Make sense of nanochemistry and nanotechnology

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A class in a Scientific-Technological Lyceum (age 17) decided to produce a PowerPoint presentation to introduce nanochemistry and nanotechnology to the students in lower grades. Because the subject is very new, there was nothing in the School textbooks and, therefore, the students had to cooperate in order to find materials, to use ICT sources and to take decisions, such as selecting information and choosing slide layouts. Furthermore, the Cooperative Learning methodology was employed to solve the problem of setting up the presentation. To make nanochemistry and nanotechnology a reality for the students, they used a link between these new frontiers of Chemistry and subjects currently tackled at the Secondary School level. This was the quantitative determination of Ca" ions by using calcein, a luminescent chemosensor, in which well known concepts, such as chemical equilibrium and stability constants of coordination compounds, are involved. The educational aims of the project were to promote both content knowledge and social skills in Secondary School students. The activity created a good class atmosphere and also led to the retention of content knowledge.

Keywords: situated learning, cooperative learning, social skills, nanotechnology, quantitative analysis

Introduction

A booklet of the European Association for Chemical and Molecular Sciences (EuCheMS 2006) states: “the chemical and molecular sciences have been fundamental to the current economic and social achievements in Europe, and will continue to be the key underpinning sciences for future European innovation and industrial advances.” The students, who will be our future society, must learn for tomorrow’s world and so they need a meaningful knowledge of the basic principles of science. The PISA 2003 report (see the web site http://piscacountry.acer.edu.au/) showed that Italian students do not perform very well in Science; indeed, they have scored 486 (the average score was 500), which made them 27th out of 40 countries. Chemistry, like physics and mathematics, is not very popular among our students. Chemistry, in particular, is considered too hard to study, abstract and distant from everyday life. Many students believe they will never have to do anything with Science and Chemistry, or use them outside the school. Therefore, it is important that they understand how the Sciences impact on human life and how it might help in taking decisions concerning social, technological, and economic problems. A good strategy might be, in order to catch the students’ interest and motivate them, to starting with challenging topics at the cutting edge of science.

In this article we present a teaching-learning activity based on nanochemistry and nanotechnology. This choice required both the use of new technologies to carry out the activities and a non-traditional approach in teaching-learning methodologies to develop content knowledge and social skills.

The topic is unusual and it is not in the curriculum, so Information and Communication Technology (ICT) was indispensable to find and communicate the necessary information. Knowledge is indispensable but it must now be combined with a growing number of new skills in intercultural, computer, linguistic, and ecological fields. In preparing citizens for the future the role that education plays is fundamental. Tarozzi (2005), describing the profile of the ideal graduate of interest to a well-known chemical company, stresses the following abilities: business direction (strategic component), implementation (results), networking/team building, people development, personal leadership characteristics, communication skills. Content knowledge alone seems no longer to be sufficient, and social skills are a must in order to work successfully in a team as our complex society requires. Schools must keep up with cognitive, socio-cultural and technological changes. In this society that evolves so quickly, learning to learn has become a key concept. Starting from these considerations a complex activity was decided on to enhance the students’ capacity to face a complex society. The work involved individual and group activities, decision making, ICT use, practical work in the chemistry laboratory, and numerical exercises. The project was created on the basis of the constructivist theory for learner driven learning. Both traditional face-to-face instruction and the cooperative learning approach were used to carry out the project.

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Aims and activities

The educational aims of the project were to promote in Secondary School students’ content knowledge, consisting of a meaningful introduction to Nanochemistry and Nanotechnology, and to enhance the students’ social skills such as team work, communication and conflict management. The Cooperative Learning approach was employed to pursue both the aims.

The activities carried out by the students to develop the project are summarized in Table 1. To make nanochemistry and nanotechnology a reality for the students, it was necessary to find a link between them and subjects currently tackled at the Secondary School level. This link was the quantitative determination of Ca\textsuperscript{2+} ions by using calcein, a luminescent chemosensor; this process involves well known curricular concepts such as chemical equilibrium and stability constants of coordination compounds. A chemosensor is able to bind, selectively and reversibly, an analyte, and responds to the interaction with an analytically useful signal. A luminescent chemosensor responds to the interaction with a change in its luminescence. Calcein forms a fluorescent chelate with Ca\textsuperscript{2+} ions that can be quantitatively detected with a spectrofluorimeter (Hoelzl Wallach et al., 1959). In a supramolecular perspective calcein can be regarded as a simple multicomponent system (Lehn, 1995; Balzani et al., 2003) in which two different units, the receptor and the fluorophore are respectively responsible for target recognition and signal transduction. Although such system is not comparable in complexity and level of sophistication to the most recent prototypes of nanodevice, it presents some fundamental advantages: it is commercially available and reasonably cheap, and its simple function, namely the calcium recognition and its quantification can be intuitively understood, and visualized by means of accessible techniques such as absorption and emission spectroscopy. Finally, because of the important role played by Ca\textsuperscript{2+} and other ions in biological systems, this study focused on chemosensors and nanochemistry, provides a starting point for a multidisciplinary nanoscience approach.

<table>
<thead>
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<th>Table 1. Performed activities</th>
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<tr>
<td>• Creation of a PowerPoint presentation on Nanochemistry and Nanotechnology</td>
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<td>• Use of ICT</td>
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<td>• Design of a rubric to evaluate the presentation</td>
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<td>• Formulation of questions related to the objectives and contents of the presentation</td>
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<td>• Project processing, presentation and behavioural evaluation</td>
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<td>• Practical work concerning the spectrofluorimetric determination of Ca\textsuperscript{2+} in samples of water</td>
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Subjects and setting

A class (age 17) of the Scientific-Technological Lyceum – I.T.I. “L. Nobili” – of Reggio Emilia, a town in the northern part of Italy, had the opportunity of attending a series of seminars on the new frontiers of Chemistry. At the end of the seminars the class was requested to choose the best way to introduce to the students in the lower grades one of the topics discussed in the Seminars. The class, inspired by the lecture “Natural and artificial molecular machines” delivered by Margherita Venturi, chemistry professor of the University of Bologna, decided to select “Nanochemistry and Nanotechnology” as the topic and to prepare a PowerPoint presentation (see the web site: www.itisnobili.org/seminari.htm). Nanotechnology, the new technology dealing with the manipulation of materials billonths of a meter in size, was introduced by explaining how it could impact our life in years to come. Scientists are struggling with individual atoms to develop molecule-sized computers, tiny tools for health care and even stain and wrinkle-resistant clothes and sun screen creams.

First, the students looked at the PowerPoint presentation of the European Commission, Community Research (CORDIS): ‘How can you explain what is meant by nanotechnology?’, and then they started to plan the work.

Because the subject is very innovative, nothing could be found in the available Secondary School textbooks. Therefore, the students had to work together in order to find materials and to take decisions. Materials, like information and images, were found by using the Internet. Then they had to select information and choose the layout for the slides. This kind of activity is an open ended problem and can be viewed with favour by the students who dislike Science because only one solution is expected to be correct (Millar, 2006). Furthermore, the students of the class involved in the project seemed to be lacking in critical thinking. When stoichiometric problems on equilibrium, like acid-base, solubility or coordination compound stability, were posed, they immediately applied any algorithm, and rushed through a numerical output without considering its congruence within the context. This kind of behaviour shows their scarce capability to be critical and their disinclination to analyse. “The focus of the students is on getting the “right” answer whether or not it is reasonable” ... “they take every number in the question and others that they assume have some relevance and bang them into the calculator in a desperate attempt to get an answer, and it’s just a matter of “garbage in, garbage out”” (Hoffman, 2007).

To prevent this behaviour, which seems to be widespread in the student community, it is necessary to improve their High Order Cognitive Skills (HOCS), such as creative and critical thinking (Zoller and Tsaparlis, 1997) because “a chemically literate person is able to raise a question, look for information and relate to it” (Shwartz, 2006).

Research has revealed (Sharan and Sharan, 1992; Kagan 1994) that Group Investigation methodology is effective in increasing student HOCS and therefore this approach was adopted to create the presentation.

The Group Investigation approach calls for social skills such as group work planning and co-operative work to achieve the identified objectives, and the review of the contributions and agreement on the ways to improve the team work. The creation of the final product required that the students found, interpreted and selected information, all of which enhanced their content knowledge. This situation
corresponds to a situated learning approach (Stein, 1998) in which knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday life: knowledge is socially embedded, and learning occurs from socially-mediated collaborative processes.

This group investigation project was largely based on the use of ICT, making the computer, the main components of the learning environment. As a consequence, these students learned to use ICT well, which is not only a curricular subject, but also a very popular information source in everyday life and in almost every work place. Furthermore, situated learning that involves well known tools could help in approaching the new topic with a positive feeling. To carry out the group investigation the students had to use knowledge, social skills and technological tools similar to those encountered in the real world, and therefore this activity can be regarded as authentic learning. Authentic learning (Muller) needs authentic tasks that are used to assess the ability of the students in applying standard-driven knowledge and skills to real-world challenges. A task can be considered authentic when the students have a) to construct their own responses rather than select one answer in a predefined list, and b) to face challenges similar to those of the real world. Authentic learning needs authentic assessment. Authentic assessment includes a task that the students have to perform and a rubric by which their performances and the task will be evaluated.

The steps for authentic assessment are: 1) selection of the standards, 2) selection of an authentic task, 3) identification of the criteria of the task and 4) design of the rubric. For this project the teacher and the class identified the following Standards:

- Process Standard: finding and evaluation of relevant information; use of ICT to communicate.
- Content standard: description of the nanotechnology and its applications; use of a luminescent chemosensor for the quantitative determination of Ca²⁺.

The authentic task consisted in the creation of the PowerPoint presentation to be used for peer education.

**Methods**

Cooperative Learning (Johnson and Johnson, 1994) was the principal method employed and the structures chosen for the activities (Kagan, 1994) were:

- ‘Jigsaw’ for practical work
- Group investigation to set up the presentation.

**‘Jigsaw’ for practical work**

The activity concerning practical work was structured according to the jigsaw approach developed by Aronson (Aronson) in the seventies. In this technique the learning unit is divided into parts and each member of a group specializes in one of these parts. As every part is essential to compose the jigsaw, every student’s contribution is essential to complete the entire product. In the jigsaw approach each member of the groups learns to become an expert in a subtopic, and the students involved in the same subtopic study together to master the subject. After this stage the ‘expert’ comes back to his original team to teach the subtopic to the team-mates, and to learn from them the other subtopics.

For the practical work carried out in the laboratory, each group was composed of five students to whom different roles were assigned.

1. **Sampler**: the student taking care of all the operations needed for the sample preparation
2. **Instrument setter**: the student setting the instrumentation used
3. **Recorder**: the student involved in keeping records of all the observations and the data collected
4. **Data analyser**: the student elaborating data and graphics like calibration curves
5. **Ambassador**: the student responsible for communication within the group, with other groups and with the teacher.

The arrangement of the students into expert groups enabled them to share opinions and to solve problems more successfully. The **sampler expert group** gained experience in using micropipettes, in calculating concentrations, and in manipulating the sample correctly (e.g. avoiding a long exposure to air). The **instrument expert group** learned how to set the instrument, and why, and how to insert the sample properly. The **recorder expert group** found the best way to record observations, times and data. The **data analyser expert group** solved a series of problems to facilitate the set up of the calibration curve and the quantitative determination of the calcium concentration in samples of water the **ambassador expert group** ensured that all the information was shared by the group-mates, kept the different groups in touch and, when necessary, asked the teacher for help. Each expert group identified the critical points in their task and cooperated to solve them.

**Group Investigation to set up the computer aided presentation**

The Cooperative Learning method was employed to solve the problem of setting up the presentation. Students, grouped in four teams of mixed abilities, worked on structured tasks under the conditions that meet the five criteria of Cooperative Learning:

1. Positive interdependence
2. Individual accountability
3. Face to face interaction
4. Appropriate use of interpersonal skills
5. Regular group processing.

The **Group Investigation theory and philosophy** was described by Sharan and Hertz-Lazarowitz (1980). According to Sharan (1994), Group Investigation comprises four basic features: investigation, interaction, interpretation and intrinsic motivation. All these features are incorporated in the six stages of the **Group Investigation model** that are briefly discussed in the following.

**Stage 1: the class defines subtopics and organises into research groups.** The students chose the topic of the research having examined the material provided by the teacher and the seminar speaker; then they split the topic into subtopics. To identify the subtopics the students formulated questions. The aim of these questions is to generate a pool of information
Table 2. Rubric designed for the authentic assessment of the PowerPoint presentation.

<table>
<thead>
<tr>
<th>Criteria \ Score</th>
<th>Exemplary</th>
<th>Proficient</th>
<th>Satisfactory</th>
<th>To be resubmitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research and Organization</td>
<td>Note cards indicate that you accurately researched a variety of information sources, recorded and interpreted significant facts.</td>
<td>Note cards show that you recorded, evaluated, and synthesized relevant information from multiple sources.</td>
<td>Note cards show that you sometimes misinterpreted information from four or fewer resources.</td>
<td>Note cards show that you recorded information from four or fewer resources.</td>
</tr>
<tr>
<td>Content</td>
<td>The content is written clearly and concisely with a logical progression of concepts and information. The project gives a clear sense of the main idea.</td>
<td>The content is vague in conveying a point of view and does not create a strong sense of purpose. Some of the information is not appropriate.</td>
<td>The content lacks a clear point of view and a logical sequence of information. The sequence of concepts is unclear.</td>
<td></td>
</tr>
<tr>
<td>Presentation</td>
<td>All slides have transitions and effects that work. Backgrounds look good concerning font styles and colour.</td>
<td>Transitions and effects work only in some slides. Backgrounds look good concerning font styles and colour.</td>
<td>Few, if any, transitions and effects are placed on slides. Backgrounds clash with font colour and styles.</td>
<td>No transitions and effects are placed on slides. No backgrounds were chosen to go on the slide.</td>
</tr>
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</table>

The final grade of the computer aided presentation, obtained as total score/3, is compared to the evaluation scoring scale: exemplary (9-10); proficient (8-7); satisfactory (6); to be resubmitted (<6).

useful for giving a description of nanotechnology good enough for younger students. The three major questions that arose were:

1. What is meant by nanotechnology and when did it begin?
2. What is nanotechnology used for?
3. Where can the research centres on nanotechnology be found and what are the research achievements?

Each of the first three groups had the task of developing an adequate answer to one of the previous questions, while the fourth group had the coordinating role, which consist of maintaining the contact between the groups and the teacher, ensuring that the research results were shared by all the groups, and that they all meet the deadline.

Stage 2: the groups plan their investigations. The team members worked together in carrying out the research, mainly by using the Internet. They decided how to reach the objectives and how to assign tasks among the members. This operation allowed them to become conscious about their abilities and skills and how to share them to be a complementary and successful group. Every team had an ‘ambassador’ and a ‘time-keeper’. The ambassador took care that the information was shared inside the group and with the coordinator group; furthermore, when necessary, he had the role of asking for help from the teacher. The time-keeper helped the group to carry out the task without wasting time.

Stage 3: the groups carry out their investigations. The team members found, analysed and selected information. They organized the materials and decided on the information, images and films to be selected. Decision making and conflict management were the skills to tackle.

Stage 4: the groups plan their presentations. Each group planned its presentation after having chosen the main ideas on the topic and after having taken the decision about the most effective sequence, layout, and animation. In the meantime, a rubric was designed by the students and revised with the help of the teacher (Table 2) to make authentic assessment of the presentations.

Stage 5: the groups make their presentations. Each group gave its presentation; the speakers were randomly chosen from the groups. The students from the Group 4, did not give any presentation, they were involved, with their classmates, in assessing the presentation. Their communication abilities were not meant to be assessed this time, whereas they cooperated in the creation of the overall presentation.

Stage 6: the teacher and all the students evaluate the projects. All the students assessed the presentation using the rubric. They shared ideas about the effectiveness of their products, their feelings and roles during the experience, and proposed suggestions for the future.

Results

The outcomes were assessed in several ways. The traditional methods (i.e. questions, exercises tests, gap-filling exercises, summaries, etc…) alone were not appropriate to the learning environment created during the development of the project. As a consequence, it was decided that a combination of methods would be used: the traditional ones to assess the subject content and the authentic assessment (Burke, 1999) for the authentic learning tasks. The assessment tools were:

- rubric design to assess the presentation,
- behavioural checklist,
- cooperative project evaluation,
- open ended questions for academic assessment.

The overall presentation was assessed with the aid of the rubric designed by the students as shown in Table 3. Checklists (Johnson and Johnson, 1994) and open-ended
reflection sheets were used by the students to assess their own social skills and those of their group-mates; the checklist results are shown in Table 4. This was done to enhance metacognitive reflections and cooperative behaviours.

For the project evaluation the students were asked to describe briefly their contribution to the cooperative project, and the other group members confirmed this assessment with their signatures. Furthermore, to help self-reflection, the students had to answer to the following questions. Are you satisfied with the development of the project? If not, what could be done to improve it? How could your team work together more effectively? These were intended to help the metacognitive process. The teacher and the class discussed the observed difficulties and highlighted the positive results both from the academic and social viewpoints.

Then the teacher assessed the individual achievements with open ended questions. After the seminars almost all the students achieved the objectives of content knowledge (Figure 1) where the results of the academic assessment at different times are reported. After the project has been carried out, all the students performed at higher levels, with the exception of a weak student who had language problems. After some months even the weak student had recovered, and the whole class performed at an adequate or very good level.

**Conclusion**

Starting from a challenging topic at the cutting edge of Chemistry, which could be perceived as abstract and distant from everyday life, the students have been able to find and select information about it and to handle a simple multicomponent system to carry out a quantitative determination of calcium ions in commercial samples of water. The self assessment behavioural checklist results demonstrate that almost all the students always or frequently showed positive behaviour. They contributed ideas and knowledge, asked and gave help and participated in making the group work, which helped to enhance social skills, especially team work.
Almost all the students assessed the project as valuable, especially for the clear and logical progression of significant content. The research work and the selection and organization of the content were assessed as valuable as well. The group processing involved in these moments of reflection and evaluation demonstrated highly positive results. The increase in the students’ subject knowledge and its long term retention, the positive results of the rubric scores for the presentation, and the self assessment outcome clearly highlight the project’s effectiveness.

We hope that this approach, that enabled the students to learn effectively in a supportive environment, could be a step towards a better understanding and perception of Chemistry and its important role in everyday life.

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