

RESEARCH REPORT

Providing high school chemistry students with opportunities to develop learning skills in an inquiry-type laboratory: a case study

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An inquiry-type laboratory was implemented into the chemistry curriculum in high schools in Israel. The study included development of inquiry-type experiments, assessment tools for a continuous assessment of students' achievements and progress, and a long-term professional development program for teachers who decided to implement the program in their schools. The main goal of the study was to provide students with opportunities to learn in an authentic environment in which they can construct their knowledge regarding chemistry phenomena. In addition, by conducting the experiments students were able to practice inquiry skills such as asking questions, hypothesizing, and suggesting a question for further investigation using an experiment that they planned. The analysis of students' laboratory reports clearly showed that they improved their abilities regarding inquiry learning in the chemistry laboratory.

Background

Laboratory activities have long had a distinctive and central role in the science curriculum, and science educators have suggested that many benefits accrue from engaging students in science laboratory activities (Garnett et al. 1995; Hofstein and Lunetta 1982, 2002, Lunetta 1998, Tobin 1990). More specifically, they suggested that, when properly developed, inquiry-centered laboratories have the potential to enhance students' meaningful learning, conceptual understanding, and their understanding of the nature of science. Inquiry-type experiences in the science laboratory are especially effective if conducted in the context of, and integrated with, the concept being taught.

At the beginning of the twenty-first century, we are entering a new era of reform in science education. Both the content and pedagogy of science learning and teaching are being scrutinized and new standards that intended to shape and rejuvenate science education are emerging (National Research Council 1996). The *National Science Education Standards* (National Research Council 1996) reaffirm the conviction that inquiry is central to the achievement of scientific literacy. The *Standards* use the term inquiry in two ways (Bybee 2000): (1) inquiry as *content understanding*, in which students have opportunities to construct concepts, patterns and to create meaning about an idea in order to explain what they experience; and (2) inquiry in terms of *abilities*. Under the category of abilities or skills, Bybee

includes identifying questions, forming hypotheses, designing and conducting scientific investigations, formulating and revising scientific explanations, and communicating and defending scientific arguments. Many of these abilities are in line with those that characterize inquiry-type laboratory work.

Teaching and learning science by inquiry is an approach that places the student in the center of the learning process. Such an approach to the teaching and the learning of science poses challenges to both students and their teachers (Krajcik et al. 2001).

Learning in and from science laboratories

Many research studies have been conducted to investigate the educational effectiveness of laboratory work in science education in facilitating the attainment of the cognitive, affective, and practical goals. These studies were critically and extensively reviewed in the literature (for example, Blosser 1983, Bryce and Robertson 1985, Hodson 1990, Hofstein and Lunetta 1982, 2002, Lazarowitz and Tamir 1994). From these reviews it is clear that, in general, although the science laboratory has been given a distinctive role in science education, research has failed to show simplistic relationships between experiences in the laboratory and student learning. Hodson (1990) has criticized laboratory work and claimed that it is unproductive and confusing, since it is very often used unthinkingly without any clearly thought-out purpose, and called for more focus on what students are actually doing in the laboratory. Tobin (1990) suggested that meaningful learning is possible in the laboratory if students are given opportunities to manipulate equipment and materials so as to be able to construct their knowledge of phenomena and related scientific concepts. However, he claimed that, in general, research has failed to show evidence that such opportunities really exist. Gunstone (1991) suggested that using the laboratory to have students re-structure their knowledge is straightforward; however, he also claimed that this view is naive. This is true, since the picture relating to practical work, as derived from constructivism, is more complicated. Also Gunstone and Champagne (1990) suggested that learning in the laboratory would occur if students were given ample time and the opportunities for interaction and reflection in order to initiate discussion. This approach, according to Gunstone, was under-used, since students in the science laboratory are usually involved in technical activities and few opportunities are given to them to present their interpretation and beliefs about a practical exercise.

It is suggested that, if designed properly the science laboratory has the potential to play an important role in attaining cognitive skills such as scientific thinking, inquiry skills as well as understanding the process of scientific protocols. An attempt to investigate personal construction of meaning in the science laboratory was conducted by Keys et al. (1999). In their study conducted among eighth-grade students they found evidence that the use of science writing heuristic facilitated students to generate meaning from experimental data make connections among procedures, evidence, and claims, and engage in meaningful learning.

Several methodological shortcomings inhibited the research community's ability to present a clear picture regarding the science laboratory as an effective environment for helping students to develop cognitive skills. These include the following:

- Lack of control over the type of activities in which students are involved (Hofstein and Lunetta 1982, 2002). Also, the learners are only rarely given opportunities to ask questions about phenomenon, conduct hands-on research, and prove and investigate ideas. In other words, in the science laboratory, students obtain very little opportunities to be in control of their own learning, and thus to develop and enhance cognitive skills (Baird 1990, 1998, Keys et al. 1999, Roth 2001).
- A mismatch between teachers' goals for practical work and students' expectations of such work (Chang and Lederman 1994, Wilkenson and Ward 1997).
- The lack of valid and usable tools with which to assess students' achievement and progress in inquiry-type science laboratories (Lazarowitz and Tamir 1994). In addition, many teachers lack experience with assessment methods aimed at assessing their students in the science laboratory (Yung 2001). As a result, in many cases, students' final grades do not include their achievements in practical experiences. Thus, it is always possible that students do not perceive the practical work to be an important and an integrated component of their chemistry learning.
- Lack of appropriate professional development of science teachers to teach in inquiry-oriented, student-centered laboratories, such that they act as facilitators and as providers of guidance, and not solely as the source of scientific information and knowledge (Tamir 1989, Gardiner and Farragher 1997).

The study

Objectives of the study

The main goal of this study was to develop, implement, and assess the learning outcomes of inquiry-based laboratory experiments in the context of high school chemistry in Israel. The study was designed so that the aforementioned shortcomings would be minimized. It is suggested that control over these variables might create conditions in which students will have opportunities to construct their knowledge and accept responsibility for and assume control over their learning process. More specifically, the objectives of this study were as follows.

- To develop inquiry-type chemistry experiments in which the students will be involved in the various components that comprise such experiments, and also to provide students with opportunities to experience learning and construct knowledge in a direct way.
- To develop a valid, reliable, and usable tool to assess students' achievements and progress in such experiments. It is suggested that assessing students' achievement continuously over the years in which they learn chemistry will enhance their motivation to learn in the laboratory.
- To develop a method for the professional development of chemistry teachers to enable them to implement inquiry-type laboratories.
- To analyze students' ability to learn in and from chemistry laboratories in general, and to develop scientific (inquiry-type) skills in particular, as are presented in their reports.

Components of the study

The development and implementation of the inquiry-type experiment consisted of three components; namely, the development of laboratory exercises, the development of assessment tools, and the professional development of teachers.

Development of inquiry-type experiments

The first stage of this study was devoted to the development of a series of about 50 experiments to be incorporated in the regular chemistry curriculum used in Grades 11 and 12 in Israel. Almost all the experiments were integrated into the framework of the key concepts taught in chemistry (e.g. acids–bases, stoichiometry, oxidation–reduction, bonding, energy, chemical equilibrium, and the rate of reaction). The inquiry experiments that were developed range from those that are totally ‘open’ to investigation, to those in which the student is asked to conduct only a ‘partial inquiry’. Some of the experiments include the design and planning of the experiment as well as interpreting results and arriving at a scientific conclusion, while other experiments also included the stage of suggesting a hypothesis and asking relevant questions. The teachers have the option of focusing on certain skills based on their teaching objectives and their students’ abilities and interests. It should be noted that students who study chemistry in which the inquiry-type experiments were not implemented are conducting experiments that are largely confirmatory in nature, mainly following stage-by-stage procedural instructions provided by the laboratory manual. These students have only limited opportunities (including time) to develop those abilities that characterize inquiry-type laboratories.

Table 1 presents the stages that students undergo in conducting a typical inquiry-type experiment, familiarly called ‘experimenting with a couple of test tubes’. This experiment can be conducted as an introductory experiment in the context of learning the topic that deals with energy changes in chemical reactions (for more details about the experiment, see appendix 1). Note that students get no information regarding the compounds and the reaction that takes place. This ensures that students will focus on the task and will follow the various stages of the inquiry pathway.

Development and implementation of assessment tools

The science laboratory was defined by Kelly and Lister (1969) and by Tamir (1972, 1990) as a unique and distinct mode of learning and instruction that differs from other modes of instruction used in science. Thus, it deserves a distinct method of assessment. In general, because of logistical constraints, lack of experience, and limited exposure to professional development activities, science teachers are reluctant to implement practical assessment tools (even if they exist) in their classroom laboratories. More recently, Yung (2001), on the basis of a study conducted in Hong Kong, presented data that demonstrates the complexity of assessment in school science laboratories. He claimed that teachers should be aware of the potential of assessing their students regarding the improvement of teaching and learning. Unfortunately, in many cases, students are assessed on the basis of paper-and-pencil achievement tests that, in general, neglect many of the most

Table 1. Phases in an inquiry-type experiment.

<i>Phase</i>	<i>Abilities and skills</i>
Phase 1: pre-inquiry	
Describe and detail the apparatus in front of you	Conducting an experiment
Add drops of water to the small test tube, until the powder is wet. Seal the test tubes immediately	
Observe the test tube carefully, and record all your observations in your notebook	Observing and recording observations
Phase 2: the inquiry phase of the experiment	
1. Hypothesizing	
Ask relevant questions. Choose one question for further investigations	
Formulate a hypothesis that is aligned with your chosen question	Asking questions and hypothesizing
2. Planning an experiment	
Plan an experiment to investigate the question	
Present a plan to conduct an experiment Ask the teacher to provide you with the equipment and material needed to conduct the experiment	Planning an experiment
Conduct the experiment that you proposed	
Observe and note clearly your observations	Conducting the planed experiment
Discuss with your group weather your hypothesis was accepted or you need to reject it	Analyzing the results, asking further questions, and presenting the results in a scientific way

important components of students' performance in the science laboratory in general, and the inquiry-type laboratories in particular.

To assess students' achievement and progress during the performance of the experiments, two assessment tools were developed (Levy Nahum, 2000). These tools are used continuously by the chemistry teachers in their classroom laboratories. The assessment tools combine the assessment of a group by means of a 'hot report' and the teacher's observations of the individuals in the group. The 'hot report' is the group's product and is prepared in the laboratory during or immediately after the laboratory exercise.¹ The development of the assessment tools included the identification of assessment criteria and the weight assigned to each criterion. This procedure was conducted by the trial chemistry teachers who participated in the intensive professional development workshop aimed at preparing them for the implementation of the inquiry experiments in their schools. For details about the weight assigned to each criterion, see table 2.

Note that such a table is prepared for each student for each experiment. The teacher can decide whether to assess all the experimental components or only part of them. This depends on the teacher's goals, curricular constraints, and the topic taught at that time.

All together, the assessment tools underwent several revisions. The changes made were based on the trial teachers' feedback from their respective schools and from the discussions and deliberations that were held during the professional development of the trial teachers (for more details on the trial teachers' professional development, see the next section). This procedure ensured the improvement of the assessment tools with regard to their validity and usability. In order to ensure a high level of reliability, the last version of the assessment tool was validated by comparing its use by two assessors (trial teachers). The degree of agreement between the two assessors was obtained by calculating the *Weighted Kappa Coefficient* (Agresti 1990). The degree (percentage) of agreement that was obtained between two assessors was in the range 0.65–0.75. As mentioned earlier, individual students were also assessed by the teacher directly observing some of the criteria such as social skills and each student's contribution to the development of the various inquiry stages of the experiment. The sum of the results of the assessment of the 'hot reports' and of the teacher's direct observations, in about 20 experiments, during a period of 2 years, determines the students' grades in the laboratory. This grade counts for 20% of their total grade in chemistry.

Professional development of chemistry teachers

To teach science using the inquiry method, teachers need to undergo intensive and comprehensive professional development that will equip them with the necessary knowledge and abilities. More specifically, teachers need to undergo inquiry-type experiences similarly to their own students (Kennedy 1998, Kracjik et al. 2001). According to Tamir (1989), short-term professional development experiences cannot provide teachers with the know-how that will help them to adequately operate in the more demanding, student-centered learning environment in which they may face unforeseen and unplanned situations. Marks et al. (1998) observed that, in the laboratory, teachers often face difficulties in helping students to formulate thoughtful questions, in designing investigations, and drawing conclusions. Also, DeCarlo and Rubba (1994), in the context of the chemistry laboratory, found that in general teacher–student interactions were mostly based on low-level procedural questions and answers. In order to sustain changes in teachers' beliefs about their role in the science laboratory, to improve the effectiveness of their teaching, and to reduce their anxiety regarding open-ended type experiences in such laboratories, there is a vital need to adopt new professional development standards for science teachers (Tobin 1990).

The *National Standards in Science Education* (National Research Council 1996) and other publications (for example, Bell and Gilbert 1996, Loucks-Horsley et al. 1998) state that, in order to bring about profound changes in teachers' behavior and in their teaching styles, we need to provide them with long-term and continuous professional development. Such experiences have the potential to bring teachers to a higher-level of knowledge (both content and pedagogical content knowledge), with more flexibility and confidence, regarding their ability to make the laboratory a more educationally effective learning environment.

As mentioned earlier, in order to implement learning by inquiry in the science classroom and the laboratory, it is essential that teachers have first-hand experience with all the cognitive dimensions and the practical stages that accompany such learning. This includes asking relevant questions, handling and solving unforeseen problems, designing experimental conditions to resolve research questions, working in small collaborative groups, and conducting experiments. To sum up, teachers must switch from the 'teaching-by-telling' instructional method, to listening to students' ideas and questions. In addition, in order to make the teachers more aware of the importance of assessing their students in the laboratory (Yung 2001), they themselves need training and experience in using assessment tools that have been developed. The teachers who were involved in this study had to undergo an intensive summer school course (56 hours) in which they had an opportunity to conduct about 40 experiments that were also conducted in small groups, which also included practicing the use of assessment tools. The professional development was conducted during the period of 2 years, during which the trial teachers met once every month for about 5 hours. During this period the teachers implemented the inquiry method in their schools and their professional development was provided with continuous support and guidance. Throughout the professional development, the teachers were asked to fill in feedback questionnaires in which they were asked to report on problems that they had encountered throughout the implementation phase. Information was also gathered regarding the usability of the assessment tools, and the adjustment they made with the inquiry method in order to tailor the exercises to the teacher's goals and also to their students' abilities and interests. The feedback provided by teachers and the deliberations held with their professional development tutors helped in the improvement of the assessment tool regarding its validity and usability.

Conducting the inquiry-type laboratories

Inquiry-type experiments were implemented in the school chemistry laboratory. As previously mentioned, this implementation took place in a situation in which control was provided over such variables as professional development of teachers, the continuous assessment of students' achievement in the laboratory, and the allocation of time and facilities (materials and equipment) for conducting inquiry-type experiments.

In the chemistry laboratory the students performed the experiments in small groups (three or four students), following the instructions given to them by the laboratory manual. Table 1 illustrates the various stages that each of the groups underwent in order to accomplish the inquiry task. In the first phase (the pre-inquiry phase), the students are asked to conduct the experiment based on specific instructions. This phase is largely 'closed', in which the students are asked to conduct the experiment based on specific instructions given in the laboratory manual. Thus, this phase provides very limited inquiry-type experiences. The 'inquiry phase' (the second phase) is where the students are involved in more 'open-ended' type experiences such as asking relevant questions, hypothesizing, choosing a question for further investigation, planning an experiment, conducting the experiment (to include observations) and, finally, analyzing the findings and arriving at conclusions. It is thought that this phase allows the students to learn and experience science with understanding. Moreover, it provides them with the opportunity to construct their knowledge by actually doing scientific work.

Table 3. The distribution of the groups according to experience with inquiry-type experiments and their grades.

	<i>11th-grade students</i>		<i>12th-grade students</i>	
	<i>Inexperienced</i>		<i>Inexperienced</i>	<i>Experienced</i>
Number of classes	2		2	3
Number of groups (reports)	9		8	8

Of special interest regarding the issue of learning is part 1 of the second phase (see table 1), in which students are asked to construct a mental model while hypothesizing about a certain scientific phenomena. This includes:

1. asking relevant questions regarding the phenomena that they have observed;
2. formulating a hypothesis that is in alignment with the suggested questions;
3. choosing a researchable question for further investigation; and
4. planning an experiment in order to investigate this question.

Analyzing the 'hot reports'

Typically, during the period of 2 years, the students who opted to specialize in high school chemistry in Grades 11 and 12 (in schools in which the inquiry-type laboratory was implemented) conduct about 20 inquiry-type experiments. In this way, they were involved in the following components of the inquiry method: identifying problems, formulating hypotheses, designing an experiment, gathering and analyzing data, and drawing conclusions about scientific problems or science phenomena. The laboratory manual that was developed provided the necessary control regarding what students are doing during the laboratory sessions. Each group of students produced a 'hot report'. These reports were analyzed regarding the questions that students asked, the question that was selected for further investigation, and the experiment that was suggested to investigate the selected question. Altogether we analyzed 25 'hot reports' (gathered from 25 groups). Table 3 presents the distribution of the groups according to experience with inquiry-type experiments and their grades.

Analysis of the group reports revealed that through conducting inquiry-type experiments, students have opportunities to develop understanding of the process of scientific protocols (scientific thinking), namely asking relevant questions, hypothesizing, formulating researchable questions and, finally, designing an experiment in an effort to obtain an answer to this question. In the following sections information is provided regarding these inquiry abilities.

Asking questions during inquiry-type laboratories

In attempting to develop scientific literacy among students, teachers must create effective learning environments in which students are given opportunities to ask

relevant and scientifically sound questions (Penick et al. 1996). Since it is suggested that asking questions is a central tenet to learning by the inquiry approach.

As presented in table 4 in general, most of the questions asked by 11th-grade students are low-level, qualitative-type questions. Most of their questions are related to recent experiences either in the classroom or in the laboratory. For example:

Is the heat responsible for the change in state (sublimation) of the purple substance?

With the 12th-grade students, after a full year of experience with inquiry experimentation, they added more variables to their questions, and also raised quantitative components to their questions. For example, with regard to the same experiments:

What is the relationship between the amount of water added to the copper sulfate and the amount of energy released?

One can always argue that the differences between the 11th-grade and 12th-grade students is because of the differences due to experience with conceptual learning in chemistry. However, when we analyzed the reports that were constructed by groups of 12th-grade students who had only limited experience with inquiry-type experiments, we found that their performance in the various inquiry abilities was less advanced compared with those who had more experience with inquiry-type experiments (see table 4).

Selecting a question for further investigation and designing an experiment

In the specific experiment presented (see Appendix 1), students had an opportunity to select a scientific question for further investigation and to design an experiment that answers this question.

An analysis of the 'hot reports' revealed the following findings. More experienced students (after 1 year of experience with inquiry-type experiments), raised the following research question:

What is the relationship between the ratio of water to copper sulfate and the amount of energy released?

Students who raised this question suggested conducting the following experiment:

We shall take equal amounts of white powder in two beakers. To each beaker we shall add measured and different amounts of water. The temperature will be measured before and after addition of water. We shall calculate the amount of heat that is released using calorimetric method.

Students who had more extensive experience with inquiry techniques and investigation asked a more sophisticated question and planned an experiment with control over the variables (the amount of water and temperature). Also, they were able to suggest an experiment that is highly related to the particular question raised.

However, students with less experience with such experiments raised the following question:

Is there any relationship between the amount of distilled water added and amount of heat released?

Table 4. Characteristics of the performance of 11th-grade and 12th-grade students.

<i>Variable</i>	<i>11th-grade students less experienced, with inquiry-type experiments</i>	<i>12th-grade students less experienced, with inquiry-type experiments</i>	<i>12th-grade students more experienced, with inquiry-type experiments</i>
Asking questions	Almost all the questions are qualitative in nature	Most of the questions are qualitative. There is one full quantitative question (evident in 12.5% of the reports) and some semi-quantitative questions (evident in 37% of the reports)	There is a mixture of both quantitative and qualitative questions (evident in 37% of the reports)
Planning a quantitative experiment		There are indications that the students understand the importance of the control over the variables (evident in 50% of the reports), but their suggestions do not supply a real control	In the design of the experiments, there are suggestions regarding control over the variables. This is both in the planning stage as well as in the discussions of the results
Planning an inquiry-type experiment	Only simple equipment is used (evident in 100% of the reports) and not always in alignment with the question in mind (evident in 44% of the reports)	Only simple equipment is used (evident in 100% of the reports)	There is evidence that the equipment and system is very much in alignment with the questions asked (evidence for that was found in all the reports). Also, an experiment is designed in several stages (in 37% of the reports)

The experiment that these students suggested in order to investigate their research question was as follows:

We shall put two test tubes with the white compound in two beakers with water; to each test tube we shall insert a thermometer. To the first test tube we shall add two drops of water, and to the other six drops of water, and we shall measure the temperature.

It is suggested that, although these students raised a quantitative-type question, they did not suggest ways to control the variables involved in this experiment; namely, the amount of solid (copper sulfate) and the amount of water added. Also, the students with less experience suggested an experimental setting that is only partially relevant for investigating their question.

Similar findings were found with regard to qualitative-type questions. Both experienced students and less experienced students asked the following question:

What caused the iodine to sublime? Is the heat responsible for this?

However, the more experienced students (12th grade) suggested the following experiment to investigate this question.

We shall conduct an experiment that is known to be exothermic and see whether the iodine sublimates.

On the other hand, the less experienced students (11th grade) suggested conducting an experiment that was rather more complicated and less sophisticated, and with little control over experimental variables.

In addition, it was observed that the more experienced students suggested a more advanced design of equipment while the inexperienced suggest trivial equipment and procedures (e.g. heating the substance in a test tube). In addition, experienced students suggested experiments that sometimes comprise several stages, including collection of data and other relevant operations. However, the less experienced students suggested one-stage-type experiments without further experimental steps or additional calculations. To sum up, from these examples, it is clear that the inquiry experiences provide students with opportunities to develop understanding of scientific protocols. Also, clearly, experienced students improved their performance regarding these abilities. A summary of the results of the performance of 11th-grade and 12th-grade students is presented in table 4.

Discussion

From table 4 it can be seen that students' involvement in inquiry-type experiments improved their ability to ask better scientific questions. More specifically, we observed that there is a significant change in the type of questions asked; namely, more quantitative-type questions, and more questions that are related to inquiry in the chemistry laboratory. In regard to the planning of experiments, we observed that experienced students (with regard to inquiry experimentation) suggested experiments in which control over the various variables was evident. In addition, less experienced students suggested simple experimental settings while the more experienced students suggested equipment and tools that are more sophisticated and reliable. Since the inquiry abilities are unique and not highly connected to the subject matter, one can argue that because the 11th-grade and 12th-grade students' conceptual background was similar (regarding the chemistry key concepts mentioned earlier), the inquiry abilities improved significantly with time and experience.

The activities in which the students were involved in this project were very much in alignment with the claim made by Tobin (1990: 415), which suggested that:

A crucial ingredient for meaningful learning in laboratory activities is to provide for each student opportunities to reflect on findings, clarify understanding and misunderstanding with peers, and consult a range of resources, which include other students, the teacher, and books and materials.

Also, Baird (1990) wrote that: 'Purposeful inquiry does not happen spontaneously – it must be learned' (1990: 184).

This study attempted to provide students with opportunities to learn and assume responsibility for their own learning as a result of conducting and inquiry-type experiment. Evidence was presented that shows that the students improved their ability to ask better and more relevant questions as a result of gaining more experience with the inquiry-type experiments.

It is also suggested that it is equally important to obtain information about how teachers and students feel about the program. Information about the students' attitudes toward and their interest in the inquiry approach to the laboratory work in chemistry was mainly obtained from feedback questionnaires administered by their teachers and also from interviews conducted with several students.

The following are some quotes from the students who participated in the inquiry-type laboratories after experiencing at least 1 year in this program (from four different classes and schools). The students suggested that the laboratory experiences in which they were involved were interesting, and gave them opportunities to be involved in the development of scientific skills and in control of their learning. More specifically they claimed that:

1. 'It gave me an opportunity to develop independent thinking.'
2. 'We feel that we had opportunities for authentic learning. For example, when we made a mistake regarding planning of a certain experiment we had to re-think and re-plan the experiment.'
3. 'When we conduct inquiry-type experiments, I have opportunities to think critically about the experimental data and results.'
4. 'The experiments were connected to the topics and concepts that were discussed in the chemistry classroom; thus it helped me to better understand what was going on.'
5. 'I enjoyed sharing ideas and cooperating with my peers in the group.'
6. 'The teacher was always around to help, support, and encourage me.'
7. 'I found that the most difficult part of the inquiry exercise was designing an experimental setting and asking relevant questions. However, it was very challenging.'
8. 'I enjoyed the laboratory work in my chemistry studies.'

It is suggested, that the first four statements relate to the student's awareness regarding the learning process and cognitive development. In regard to statement 5, students claimed that learning cooperatively in the laboratory helped them to construct their knowledge. In addition, they felt that each member of the group had opportunities to contribute to the discussion in order to achieve a common goal. It is seen that the students generally found that the laboratory experiences were challenging (statement 7) and that it provided them with opportunities (including time) to be more involved in the learning process and in the construction of their knowledge. In addition, the students reported that, while working in the laboratory, the teachers provided support and help, and not just information about the results (statement 6). To sum up, based on these quotes, it is seen that, in general, the students who were involved in the project are aware to the meaningful contribution of the inquiry method to their learning of chemistry. It should be noted that, in general, students who are involved in the more traditional approach to the chemistry laboratories are not provided, neither with the time nor with the opportunities for similar involvement in the learning process and in such and in similar inquiry-type learning skills.

Based on our observations, feedback questionnaires and the interviews that were conducted with the teachers, the provision of intensive professional development for teachers is vital for the successful implementation of the described program. Also, the first-hand experiences that the teachers underwent throughout their professional development reduced their anxiety and increased their confidence in using an approach that is highly student-centered and requires a gradual change in their role in the chemistry laboratory. When asked about the inquiry program, the teachers claimed that:

1. 'It matched nicely with my way of thinking regarding how I teach and how my students learn.'
2. 'The inquiry lab provided me with a new method to assess the progress of my students.'
3. 'It helped me in varying the instruction of high school chemistry.'
4. 'The inquiry lab provided me with another method to assess the progress of my students.'
5. 'I have flexibility in choosing the level of inquiry to match my students' abilities and interests.'

Both the teachers and students who were involved in this study felt that the program is challenging and enjoyable. In regard to students' assessment, the teachers were given an opportunity to expand the spectrum of skills with which their students were assessed.

Concluding remarks

We believe that the chemistry students who participated in this program obtained unique opportunities to be involved in a worthwhile learning process in the laboratory. It is worthwhile to present some statistical information that shows that in 1997 we started with three trial schools, while in the academic year 2002–03 we have 51 participating schools (about 74 teachers and 2500 students in 99 classes). Introducing inquiry-type experiments into the chemistry laboratory was a 'breath of fresh air' in the way chemistry is taught and learned, in the way students are assessed, and in our attempt to improve teachers' professional development.

Note

1. The reports were fondly called 'hot reports' since they are conducted during the laboratory exercise and students cannot add additional information afterwards. This ensures that the information is reliable and thus represents the group's activities and deliberations.

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Appendix 1: details about ‘experimenting with a couple of test tubes’

Method

1. Insert 1.5 grams of white solid; anhydrous copper sulphate into a small test tube. Cork the test tube immediately.
2. Put a few small crystals of iodine on the outside of the small test tube.
3. Fit the small test tube inside a bigger test tube by means of a rubber cork. Note that it is very important, for safety reasons, to make sure that the apparatus is perfectly sealed.
4. Add water to the small test tube using a Pasteur pipette, drop after drop in order to slightly wet all the anhydrous copper sulphate. Close the test tube immediately. (It should be mentioned that the instructions given to the students do not include information about the compound or formula. The above is information given to the chemistry teachers.)

Results from the experiment

Inside the test tube, the white color gradually changes to green–blue. The space between the two test tubes fills with purple vapor.

Gradually, the inner side of the larger test tube is covered with small shiny crystals.

Interpretation of the experiment

The reaction that takes place inside the small test tube is exothermic and, as a result, the iodine sublimates (sublimation is an endothermic reaction). The iodine gas solidifies again (the shining crystals) on the inner walls of the test tube where the temperature is lower.