reflecting on the roles to be played by the different actors performing in teaching/learning processes, that is adopting enquiring ways of being. The awareness of the gap between views on quality learning of science education researchers and science teachers influenced these choices (White, 1994; Gunstone *et al.*, 1994). The belief that the tradition of teaching disciplines, with little or no reference to other disciplines or to everyday and familiar situations, experienced by teachers throughout their lives, both as students and as professionals, therefore culturally embedded, works as a barrier to using both research findings and STS in a chemistry teaching context reinforced the idea of undertaking these project with teachers. Due to the apparent pre-eminence of textbooks in shaping the roles played by science teachers in their professional activity, it was deemed necessary to use them as a starting point to develop more inquirying attitudes hopefully adopted by these professionals. A number of pre-selected excerpts taken from some of the 10th year (15-16 year old pupils) chemistry textbooks adopted in Portuguese secondary schools was used. Furthermore, some of the chemistry learning problems reported in science education literature were discussed and associated with problematic language present in some of the excerpts discussed. A limited number of Portuguese secondary school chemistry teachers participated on analysis and discussion of these excerpts with the research team. The results of this programme are encouraging, insofar as promoting awareness of some learning problems, rooted on conceptual language and symbolic representations, and of the need to develop inquiring attitudes and metacognitive strategies in teaching chemistry.

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School Science and Science Education Research

Traditional school science is presented and dealt with for its own sake, with little relation (or none) to societal and technological issues. As these are expected, among other things, to be more interesting contexts for science learning, Science-Technology-Society (STS) interrelations have been explicitly considered as important in school science by many educational authorities worldwide. The increasing importance given to such a contextual component is portrayed in many school science reforms wherever STS interrelations are emphasized and incorporated, to a different extent and in different ways, in school science curricula. The need to incorporate this component in school science appears related to evidence that most students construct and assimilate poor understanding of school science (Gamble *et al.*, 1985; Adams *et al.*, 1991; Garnett *et al.*, 1995). Research programmes on students' alternative conceptions in science have been particularly illuminating in this respect and their findings, in addition, have often shown that school science instruction does not take into account students' prior knowledge, much related to common sense knowledge (Osborne and Freyberg, 1985; Driver and Oldham, 1986). Traditional school science often stresses neat definitions, the carrying out of investigations following a pre-determined set of procedures, as well as resolving exercises following well known and previously trained applications of definitions and laws, often reduced to algorithms (de Berg, 1992).

Research on alternative conceptions in chemistry has inspired both reflections about the influence of students' ideas on subsequent learning and reflections on teaching implications aiming at improving students' understanding. In traditional teaching approaches there is little room to look at and care about the different conceptualizations constructed by students involving interactions between prior knowledge, scientific concepts and their application to observable phenomena (Novak, 1988). Moreover, the construction of plural conceptual schemes by the learner in dealing with particular aspects of science within different contexts is generally ignored (Solomon, 1983). It is unlikely that such approaches help students improve their scientific understanding by constructing views closer to those shared by scientific communities.

Problematic Discourses in School Chemistry

While recognising that students bring to instruction their own understanding of various phenomena, some research suggests that "curriculum decisions, pedagogical practices, imprecise use of language and the abstract and symbolic nature of much of the subject matter of chemistry" cause many of the alternative conceptions held by students (Garnett *et al.*, 1995).

Accordingly, words used in other contexts are also used in school chemistry with different meanings, namely words used in everyday language, like dissolve, or words used in maths, like equation (Garnett *et al.*, 1995; Ebenezer and Gaskell, 1995). In chemistry, such words, common to other contexts, are meant to have precise and theory-laden meanings. If these are not explicitly addressed, representations different from those intended are likely to be generated. Furthermore, communication in chemistry relies much on symbolic language and discourses full of assumptions linked to accepted models and theories. Description and interpretation of phenomena are often entangled and shifts from approaches based on macroscopic properties of substances and materials to others based on sub-microscopic characteristics are frequent. While such specific discourses appear appropriate among chemists, they may be inappropriate for quality chemistry learning (White, 1994). It may be necessary to "translate" them into language still accurate and meaningful to students (de Jong, 1996). According to Driver *et al.* (1994, in Garnet *et al.*, 1995), learning science involves complex interrelations between personal experience, language and socialisation. The specificity of both language and symbolism of chemistry requires teachers to play a crucial role in facilitating the discourse associated with the dialectics of chemistry learning. This may require disentangling description and interpretation and making shifts between approaches and contexts explict. In other words, breaking tradition by making implicit assumptions (common in chemistry discourses) explict so that they appear meaningful and fruitful to learners. If teaching and assessment in Chemistry do not challenge and address students′ views dissonant from those of the scientific communities, the students are bound to hold them throughout their schooling, while being, in spite of that, simultaneously, successful in their academic lives (Fensham, 1994). In the long run, ignoring and bypassing such views, will have additional negative effects in the quality of science education due to the influence and repercussions in the knowledge and skills science teachers require.

Language in School Chemistry

As a communication tool, language is part of teaching and learning in every subject. Both teachers and researchers recognize it as crucial for construction and development of conceptions. According to Vygotsky (in Watts, 1992), for instance, language and thought are related in complex ways and words are the means by which thought comes into existence. Meanings of words are regarded as thinking phenomena, evolving and changing as a person grows up and develops.

In science classrooms, in general, and in chemistry classrooms, in particular, students have to cope not only with language generically used in other subjects but also with specific symbolic language, referred to above. According to Sutton (1992) scientific language is a "system of interpretation" that allows people to "process and work over [scientific] ideas" and when scientific ideas evolve, language of science also evolves, that is, scientific ideas and language of science are interdependent. However, in classroom practices, scientific words are often reduced to labels for entities of various degrees of tangibility, often associated with time and curriculum constraints. Language interpretation is not encouraged and practiced enough by school chemistry, namely by most learning resources used in classrooms. This language discussion deficit has negative effects on students′ construction of the various meanings, often unintended, and on teachers′ awareness and understanding of the diverse senses that students make and develop. Research on alternative conceptions has highlighted this (Anderson, 1990; Garnett *et al.*, 1995).

Teachers' awareness of problems related to language of chemistry is the first step to improve its learning, which must be followed by careful use and critical control of language in classrooms. It is crucial that teachers help their students to understand the different meanings intended with similar language used in the various teaching and learning resources, namely textbooks.

To help students to engage in active meaning making processes is an important part of teachers' role. This requires particular care with language used, as well as interpretation and reinterpretation of students' views in the light of those shared by scientific communities, often referred to as scientific conceptions. This, in turn, encompasses identification and clarification of the extent to which they resemble scientific conceptions and, on the other hand, the extent to which they differ from them. Such discussions enable more meaningful meaning making, therefore will improve the ability to relate views and ideas apparently unrelated and used in separate worlds, for instance at school, home, leisure or media.

Metacognition seems powerful for science teacher professional development within these fairly novel demands, which mean teaching for better science learning (Gunstone, 1994).

Reflecting on Excerpts from Chemistry Textbooks: a Programme for Teacher Professional Development

Due to the apparent preeminence of textbooks in shaping the roles played by science teachers in their professional activity, a number of pre-selected excerpts from chemistry textbooks were used as a starting point for a professional development programme, where conceptual language was a major concern. The programme focussed on analysis and discussion of conceptual language and symbolic representations widely used in school chemistry resources. The excerpts were selected bearing in mind their relation and potential usefulness to teach "Amount in Chemistry" - the first chapter of the 10th year Chemistry course. The belief that both the correctness and the accuracy of conceptual language are of utmost importance for quality learning, conditioned and determined the choice of this chapter. Such language requisites are also regarded as required to describe observations and convey interpretations of matter and its transformations, the essence of chemistry meaningful learning.

Teachers were personally approached and invited to participate in this non-conventional programme, that lasted over two weeks. It started prompting teachers to work over the excerpts, individually, and finished with a one-day workshop. A document was produced to put in writing what was intended with the programme. Teachers were reminded that often what is taught differs substantially from what is learned, and were explicitly asked to analyse and work over sixteen pre-selected excerpts taken from some of the chemistry textbooks for 10th year (15-16 year old pupils) adopted in Portuguese secondary schools. An accompanying letter was sent to the teachers with this document. It was an invitation to participate in the one-day workshop, the opportunity planned to share views and reflections, prompted by the excerpts, with other colleagues. This material was posted to teachers about two weeks before the workshop.

This strategy was chosen to help teachers become more aware of learning problems related to specific and widely used language in school chemistry, often ambiguous, and also to help them develop metacognitive strategies by questioning and reflecting on the roles played by the different chemistry teaching and learning resources, specially textbooks. Metacognitive strategies require time to analyse and reflect on concrete situations in order to become better aware of problems they may pose. They also require reflection and discussion of solutions in the light of the information available, in which research findings are regarded as playing an important role.

In the one-day workshop the seven teachers worked in three groups, after a brief welcome and presentation of the plan for the day. Each group was assigned a different set of excerpts and integrated two or three teachers assisted permanently by one researcher. Researchers were intended to help focussing on the analysis and discussions of conceptual language problems of the excerpts, and relate them with other situations in which similar problems show up. Small group discussion provided opportunities to share individual analysis and reflections with others so that teachers′ and researchers′ own views were broadened and enhanced. Each small group prepared and made a presentation of the main ideas coming up in the analyses and discussions undertaken. The presentations were followed by discussions in which other participants shared and discussed their own views with added confidence, may be resulting from analyses and reflections undertaken before the workshop. Chemistry learning problems reported in science education literature were taken into account, discussed and associated with problematic language portrayed by the excerpts.

In addition, this programme aimed at helping these professionals adopt more enquiring ways of being, which hopefully will enable them to transfer and apply metacognitive strategies to other situations and contexts in their professional life. The awareness of the gap between views on quality learning of science education researchers (White, 1994; Gunstone *et al.*, 1994) and science teachers influenced the choices made for this programme. The perceptions of chemistry learning problems rooted on language and of the potential of metacognitive strategies to solve them, determined and inspired this chemistry teachers′ development programme, which was devised, planned and implemented with teachers as active members in the research team. Furthermore, this programme worked as a means to engage some of the participants in a collaborative action research project, aiming at devising, producing, testing and evaluating materials, in which research findings are taken into account and STS interrelations are used as contexts for chemistry learning.

It is believed that correctness and accuracy of language become particularly important when STS interrelations are used as contexts for teaching and learning chemistry. Indeed, if learning is conceived as meaning-making and constructing representations close to scientific conceptions, then the use of such contexts for students′ learning requires clear, correct and unambiguous identification of systems, models and theories applicable in each situation,. Furthermore, it requires clear identification of instances where knowledge of chemistry is valuable and the extent to which it is applicable, as well as to distinguish between the meaning of words common to the world of chemistry and to outside worlds.

Examples of the excerpts selected and discussed

The following excerpts have been translated from Portuguese textbooks.

Excerpt 1. "If you throw a bit of metallic magnesium into a beaker with dilute hydrochloric acid, you'll notice the formation of abundant bubbles, as the metal dissolves." (Corrêa *et.al,* 1994)

Excerpt 2. "If chemical transformations are characterized by changes in the way atoms bond to one another originating the various molecular buildings, it is expected that the number and quality of those atoms remain unchanged during chemical reactions, that is, that the total mass of the reactants equals the total mass of the products of the reaction, i.e, the total mass of the substances involved in the reaction remains unchanged." (Corrêa *et al*, 1994)

Excerpt 3. "The numbers that precede formulae of each reactant and product represent the relative numbers of moles (and of molecules, in a molecular scale) that participate in the reaction.These numbers are called stoichiometric coefficients. Stoichiometric coefficients are meant to balance equations, that is, to satisfy Lavoisier's law." (Corrêa *et al*, 1994)

Excerpt 4. "A chemical reaction may be accompanied by a colour change of the system, by a variation of temperature, by the formation of a precipitate, by the production of a gas, by the disappearance of one or more of the reactants, etc."

"In a chemical reaction there is always the formation of new chemical species."

"When a chemical reaction takes place, the reactants originate other species. Given that the atoms, molecules and/or ions of each reactant species are *bonded* together, it is concluded that to form new substances bond breaking has to occur in reactants and bond forming has to occur in products so that new substances may be produced. That is, in a chemical reaction there is bond breaking between particles, on one hand, and new bonds are formed in the product species, on the other hand." (Santos and Teodoro, 1994)

Excerpt 5. "Let us analyse another situation: the flask contains NO_2 molecules (dark brown) and N_2O_4 molecules (colourless), which can be confirmed by spectroscopic analysis. In this system, the reaction can occur either in one direction or in the other - it is a reversible reaction." (Corrêa *et al*, 1994)

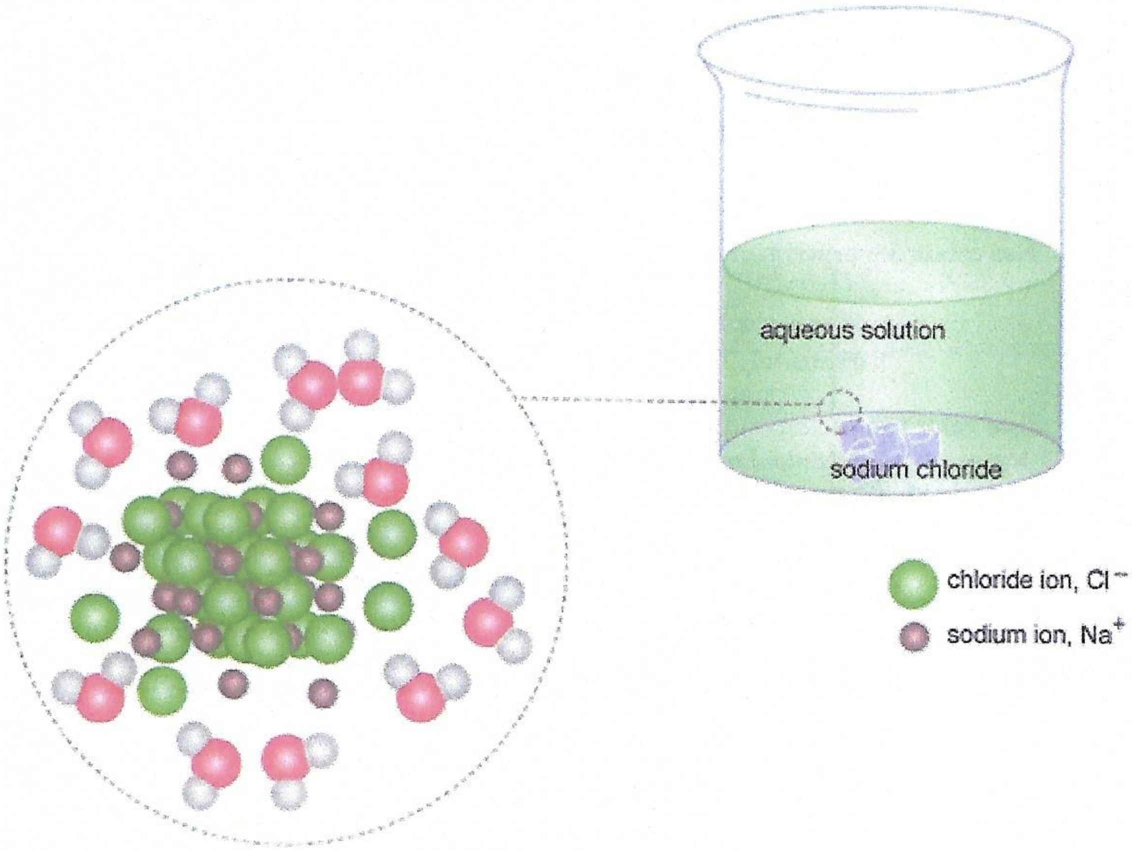
Excerpt 6." Until a saturated solution is obtained, the following process will occur:

$$NaCl\,(s) + aq \longrightarrow Na^{+}\,(aq) + Cl^{-}\,(aq)$$

When the solution gets saturated, the two following processes occur simultaneously

$$NaCl\,(s) + aq \longrightarrow Na^{+}\,(aq) + Cl^{-}\,(aq)$$

$$Na^{+}\,(aq) + Cl^{-}\,(aq) \longrightarrow NaCl\,(s)$$



(Santos and Teodoro, 1994)

Excerpt-Problems and Science Education Research

Anderson (1990) and Garnett *et al* (1995) have established a direct relationship between the use of language, by both textbooks and teachers, and some of the alternative conceptions students develop at various levels of school chemistry. An analysis of these excerpts supports this view, and allows the identification of language problems related to some of the students´ alternative conceptions in chemistry, described in literature. It points to and reinforces the need to increase teachers´ awareness of the importance of adopting more interpretative and reflective attitudes, which will help them to acquire and develop discourse analysis strategies leading to more critical use of language, particularly in chemistry classrooms.

Vague and imprecise language is common to all the excerpts herein considered. For example, careless use of scientific terms which have different meanings in everyday language (eg. "dissolve", "particle") - excerpts 1 and 4 - , or the avoidance of scientific terms, replacing them by everyday language (eg. excerpt 2, where the word "element" is absent). Sutton (1992) points out that this should be avoided, since everyday words and expressions should help in the process of building bridges to other knowledge, but shouldn't replace scientific ones. Furthermore, some instances (eg. excerpts 1, 3, 4 and 6) show that careless use of language is related to difficulties that students experience in distinguishing different levels of analysis of a phenomenom or of the components of a system (Anderson, 1990; Garnett *et al.*, 1995). Others show the reversal of cause-effect relationships (eg. excerpt 3), the transfer of properties of substances - macroscopic level, to their structural unities - sub-microscopic level (eg. excerpt 5) (Anderson, 1990; Driver, 1985; Garnett *et al.*, 1995; Pedrosa *et al.*, 1997). It appears that clear liaisons can be made between students' misunderstandings of the particulate nature of matter and excerpts 2 and 3 (Anderson, 1990; Garnett *et al.*, 1995), of chemical bonding and excerpts 4 and 6 (Anderson, 1990; Garnett *et al.*, 1995; Watts, 1992) and of the structural and interactive aspects of chemical reactions and excerpts 2, 3 and 5 (Garnett *et al.*, 1995).

Moreover, the word *dissolve* is used in excerpt 1 to describe an instance where a chemical reaction occurs. The excerpt clearly refers to a chemical reaction, but instead of referring to such a transformation, the word *dissolve* was chosen and is incorrectly used. As dissolve is a word widely used in everyday language with various meanings, to use it incorrectly in a chemistry context, as happens in this excerpt, will work as a barrier to the construction of the scientific concept. The word "particle" in chemistry classrooms is also problematic due to its use in various situations referring to different entities of quite different kinds and dimensions. The use of the word particle in excerpt 4 may help to mix up and confuse the concepts of chemical bonding, inter structural unities interactions and intra structural unities interactions, that students so often show (eg. Garnett *el al.*, 1995).

Students often mingle different levels of analysis when trying to interpret a phenomenom, often taking interpretations as observations, and the reverse, namely intertwining observations, inferences and abductions (Eco, 1982), while applying interpretative models and theories. However, this kind of vague and imprecise language and its underlying reasonings may come from discourses used by both textbooks and teachers. These may also help and reinforce such misinterpretations and misunderstandings, in particular, if and when oversimplified, quick and implicit transitions are made between levels of analysis. Discourses as the ones in excerpts 1 and 4 are good instances of misleading discourses containing such features.

Anderson (1990) points out that language used by both textbooks and teachers doesn't make a clear distinction between substances and atoms or molecules. Excerpt 3 clearly portrays this problem as the words *mole* and *molecules* are used as if the sole difference between their meanings concerned scale. Any other distinguishing features are omitted.

If teachers want to help pupils to distinguish models and theories from actual observations, then words have to be carefully chosen and the various models and assumptions underlying them have to be made explicit. Transferring macroscopic properties of substances to their constituent particles is another typical example of intermingling levels of analysis, in which the macroscopic level is mixed up with the sub-microscopic level. This problem was identified in various school groups by several researchers already referred to. The discourse used in excerpt 5 illustrates this.

Research on chemistry learning has identified some problems linked with the construction of inappropriate ideas about structural and interactive aspects of chemical reactions (Garnett *et al*, 1995). Anderson (1990) states that, even after instruction, some students think additively rather than interactively about the formation of molecules, and Watts (1992) refers to this idea stating that some students would perceive the atoms in a molecule as being "loosely joined together, like pins to a magnet". Such view may be reinforced by statements like those in excerpt 2 and illustrations like that in excerpt 6. Excerpt 5 explicitly considers reversibility of a chemical reaction as a sequence of events, quite similar to the way students inappropriately tend to view it. According to Garnett, *et al* (1995), inappropriate views of the dynamics of chemical reactions may be rooted in inadequate understandings of the particulate nature of matter and in students' inability to imagine, understand and construct representations of chemical reactions at the sub-microscopic level.

Last but not least, in excerpt 1 the word "metallic" is used to mean "solid". Ryan (1990) refers to a common use of "metals" as prototypes of "solids" and Pedrosa *et al.* (1997) found that fairly high precentages of students (including prospective science and chemistry teachers) show similar views.

Implications for Teacher Professional Development Programmes

The teachers participating in the workshop engaged actively in reflecting on conceptual language problems, in discussing them along with their own perceptions on student learning difficulties as well as with research findings related to them. In fact, some of the comments made above arose from discussions undertaken in the workshop.

As metacognitive strategies increase uncertainties and anxiety, and are time consuming, they depend strongly on teachers' inquiring attitudes to teaching as well as on professional pride. To develop such strategies, teachers need to be willing to keep learning and to value their role in helping students' learning. These requisites seem related to and linked with teachers' views regarding their role as facilitators and promotors of quality learning. That is, teachers who regard highly their contribution for better students' learning seem more motivated to engage in analyses, reflections and discussions about teaching and learning problems, and, in so doing, to improve their own knowledge, abilities and skills as teachers.

The tradition of teaching disciplines, with little or no reference to other disciplines or to everyday and familiar situations, experienced by teachers throughout their lives, both as students and as professionals, is part of school culture. It works as a barrier to using both research findings and STS interrelations as contexts in chemistry teaching. Therefore, if classroom practices are to be informed by research findings and use STS interrelations as contexts to teach disciplinary knowledge, teachers need to get information and learn on these two dimensions. The success of chemistry teaching using such contexts seems much dependent on teachers' multidisciplinary and interdisciplinary knowledge, which is at odds with their own school experience, both as students and as teachers. To construct such knowledge, of utmost importance for teachers' comfort in using STS interrelations in chemistry teaching, requires reflection by teachers and with teachers. It requires researchers and teachers to acknowledge their complementarity, namely the benefits of sharing views, uncertainties, knowledge and beliefs. It is urgent that researchers and teachers discuss the issues posed by novel teaching demands, strategies and approaches, as well as work in cooperation to take into account and make good use of research findings in classrooms.Taking part in research projects of this sort seems particularly appropriate.

The results of the development programme are encouraging, insofar as promoting awareness of some learning problems, rooted in conceptual language and symbolic representations. Teachers' apparent acknowledgment of the need to adopt more inquiring attitudes and develop metacognitive strategies to teach chemistry are also encouraging. However, as these professional ways of being do not occur overnight and effortlessly, results of development programmes of this kind are meant to be discrete and slowly achieved, when outcomes are looked for in teaching practices in real classroom settings. They require a changing of attitudes that can only be achieved in the long run. This was but the beginning of a challenging, demanding and also exciting path for some teachers in the group, as well as for researchers.

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