Developing Students' Ability to Ask More and Better Questions Resulting from Inquiry-Type Chemistry Laboratories

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Abstract: This study focuses on the ability of high-school chemistry students, who learn chemistry through the inquiry approach, to ask meaningful and scientifically sound questions. We investigated (a) the ability of students to ask questions related to their observations and findings in an inquiry-type experiment (a practical test) and (b) the ability of students to ask questions after critically reading a scientific article. The student population consisted of two groups: an inquiry-laboratory group (experimental group) and a traditional laboratory-type group (control group). The three common features investigated were (a) the number of questions that were asked by each of the students, (b) the cognitive level of the questions, and (c) the nature of the questions that were chosen by the students, for the purpose of further investigation. Importantly, it was found that students in the inquiry group who had experience in asking questions in the chemistry laboratory outperformed the control grouping in their ability to ask more and better questions. © 2005 Wiley Periodicals, Inc. J Res Sci Teach 42: 791–806, 2005

"Purposeful inquiry does not happen spontaneously—it must be learned." (Baird, 1990, p. 184)

Introduction

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, Garnett, & Hacking, 1995; Hodson, 1990; Hofstein & Lunetta, 1982, 2004; Lazarowitz & Tamir, 1994; 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. Hofstein and Walberg (1995) felt that inquiry-type laboratories are central to learning science since students are involved in the process of conceiving problems and scientific

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questions, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions about scientific problems or phenomena.

Now, at the beginning of the 21st 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 intended to shape and rejuvenate science education are emerging (National Research Council, 1996). The *National Science Education Standards* (National Research Council, 1996) as well as the 2061 project (American Association for the Advancement of Science, 1990) reaffirmed the conviction that inquiry is central to the achievement of scientific literacy. The *National Science Education Standards* use the term inquiry in two ways (Bybee, 2000; Lunetta, 1998): (a) inquiry as *content understanding*, in which students have opportunities to construct concepts and patterns, and to create meaning about an idea to explain what they experience; and (b) inquiry in terms of *skills and abilities*. Under the category of abilities or skills, Bybee included identifying and posing scientifically oriented questions, forming hypotheses, designing and conducting scientific investigations, formulating and revising scientific explanations, and communicating and defending scientific arguments. It is suggested that many of these abilities and skills are in alignment with those that characterize inquiry-type laboratory work, an activity that puts the student in the center of the learning process.

Learning in and from Science Laboratories

Developing Learning Skills in the Science Laboratory

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 have been critically and extensively reviewed in the literature (Blosser, 1983; Bryce & Robertson, 1985; Hodson, 1990; Hofstein & Lunetta, 1982, 2004; Lazarowitz & Tamir, 1994). Although the science laboratory has been given a distinctive role in science education, from these reviews it is clear that, in general, research has failed to show simplistic relationships between experiences in the laboratory and student learning. Hodson (1990) criticized laboratory work and claimed that it is unproductive and confusing since it is very often used unthinkingly without any clearly thought-out purpose. He therefore suggested that more attention be paid to what students are actually doing in the laboratory. Similarly, Tobin (1990) wrote that ‘‘Laboratory activities appeal as a way to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science’’ (p. 405). He also suggested that meaningful learning is possible in the laboratory if students are given opportunities to manipulate equipment and materials to be able to construct their knowledge of phenomena and related scientific concepts.

Gunstone (1991) suggested that using the laboratory to have students construct and restructure their knowledge is straightforward; however, he also claimed that this view is naïve. This is true since the picture regarding practical work, as derived from constructivism, is more complicated. In addition, Gunstone and Champagne (1990) claimed that learning in the laboratory will occur if students are given ample time and the opportunities for interaction and reflection to initiate discussion. According to Gunstone (1991), this approach was underused since students in the science laboratory are usually involved primarily in technical activities, with few opportunities for *metacognitive* activities. Baird (1990) referred to these metacognitive skills as ‘‘Learning outcomes associated with certain actions taken consciously by the learner during a specific learning episode’’ (p. 184). Metcaognition involves elaboration and application of one’s learning, which can result in enhanced understanding. According to Gunstone (1991), the challenge is to help learners take control of their own learning in their search for understanding. In addition, students should be provided with frequent opportunities for feedback, reflection, and modification of their ideas (Barron et al., 1998); however, as Tobin (1990) and Roth (1994) noted, in general and thus far, research has not provided clear evidence that such opportunities exist in most schools in the United States or in other countries.

Asking Questions about Scientific Phenomena

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, Crow, & Bonnsteter, 1996). Dillon (1988) noted that usually questions asked during a lesson are those initiated by the teacher and only rarely by the students, and that questions do not emerge spontaneously from students; rather, they have to be encouraged. In addition, he reported that in cases in which students do ask questions during the lessons, they are usually informative ones. The content of a question can indicate the level of thinking of the person who raised it. Note that in general, the cognitive level of a certain question is determined by the type of answer that it requires (Yarden, Brill, & Falk, 2001).

Several studies noted the importance (and value) of questioning skills. For example, Zoller (1987), in the context of chemistry, thought that questioning is an important component in a real world, involving problem-solving and decision-making processes. Similarly, Shepardson and Pizini (1993) regarded asking questions as a component of thinking skills for learning tasks and as a key stage in the problem-solving process. Asking critical-type questions regarding a specific phenomenon posed to the students through a certain experiment or an article can avoid the phenomenon that in general, students ask factual-type questions (Shodell, 1995). Shodell found that in science education, providing students with the opportunities to ask questions has the potential to enhance their creativity as well as their higher order thinking skills. More recently, Cuccio-Schirripa and Steiner (2000) suggested that "Questioning is one of the thinking processing skills which is structurally embedded in the thinking operation of critical thinking, creative thinking, and problem solving" (p. 210).

This is in alignment with the results of a study conducted by Dori and Herscovitz (1999), who found that fostering 10th-grade students' capabilities to pose questions improved their problem-solving ability. In addition, Hofstein, Shore, and Kipnis (2004), in a previous publication regarding this project, reported that providing students with opportunities to engage in inquiry-type experiments in the chemistry laboratory improved their ability to ask high-level questions, to hypothesize, and to suggest questions for further experimental investigations.

The Study

Goals and Objectives

The main goal of this article is to present evidence that students who were given ample opportunities and time to develop inquiry skills in the chemistry laboratory developed the ability to ask more and better questions, hypothesize, and ask questions related to further experimental investigations compared to students who had limited experience with inquiry-type laboratories. More specifically, the objectives of this study were (a) to investigate the ability of high-school students to ask questions in general and inquiry-type questions in particular, resulting from their experiences in the chemistry laboratory; and (b) to investigate the use of high-school chemistry in applying the ability to ask questions to another learning situation, namely the critical reading of a scientific article.

Development of Inquiry-Type Experiments

About 100 inquiry-type experiments were developed and implemented in 11th- and 12th-grade chemistry classes in Israel. (For more details about the development procedure, assessment of students' achievement and progress, and the professional development of the chemistry teachers, see Hofstein et al., 2004.) Almost all the experiments were integrated into the framework of the key concepts taught in high-school chemistry, namely acids–bases, stoichiometry, oxidation reduction, bonding, energy, chemical equilibrium, and the rate of reactions. These experiments have been implemented in the school chemistry laboratory in Israel for the last 5 years. As previously mentioned, under these conditions, we controlled such variables as the professional development of teachers, the continuous assessment of students' progress in terms of achievement in the laboratory, and the allocation of time and facilities (materials and equipment) for conducting inquiry-type experiments.

Typically in the chemistry laboratory, experiments are performed in small groups (3–4 students) by following the instructions in the laboratory manual. Table 1 presents the various

Table 1
Skills and abilities in an inquiry-type experiment

Phases in the Experiment	Abilities and Skills
Pre-inquiry	
• Insert the two solids, A and B, into the plastic bag and mix them by shaking.	• Conducting an experiment
• Pour 10 ml of water into the small glass.	
• Put the glass with the water inside the bag. (Be careful to avoid any contact between the water and the solids.)	
• Put a thermometer inside the bag to measure the temperature of the solids.	
• Tie the bag carefully at its upper part. (The thermometer is in the bag.)	• Observing and recording observations.
• Turn over the glass and let the water completely wet the solids.	
• Record all your observations and answer the questionnaire that is enclosed.	
Inquiry	
1. Hypothesizing	
• Ask relevant questions. Choose one question for further investigation.	• Asking questions and hypothesizing.
• Formulate a hypothesis that is aligned with your chosen question.	• Planning an experiment.
2. Planning an experiment	
• Plan an experiment to investigate the question.	
• Present a plan to conduct an experiment.	• Conducting the planned experiment.
• Ask the teacher to provide you with equipment and materials to conduct the experiment.	
• Conduct the experiment that you proposed.	• Analyzing the results, asking further questions, and presenting the results in a scientific manner.
• Observe and note clearly your observations.	
• Discuss with your group whether your hypothesis was accepted or you must reject it.	

stages that each of the groups underwent 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 "close-ended," in which the students are asked to conduct the experiment based on specific instructions given in the laboratory manual. Thus, this phase provides the students with 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 (including observations), and analyzing the findings and arriving at conclusions. It is thought that this phase allows the students to learn and experience science with greater understanding and to practice their metacognitive abilities. Moreover, it provides them with the opportunity to construct their knowledge by actually doing scientific work.

Of special interest regarding the issue of learning is Part 1 of the second phase (see Table 1) in which students are asked to raise a hypothesis regarding a certain scientific phenomenon. This includes:

- asking relevant questions concerning the phenomena that they have observed.
- formulating a hypothesis that is in alignment with the suggested questions.
- choosing an appropriate research question for further investigation, and
- planning an experiment to investigate this question.

Research Population and Settings

The study was conducted in six 12th-grade (ages 17–18) chemistry classes (These students learn chemistry in Grades 11 and 12.) in Israel ($N = 111$ students). The student population consisted of two groups: (a) the inquiry group (experimental group; $n = 55$) and (b) a traditional laboratory-type group (control; $n = 56$). The two laboratory programs are used in the education system in Israel, and the chemistry teachers can decide which of these to implement in their schools. These students studied chemistry in the classroom using the same syllabus and the same textbooks that were developed by the chemistry group of the Department of Science Teaching (Ben-Zvi & Silberstein, 1986), and the only difference between the groups is the approach to laboratory work. All students who participated in the study opted to enroll in an advanced-placement course. The teachers of the students who participated in the research reported that the academic achievements of the students from the inquiry group (experimental group) and those of the control group were the same. In the traditional-type chemistry laboratories, the students conduct experiments that are largely confirmatory in nature (i.e., mainly following stage-by-stage procedural instructions provided by the laboratory manual). In general, most of the tasks in this type of experiment are clear and "close-ended," and are directly related to the concept taught at that time in the regular chemistry class. The students who participate in this kind of experiment have only limited opportunities and limited time to develop those abilities that characterize the inquiry-type laboratories (mentioned earlier). It should be mentioned that neither the control nor the inquiry group was provided with specific training to ask questions in the context of other instructional techniques in the chemistry classroom.

During a 2-year period, about 15 inquiry-type experiments (in the experimental group) or traditional-type experiments (in the control group) were conducted. The lab manual that was developed provided the necessary information regarding what the students are supposed to accomplish during the laboratory sessions.

Procedure

Research Tools

To enable comparing the inquiry and control groups regarding their ability to think scientifically and ask more and better questions when performing experiments and when critically reading a scientific article, we developed a practical test and a questionnaire based on the article.

The Practical Test

The students were asked to conduct a simple experiment in which they were instructed to mix two unknown powders with a small amount of water, subsequently placed in a small plastic bag. They were asked to observe the changes carefully and to record their observations. Note that the experiment was novel to both groups of students. (The experiment and the questionnaire given to the students are described in more detail in Appendices 1 and 2, respectively.) During the students' activities, in addition to recording all their observations, they were asked to record all questions that they thought were relevant to the phenomena they had observed, to choose a question for further investigation, suggest an answer to this question, and propose an experiment that can support their hypothesis. The students in the control group, who had no previous experience working in inquiry-type laboratories, obtained a short prelab explanation with examples about inquiry-type questions, hypotheses, selecting a question for further investigation, and planning a suitable experiment to answer the question. The students performed the experiment in groups of 2 to 3, but each student answered the questionnaire individually.

Critical Reading of a Scientific Article

The students were asked to read an original scientific article (Wu et al., 2001) that can be classified as primary literature. Primary literature is the term used for scientific articles that were originally written by scientists; namely, a scientist's report on his or her research work published in a professional journal (Yarden et al., 2001). The following is a short description of the content of the article by Wu et al. (2001):

> Nitric oxide (NO) acts as a single molecule in the nervous system, as a defense agent against infections, as a regulator of blood pressure, and as a 'gate keeper' of blood flow to different organs. In the human body it is thought to have a lifetime of a few seconds. Thus, its direct detection in a low concentration is rather difficult. The article reports on the design of a new electronic sensor sensitive to small amounts of NO in physiological solutions and at room temperature. The following are the stages of the detection process: NO binds to the surface area of the detection device (composed of an organic compound). The organic compound is attached to an alloy of GaAs (Gallium Arsenic), a semiconductor. As a result of the change in the surface, due to the binding of NO, the current flow in the alloy changes and is sensed by a detector.

The article underwent a simplification stage to adopt it to the students' reading ability and to their chemistry background. For the purpose of simplification, the article was organized (and written) in sections; namely abstract, introduction, research methods, results, and summary. The introduction presented the needed scientific background. Also in the introduction was a glossary of new and unfamiliar words (e.g., semiconductors and resistors). The research method part introduced the students to one method that the scientists used in their work. At the end of the article, we wrote a short summary containing the main ideas incorporated in the article. The results were presented on a graph that shows the different experimental conditions. The article was selected since we assumed that it presented a topic that could be characterized in terms of "frontiers of chemistry," of being relevant, and of containing a technological application. Thus, we thought that it would be of interest to the students.

The students were asked to read the article and answer a questionnaire (see Appendix 2). For the purpose of this study, only the following two questions were selected for analysis:

1. Write down all the questions that you would like to ask after reading this article.
2. From this list of questions, select the most interesting one that you would like to investigate.

Analysis of Data

The analysis of the results was based on a comparison between the inquiry and the control groups regarding the number of questions each student presented, the level of the questions, and the level of the question that was chosen for further investigation. The questions presented by the students resulting from the practical test and from the critical reading of the article were validated according to content. The questions were evaluated (judged) by four experts (science educators and experienced teachers) who were asked to define them according to low- and high-level-type questions. Questions to which no agreement was reached were omitted from the final statistical analysis.

In the practical test, low-level questions (see Table 2) are related to the facts and explanations of the phenomena that were observed in the experiment performed by the students. In the article, low-level questions were those that were highly based on the text (textual questions) and the

Table 2
Low- and high-order-type questions related to the practical test and the critical reading of an article

Asking Questions	The Practical Test	Critical Reading of an Article
Low-Order Questions	–What is A? –Which reaction occurred? –Why did the temperature drop? –Why did the bag puff up?	–Which compounds are the semiconductor composed of? –Why does the connection of NO to the organic molecules change the current? –Where are the NO molecules connected in the device? –Why do the molecules have to be connected to the device?
High-Order Questions	–Is the size of the bag influenced by the final temperature? –How does the amount of A and B influence the change in temperature? –What would have occurred if we had used another liquid instead of water? –What is the relation between the amount of the water and the temperature change?	–What will happen if the experiment is conducted at a lower temperature than room temperature (25°C), for example 5°C ? –What will happen if we conduct the experiment under basic conditions? –Can the device also detect high concentrations of NO(g)? –How can the device be installed inside the human body?

answers could be found in the text. In general, the answers to these questions can be a single word, statement, or explanation.

In both cases, high-level-type questions (see Table 2) are questions that can be answered only by further investigation, such as conducting another experiment or looking for more information on the Internet or in chemistry literature. These questions are more complicated, and the student has to think critically about the research to be able to pose them.

Although we checked other issues concerning the critical reading and the practical test, our presentation focused on three common features in the two aspects that were investigated: (a) the number of questions that were asked by each student, (b) the level of the questions posed, and (c) the questions that were chosen by the students for further investigation.

The first two aspects were analyzed quantitatively (using statistical analysis χ^2 and *t* test followed by calculation of η^2 for common variance) while the third aspect was analyzed qualitatively. The results of the statistical analysis are presented in two sections. In the first section, we present the questioning ability of the two groups, based on their practical test. In the second section, we present the questioning behavior of the students, based on their critical reading of the article.

Results

Students' Questioning Ability Resulting from the Practical Test

The two groups (inquiry and control) were compared quantitatively with regard to the mean of the number of questions that were asked by each student, using *t*-test analysis and the value of the proportion of explained variance η^2. The results are summarized in Table 3 and in Figure 1.

When we compared the number of questions from each level that were asked by the inquiry-group students and the control-group students, we found that the students in the inquiry group asked many more high-level-type questions than the students in the control group (see also Figure 2 and Table 4). Chi-square statistics revealed a highly significant difference between the two groups: $\chi^2(1) = 51.0, p \leq 0.001$.

However, no significant differences were found between the number of low-level questions that were asked by the students in the inquiry group and those in the control group. This can be explained by the fact that we instructed the students to write all questions that came to mind. Thus, we found that students in the inquiry group suggested questions defined as low level in addition to the high-level questions posed by them. In other words, the most pronounced difference between the groups is the number of high-level questions posed. When we explored the questions that were chosen by the students for further investigation, we found that several students in the control group

Table 3
Comparison of the mean number questions asked in the practical test by students in the experimental and control groups

	Inquiry Group $n = 55$ Mean (*SD*)	Control Group $n = 56$ Mean (*SD*)	*t* value, η^2
Questions asked by a student	5.64 (1.40)	3.29 (1.41)	8.79*, 0.41

*$p \leq 0.001$ (two-tailed).

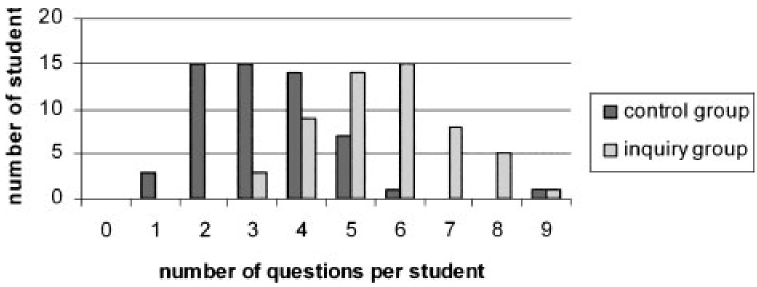

Figure 1. Number of questions that were asked by each student in the practical test.

did not choose any question at all, and the questions that were chosen by most of them were low-level-type questions. Many students in the control group chose to investigate a question that could not be characterized as an inquiry-type question; namely, a question that deserved further investigation, such as:

- Why did the bag puff up?
- Did the temperature decrease?
- Why did the temperature decrease?
- Why did the water react with the powder?
- What is the white solid?

Questions chosen by the students in the inquiry group were of a higher level. Most of them were formulated as inquiry questions with one or two variables, namely:

- What will happen if we insert a different amount of water?
- Will the temperature increase if we insert more water?
- Does the amount of powder influence the puffing up of the bag?

Questioning Behavior Resulting from the Critical Reading of a Scientific Article

Altogether, as a result of reading the scientific article, the students in the inquiry group asked 117 different questions whereas the control group asked only 23 questions (see Table 5 and Figure 3). Analysis of variance using *t*-test statistics and the resulting η^2 revealed a significant difference between the mean number of questions in the inquiry group and in the control group.

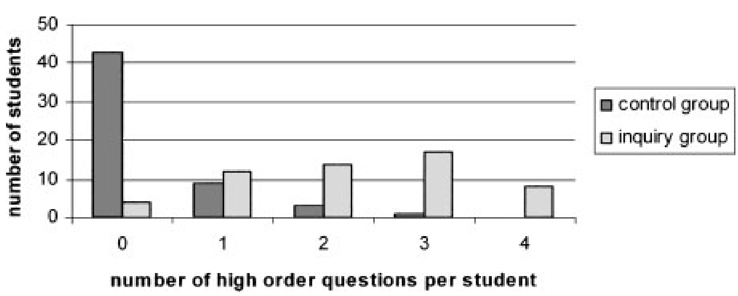

Figure 2. Comparison of the number of the high-order questions asked by each student in the two groups during the practical test.

Table 4
Distribution of low- and high-level-type questions asked in the practical test

Level of Questions	Experimental Group ($n = 55$) No. of Questions (%)	Control Group ($n = 56$) No. of Questions (%)
Low	184 (59.9)	165 (90.2)
High	123 (40.1)	18 (9.8)

The chi-square test was conducted to analyze the level of the questions in the two groups with $\chi^2(1) = 87.6, p \leq 0.001$. Table 6 summarizes the results for the level of the questions posed by the students in the two groups

Regarding the assignment in which the students were asked to choose a question for further investigation, it was found that the students in the inquiry group posed questions that could be characterized as high level (see Figure 4).

- How is the $NO_{(g)}$ molecule released from the device?
- Can the device change the concentration of $NO_{(g)}$?
- Why in critical situations within the human body is there a release of $NO_{(g)}$?
- Can the scientists use the device to detect other molecules?

Note that in few cases in the control group, there were students who did not choose any question for further investigation, and most questions that were chosen by students in the control group were of the low-order type, such as:

- How is the current recorded?
- Can the detection of $NO_{(g)}$ be used for medical applications?
- What does the device detect?
- What is presented by the graph?

Discussion, Summary, and Recommendations

In this article, we described a study in which we provided students with opportunities to learn and assume responsibility for their own learning as a result of conducting an inquiry-type experiment. Evidence was presented that shows that the students improved their ability to ask

Table 5
Comparison of the mean number of questions asked during the critical reading of an article by students in the experimental and control groups

	Inquiry Group $n = 55$ Mean (*SD*)	Control Group $n = 56$ Mean (*SD*)	t value, η^2
Questions asked by a student	4.03 (1.17)	1.41 (1.12)	11.89*, 0.56

*$p \leq 0.0001$ (two-tailed).

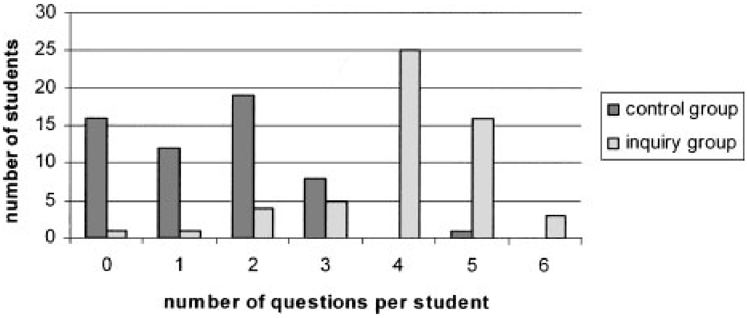

Figure 3. Number of questions that were asked by each student resulting from reading the article.

better and more relevant questions as a result of gaining experience with the inquiry-type experiments. In addition, the students who were involved in the inquiry experiences clearly were more motivated to pose questions regarding scientific phenomena that were presented to them via an article.

These findings are not surprising because during the inquiry activity, which was an integral part of their chemistry laboratory activities, these students had practiced asking questions and formulating inquiry questions. As mentioned in Table 1, the activity of asking inquiry questions (that are, by definition, high-level questions) is one of the operations that the students are required to do during every full-inquiry experiment. In contrast, the students of the control group, who had learned the traditional-type program which does not contain the inquiry experiments, did not have any opportunity to practice the activity of asking questions, and specifically asking inquiry questions (which are higher level questions), and therefore their skills in asking questions as indicated by the test were lower.

In observing the students during the two activities, we also noted a difference in their attitudes toward the mission. The students of the inquiry group devoted more time and attention to completing the questionnaires. Nearly all the students completed all the assignments seriously. In contrast, a large number of students from the control group did not answer some questions at all; in particular, they did not suggest a question for further investigation (in both tools), or formulate a hypothesis or plan an experiment (in the practical test). We feel that through the involvement in inquiry experiments, the students developed scientific skills and habits that are applicable to other learning situations. They were provided with opportunities to ask questions, suggest hypotheses, and design investigations that were "minds-on" as well as "hands-on." We believe that these results will eventually encourage more chemistry teachers in Israel to implement this inquiry-oriented program.

Table 6
Distribution of low- and high-level-type questions asked after the critical reading of an article

Level of Questions	Experimental Group ($n = 55$) No. of Questions (%)	Control Group ($n = 56$) No. of Questions (%)
Low level	26 (11.7)	48 (64.0)
High level	196 (88.3)	27 (36.0)

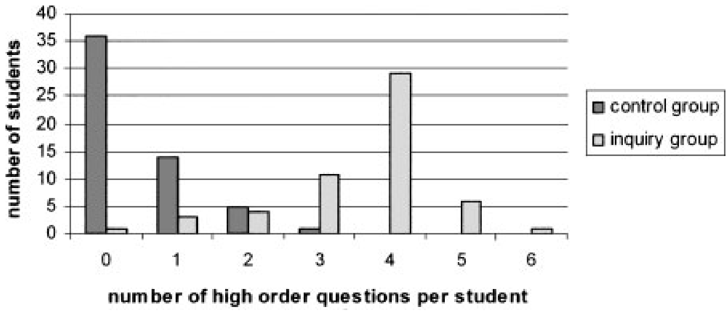

Figure 4. Comparison of the number of the high-order questions that were asked by each student as a result of critical reading of the article.

The activities in which the students were involved in this project are very much in alignment with the claim made by Tobin (1990), who noted 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. (p. 415)

These activities also are in alignment with Krajcik, Mamlok, and Hug (2001), who suggested that students who perform the various phases of inquiry are challenged by asking appropriate questions, finding and synthesizing information, monitoring scientific information, designing investigations, and drawing conclusions.

In many countries around the world, achieving scientific literacy for all students has become a central goal for education. Although admirable, this goal represents a challenge for both science-curriculum developers and teachers who cooperatively work to attain this goal. The target population is not only those who will eventually embark on a career in the sciences but also all citizens. As such, they will often find themselves in situations in which they will need to ask critical questions and seek answers upon which they will need to make a valid decision. Thus, the development of students' ability to ask questions should be seen as an important component of scientific literacy and should not be overlooked.

In recent years, there has been substantive growth in understanding associated with teaching, learning, and assessment in school science laboratory work. At the beginning of the 21st century, when many are again seeking reform in science education, the knowledge that has been developed about learning based on careful scholarship should be incorporated in that reform. The ''less is more'' slogan in the *Benchmark for Science Literacy* (American Association for the Advancement of Science, 1993, p. 320) has been articulated to guide curriculum development and teaching consistent with the contemporary reform. The intended message is that that formal teaching results in greater understanding when students study a limited number of topics, in depth and with care, rather than a large number of topics much more superficially, as is the practice in many upper secondary school science classrooms. In the Israeli case (described in this article), to make room for the inquiry laboratories, the syllabus (content) was reduced by 25%. Well-designed, inquiry-type laboratory activities can provide learning opportunities that help student develop high-level learning skills. They also provide important opportunities to help students learn to investigate (e.g., ask questions), to construct scientific assertions, and to justify those assertions in a classroom community of peer investigators in contact with more expert scientific community. There is no doubt that such activities are time consuming, and thus, the education system must provide time and opportunities for teachers to interact with their students and also time for students to perform and reflect on these and similar complex inquiry and investigative tasks. Such experiences should be integrated with other science classroom learning experiences to enable the students to make connections between what is learned in the classroom and what is learned and investigated in the laboratory. This is highly based on the growing sense that learning is contextualized and that learners construct knowledge by solving genuine and meaningful problems (Brown, Collins, & Duguit, 1989). One of the most crucial problems regarding the implementation of inquiry-type laboratory experiments is the issue of assessing students' achievement and progress in such a unique learning environment. In general, large numbers of science teachers are not using authentic and practical assessment on a regular basis. The National Science Education Standards (National Research Council, 1996) indicates that all students' learning experiences should be assessed. A science teacher whose goal is to assess comprehensively what takes place in school science generally or in the laboratory more specifically should be provided appropriate assessment tools and methodologies to identify what students are learning both conceptually as well as procedurally.

In addition to the organizational factors regarding the volume of the content taught and the context in which laboratory experiences are conducted, we have to pay much attention to the science teacher. Clearly, serious discrepancies exist between what is actually occurring in the laboratory classroom and what is recommended for high-level science teaching. Unfortunately, many science teachers do not utilize or manage the laboratory effectively.

In their recent review of the literature, Hofstein and Lunetta (2004) noted that:

> Conditions are especially demanding in science laboratories in which the teacher is to act as facilitator who guides inquiry that enables students to construct more scientific concepts.... Teachers are often not well informed about new modes of learning and their implications for teaching and curriculum. While excellent examples of teaching can be observed, the classroom behavior of many teachers continue to suggest conventional beliefs that knowledge is directly transmitted to the students and that it is to be remembered as conveyed. (p. 45)

This is in fact a call for changing the strategies that are employed in preservice and inservice professional-development courses provided to the science teachers. It is suggested that to implement similar learning strategies described in this article, teachers need to undergo continuous and long-term professional development aimed at enhancing both their content knowledge as well as their pedagogical content knowledge. Such professional development experiences have the potential to help teachers develop skills and the confidence to construct effective learning environments that include substantive and meaningful science laboratory experiences. More research is needed to investigate the effectiveness of different models for science teachers' professional development that are used to provide teachers with the skills to implement student-centered instructional techniques in general and inquiry-type experiences in the science laboratory in particular.

Appendix A

The Experiment

Method

Seven grams of citric acid and 10 g of sodium hydrocarbonate are mixed in a small transparent plastic bag. A small glass with 10 ml of water is inserted into the bag. (At this stage the water stays in the glass.) A thermometer also is inserted into the plastic bag. The air is forced out of the plastic bag, and the bag is closed hermetically by a rubber band, with the thermometer still inside. When the water is poured inside the bag, it wets the solids and starts an endothermic reaction in which carbon dioxide is emitted. The students can observe the dropping of the temperature and the blowing up of the plastic bag.

Instructions for the Students

- The experiment will be done in groups of 3 students. Every student will answer the questions by himself.
- Insert the two solids, A and B, into the plastic bag and mix them by shaking.
- Pour 10 ml of water into the small glass.
- Put the glass with the water inside the bag (be careful to avoid any contact between the water and the solids).
- Put a thermometer inside the bag, to measure the solids' temperature.
- Tie the bag carefully at its upper part (the thermometer is in the bag).
- Turn over the glass and let the water completely wet the solids.
- Record all your observations and answer the questionnaire that is enclosed.

Appendix B

The Questionnaire used in the Practical Test

Write your observations.
After performing the experiment, answer the following questions:

1. What questions do you have after the experiment?
2. Choose one of those questions as an inquiry question.
3. Why did you choose that question?
4. Write a hypothesis that fits your inquiry question. The hypothesis is your expected answer to your inquiry question.
5. Suggest an experiment that can verify if your hypothesis is correct. In your suggestion justify the need for any stage of the experiment.

The Questionnaire used in the Critical Reading of the Article

1. Describe, based on the description in the article, the following concepts: a. Resistor, b. semiconductor.
2. What is the main idea described in the article?
3. What measurements should the researcher take in order to detect changes in the system?
4. What is the shape of the graph at the moment that NO is injected into the solution?
5. Where in the graph is the control experiment described?
6. Write down the scientific concepts that were not clear to you.
7. Write down all the questions that you would like to ask after reading this article.
8. From this list of questions, select the most interesting one that you would like to investigate.

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