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THE INQUIRY LABORATORY AS A SOURCE FOR DEVELOPMENT OF METACOGNITIVE SKILLS

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ABSTRACT. The study described in this article is based on a long-term comprehensive series of investigations that were conducted in the context of teaching high school chemistry in the laboratory using inquiry-type experiments. The students that study chemistry according to this program are involved in an inquiry process that included all the inquiry skills namely: identifying problems, formulating hypotheses, designing an experiment, gathering and analyzing data, and drawing conclusions about scientific problems and phenomena. While conducting these activities in small collaborative groups, they were encouraged to discuss their ideas about the scientific phenomena they were observing with their classmates and they were provided the time needed to accomplish it. A case study of inquiry activity of a group of three students is described and analyzed using a model of *metacognition* that was presented by Schraw (1998). The transcripts of the interviews of 20 students were analyzed using a model of Flavell et al. (2002). It was found that while performing the inquiry activity, the students practiced their *metacognitive* abilities in various stages of the inquiry process. The analysis of the interviews indicated that the students that participated in the research expressed their *metacognitive* knowledge regarding the inquiry activity. Thus, it is claimed that an inquiry-type laboratory that is properly planned and performed can give students an opportunity to practice *metacognitive* skills, which are regarded in recent years as one of the key goals in our attempt to broaden the scope of learning skills developed through learning science.

KEY WORDS: inquiry-type laboratory, laboratory work, metacognition

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 (Dori, Sasson, Kaberman & Herscovitz, 2004; Garnett, Garnett & Hacking, 1995; Hodson, 1990; Hofstein & Lunetta, 1982; 2004; Tobin, 1990; Lazarowitz & Tamir, 1994; Lunetta, 1998). More specifically they suggested that when properly developed, inquiry-centered laboratories have the potential to enhance students' meaningful learning, conceptual understanding, and understanding of the nature of science. Inquiry-type

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experiences in the science laboratory are especially effective if conducted in the context of, and integrated with, the concept being taught. Hofstein & Walberg (1995) suggested that inquiry-type laboratories are central to learning science, since students are involved in the process of conceiving problems and scientific questions, formulating hypotheses, designing experiments, gathering and analyzing data, and drawing conclusions about scientific problems or phenomena.

As the beginning of the 21st century is being ushered in, 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; 2005). The National Science Education Standards (NRC, 1996) and also the 2061 project reaffirm 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): (1) inquiry as *content understanding*, in which students have opportunities to construct concepts and patterns and to create meaning about an idea in order to explain what they experience, and (2) inquiry in terms of *skills* and *abilities*. Under the category of abilities or skills, Bybee includes 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 at the center of the learning process.

Learning at 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 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). 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 he called for more emphasis on what students are actually doing in the laboratory. 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 in order 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 naive. This is true, since the picture relating to practical work, as derived from constructivism, is more complicated. In addition, Gunstone & Champagne (1990) suggested that learning in the laboratory would occur if students were given ample time and opportunities for interaction and reflection in order to initiate a discussion. This approach, according to Gunstone, was under-used, since students in the science laboratory are usually involved in technical activities with only few opportunities for *metacognitive* activities. We claim that an inquiry-type laboratory that is properly planned and performed can give students the opportunity to practice *metacognitive* skills, which are regarded as important goals for scientific education.

In this paper we present research that investigates a chemistry laboratory program that is based on inquiry-type experiments. The students that study chemistry according to this program were involved in an inquiry process that included all the inquiry phases: identifying problems, formulating hypotheses, designing an experiment, gathering and analyzing data, and drawing conclusions about scientific problems or science phenomena. During this activity, they were encouraged to discuss their ideas about the scientific phenomena that they were observing with their classmates and they were provided the time needed for this purpose. Since the conditions for practicing *metacognition* by the students exist in the inquiry laboratory, we thought that it is logical to examine the role of *metacognition* in this activity.

METACOGNITION: THEORETICAL BACKGROUND

Metacognition in Science Learning and Teaching

In recent years, *Metacognition* is regarded as an important component of learning in the sciences. The following are a sample of reasons suggested by the literature for this:

(1) In many research studies in the area of science teaching it was found that *metacognitive* processes promote meaningful learning, or

learning with understanding (e.g., Baird, 1986; Baird & White, 1996; Gourgey, 1998; White & Mitchell, 1994; Conner, 2000; Rickey & Stacy, 2000; Thomas & McRobbie, 2001; Davidowitz & Rollnick, 2003; Kuhn, 1999). Meaningful learning, which, as a result of it students improve their ability to apply what they have learned in a new context, is one of the goals of teaching (Kuhn, 1999). Most of these researchers suggest that one of the main characteristics of meaningful learning is the student's ability to *control* a problem-solving process and the performances of other learning assignments. These researchers link this *control* to the student's *awareness* of his/her physical and cognitive actions during the performance of a certain task.

(2) In view of a constantly changing technological world when, not only is it impossible for individuals to acquire all existing knowledge, but it is also difficult to envisage what knowledge will be essential for the future (Georghiades, 2004) The development of *metacognitive* abilities that will enable the student to study any desirable knowledge in the future becomes essential.

(3) One of the goals of science education is the development of an independent learner (NRC, 1996; 2005). Efficient independent learning requires the learner to be aware and in control of his/her knowledge and of the options to expand it. This means in other words that the student must utilize and develop *metacognitive* skills.

Metacognition in an Inquiry Science Laboratory

White & Mitchell (1994) specify students' behaviors that, in their opinion, are characterized as "good learning behaviors" for students who developed certain *metacognitive* skills. A large part of these behaviors (and skills) are actions that constitute an integral part of the inquiry laboratory activity, such as asking questions, checking work against instructions, correcting errors and omissions, justifying opinions, seeking reasons for aspects of current work, suggesting new activities and alternative procedures, and planning a general strategy before starting. Since the students that participate in the inquiry laboratory activities are obliged to act according to the activities that are typical of students with developed *metacognition*, it is logical to assume that during the study of the inquiry laboratory unit the students can practice and develop their *metacognitive* skills. Kuhn, Black, Keselman & Kaplan (2000) argued that students who experience inquiry activity "come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own, and that such knowledge is empowering" (p. 496).

Baird & White (1996) claimed:

> If carried out thoughtfully, this process of purposeful inquiry will generate a desirable level of *metacognition*; the person will know about effective learning strategies and requirements, and will be aware of, and be capable of exerting control over, the nature and progress of the current learning task (p. 191).

They also claimed that four conditions are necessary to induce the personal development entailed in directing purposeful inquiry: time, opportunity, guidance, and support. In the inquiry laboratory activity the students get the time and the opportunity to practice *metacognitive* skills, and the teacher gives them the guidance and the support that they need. Thus, one can conclude that the inquiry laboratory activity is specially suitable for enhancing *metacognition* and meaningful learning, because during the activity the students perform open inquiry, which integrates strategies that are known in the literature as *metacognition*'*s* promoters: working in small groups, supplying time for group discussion, observing phenomena that should be explained at the particle level, and exploring a question that was asked by the students.

The Two Models of Metacognition Structure used in this Study

Since *metacognition* has many definitions and meanings, we chose to present here two models that were used in this study for the purpose of analysis of the data. Reasons for including these two models will be discussed later in this paper. These two models we suggest are highly aligned with the nature of *metacognition* that has the potential to be developed in inquiry-type science laboratories.

The first model is based on Schraw's (1998) definition of *metacognition* and is similar to Yore & Treagust's (2006) conception of metacognition. According to this model, there are two main components in the *metacognition*:

1. *Knowledge of cognition* refers to what individuals know about their own cognition or about cognition in general. It includes at least three different kinds of *metacognitive* awareness: declarative, procedural, and conditional knowledge.

    - *Declarative knowledge* includes knowledge about oneself as a learner and about factors that influence one's performance (knowing 'about' things).

- *Procedural knowledge* refers to knowledge about doing things. Much of this knowledge is represented as heuristics and strategies (knowing 'how' to do things).
- *Conditional knowledge* refers to knowing when and why to use declarative and procedural knowledge (knowing the 'why' and 'when' aspects of cognition).

2. *Regulation of cognition* refers to a set of activities that help students control their learning. Although a number of regulatory skills have been described in the literature, three essential skills are included in all accounts: planning, monitoring, and evaluation.

   - *Planning* involves the selection of appropriate strategies and the allocation of resources that affect performance.
   - *Monitoring* refers to one's on-line awareness of comprehension and task performance.
   - *Evaluating* refers to appraising the products and efficiency of one's learning.

The structure of *metacognition* according this model is illustrated in Figure 1.

Regarding the inquiry laboratory activity, knowledge of cognition should be reflected during the discussion about the observations by asking appropriate questions and operating a suitable inquiry stage. Regulation of cognition should be expressed during the planning of the experiment, while performing it, and evaluating the results regarding the assumption.

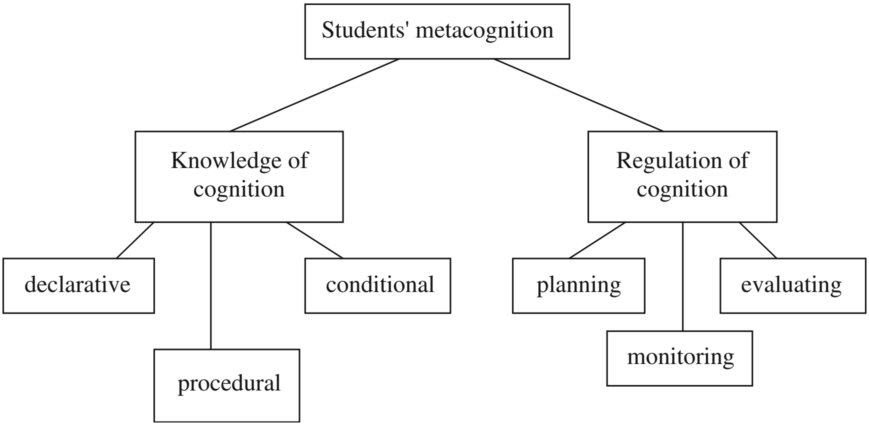

Figure 1. The metacognition's structure. Based on the model of Schraw (1998).

The second model is based on Flavell, Miller & Miller (2002) who suggest dividing the *metacognition* into two central components: one component is called *metacognitive knowledge* and the other is *metacognitive monitoring and self-regulation*. They argue that *metacognitive* monitoring and self-regulation are "one's management of one's cognitive activity during problem solving" (p. 166). This component of *metacognition* resembles Kuhn's *metastrategic knowledge* (Kuhn, 1999; 2000) and Schraw's *regulation of cognition* (Schraw, 1998), and it is expressed during problem solving and inquiry activities. According to Flavell et al. (2002) "*metacognitive knowledge* refers to segment of your acquired world knowledge that has to do with cognitive matter. ...*Metacognitive knowledge* can be roughly subdivided into knowledge about persons, tasks, and strategies." (p. 164).

The person category includes any knowledge and beliefs one has concerning what human beings are like as cognitive processors. It includes cognitive differences within people, cognitive differences between people, and cognitive similarities among all people.

The task category has two subcategories. One subcategory is concerned with the nature of the information that is encountered in any cognitive task. The other subcategory concerns the nature of the task demands (for example, to know that it is easier to recall the abstract of a story than its exact words).

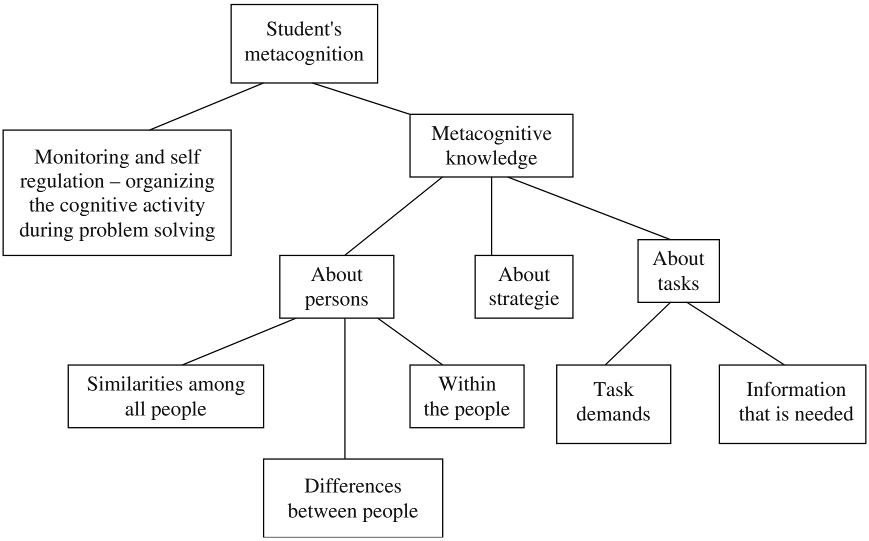

Figure 2. Metacognition's components based on Flavell et al. (2002).

The strategy subcategory includes knowledge about which strategy is effective for a certain cognitive goal: in comprehending X, remembering Y, solving problem Z, and so on. The *metacognitive* learner knows what tasks are worth investing efforts, which knowledge is required to achieve the goal, and what is the best way to get this knowledge. Figure 2 illustrates the structure of *metacognition* regarding this framework.

PURPOSE OF THE STUDY

The main goal of the research is to investigate the potential of the inquiry laboratory for developing *metacognitive* skills among chemistry students. More specifically, the two research questions are:

(1) Does the inquiry laboratory provide opportunities for developing *metacognitive* skills and in which stages of the inquiry do those skills find expression?
(2) What are the *metacognitive* characteristics that find expression in the various inquiry laboratory stages?

DESIGN AND PROCEDURE

The Inquiry Laboratory Program

About 100 inquiry-type experiments were developed and implemented in 11th and 12th grade chemistry classes in Israel (for more details about the procedure of development, assessment of students' achievement and progress, and professional development of the chemistry teachers, see Hofstein, Shore & Kipnis, 2004; Hofstein, Navon, Kipnis & Mamlok-naaman, 2005). 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 reaction. These experiments were implemented in the school chemistry laboratory in Israel in the last 8 years. This implementation took place in a situation in which control was provided over such variables as the 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. Typically in the chemistry laboratory the students perform the experiments in small groups (3–4 persons), following the instructions given to them in the laboratory manual.

Table I illustrates the various stages that each of the groups undergoes 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 ‘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 a more ‘open-ended’-type experience such as asking relevant questions, hypothesizing, choosing a question for further investigation, planning an experiment, conducting the experiment (including 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 and to enhance their *metacognitive* abilities. Moreover, it provides them with the opportunity to construct their knowledge by actually doing scientific work.

The study was conducted in 12th grade chemistry classes in urban and suburban academic high schools in Israel. Typically, during a period of 2 years, the students who opted to specialize in high-school chemistry in grades 11 and 12 conduct about 15 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 lab manual that was developed provided the necessary control regarding what students are doing during the laboratory sessions. Simultaneously with the experimentation, each group of students produced a report that is assessed by the teacher, and this assessment is included in the students’ final grade.

Collecting Data

In order to attain triangulation (Lincoln & Guba, 1985), we collected data from several sources and got several points of view that gave us a deeper understanding of the research subject. The three sources that were used are: observation of students during the practical activity, interviews with the students, and the students’ reflection essays.

Observations of the Practical Activity

During the research, 20 observations were conducted in eight different 11th and 12th grades classes during the inquiry laboratory activities. The

TABLE I

Phases in inquiry-type experiment

Phase	Abilities and skills
Phase 1: Pre-inquiry	
Describe in detail the apparatus in front of you	
Add drops of water to the small test tube, until the powder is wet. Seal the test tubes immediately	Conducting an experiment
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 investigation	Asking questions and hypothesizing
Formulate a hypothesis that is aligned with your chosen question	
2. Planning an experiment	
Plan an experiment to investigate the question	Planning an experiment
Ask the teacher to provide you with the equipment and material needed to conduct the experiment	
3. Conducting the planned experiment	
Conduct the experiment that you proposed	
Observe and note clearly your observations	
Discuss with your group whether your hypothesis was accepted or you need to reject it	Analyzing the results, asking further questions, and presenting the results in a scientific way

researcher who performed the observation sat in the classroom with one of the groups of the students and took notes. The discourses in the different groups were audio-recorded and transcribed.

From all the observed activities we choose to present in detail an activity of one group (three students) of the 12th grade. The findings from this activity are presented as a case study analyzed according to the model of *metacognition* that had been developed by Shraw (1998). We chose this model because it specifies the regulation of cognition, which is the important component of cognition regarding the inquiry activity.

Students' Interviews

During the research, twenty 12th grade students who studied the inquiry laboratory program with eight different teachers were interviewed and the conversation was audio-recorded. The students talked about their chemistry course and particularly about the inquiry activity. Since the students that were interviewed were different regarding their academic achievement, in the topics that they learn besides chemistry, in their attitudes to the chemistry lessons and to the chemistry laboratory activity, we assume that the picture that is accepted from the interviews represents the situation in many classes that study the inquiry program in Israel. A qualitative analysis of the interviews' transcripts enabled us to propose an assertion based on the model of *metacognition* that was developed by Flavell et al. (2002) and was mentioned above. This model was chosen for the current analysis because it specifies the components of *metacognition* knowledge, which is the *metacognitive* aspect that can be expressed in conversation, as opposed to regulation of cognition, which can be expressed in the laboratory activity.

Students' Reflections

Some of the chemistry teachers who had taught the inquiry program asked their students at the end of the 12th grade to write a reflective essay about their inquiry laboratory experiences. Altogether, 137 reflective essays were collected from ten different teachers. The reflections were written according to the teachers' requirements, which had many variations. Therefore, as a result, we collected many kinds of reflections that differed regarding their length, the subjects that were discussed in it, and in their level of specification. Because we did not have any control over the writing of these reflections, we did not include any systematic analysis of it in this paper, but we used those reflections in order to strengthen our arguments.

RESULTS AND DISCUSSION

Metacognitive Aspects in the Students' Discourse during the Inquiry Laboratory Activity: A Case Study

As mentioned before, the inquiry laboratory activity provides the students with the opportunity to develop *metacognitive* skills. An example of an activity is where while recording their observations, the students had to suggest questions for inquiry. They did this easily and during their discussion they referred to the reason they asked those particular questions:

Ravit: I suggest 'what is the connection between the waiting time and....'

Liran: Why the waiting time?

Ravit: You need something.... Think about a graph, something that you can draw a graph.

Liran, who wants to know Ravit's motivation to suggest this particular question, refers to her cognition. He understands that she has her own thoughts, which are unlike his own, and by this phrase he demonstrates his *metacognitive* knowledge about the thoughts of others. Ravit's explanation for her purpose by choosing this question expresses *metacognitive* procedural knowledge. She understands that the inquiry process should terminate with conclusions; therefore, she was looking for a question that will enable her to present the results in a graph, an action that helps to arrive at conclusions. We can see here the component of planning that exists in the *metacognitive* regulation that is expressed by choosing the proper strategy, namely the strategy that enables her to show the results in a graph.

Since the students have to ask several questions, they continue their discussion about the questions and try to choose a question for further inquiry. After examining the questions, they decide to explore a new question: 'What happens if the sparkling water with the indicator is heated in a closed vessel?' In their discussion they indicate the variants that should be examined in order to answer this question: the speed of the gas emission and the color of the solution. They hypothesized that the gas emission will be slower than in an open system and the solution's color will be more yellow than in an open system, because in the closed system the reaction will arrive to equilibrium. When they present the experiment to the teacher, he explains that it is not safe to heat the sparkling water in a closed system, and therefore the students should provide an alternative experiment:

Liran: If it is not sealed the pressure is lost...

Ravit: We want the gas to stay. So, maybe we should cool it? We do not need heating, we need ice and another big bowl for cooling....

In this conversation we noticed regulation of cognition. The students discover that their proposed procedure is not proper, and therefore they propose another procedure, which they perceive as suitable for their aim. In this section, the monitoring is done by the teacher, who is aware of the safety problem, but all the other actions are done by the students: they choose another strategy (the planning component) that is effective, in their opinion, regarding their inquiry question (the evaluation component).

When formulating a hypothesis related to the inquiry question, Ravit discovers that she had a misunderstanding about the reaction that had occurred:

Ravit: Because it will be the opposite. While cooling the opposite reaction will occur.

Liran: Which opposite reaction? That it will want to enter the water?

Ravit: To.... dissolved CO_2....oh! Just a minute, it is the opposite!

Liran: What is the opposite?

Ravit: The yellow. The opposite reaction will be yellow, because the CO_2 will be dissolved in the water and then it will be acid.

Liran: Does CO_2 produce an acid?

Ravit: Oh, we made a mistake!

In this conversation, Ravit shows an awareness of her declarative knowledge and acknowledges her mistake, and after examining her knowledge and finding the mistake, she corrects it and the students change their hypothesis.

At the end of this part of the activity, the students write an order for the materials and equipment needed for performing the inquiry experiment. In this stage they suggest investigating the influence of changing the temperature of the closed system by cooling the vessel at different temperatures.

In the second part of the activity, which took place 2 weeks later, another girl joined this couple. At the beginning of this class the students got the materials and equipment for their experiment. The equipment differs from the original order because after the first part of the activity the teacher and the laboratory assistant checked the students' orders and commented about their proposals. They discussed the proposals with the students and suggested improvements. After reaching an agreement with the students, the laboratory assistant checked the experimental system and modified it to the suggested experiments. The observed group got a system that included a sealed beaker with an injector in its cork. This system can be safely heated and they could perform their original experiment: to check the volume of the gas that is emitted when the sparkling water is heated in a water bath that heats it to different temperatures. The students worked independently. They knew exactly what they should do and they acted accordingly. At the beginning of the class, Gal, the new student in the group, tried to understand what was going on and she asked her classmates what the experiment's goal was. When she received an answer, she began to organize her knowledge and explained what was already known and what should be examined:

Gal: Like we said, when we heat, the speed of the gas emission will increase. We will take a stopper and say: such an amount of gas is emitted in that period of time and we see the rate. We will see it at different temperatures. We need a stopper for it....

When Gal understood the assignment, she became the dominant student in the group. She explained to Ravit and Liran what had to be done, in her opinion, how the variants can be controlled, and what is the best way to get results leading to conclusions:

Gal: It is not right because you did not begin at 0. You began with a system that contained gas. You should begin to heat when the injector is fully pressed at 50°, fully pressed at 60°, fully pressed at 70°.....

She organized her knowledge and explained to her classmates the correct way of doing the experiment. She gave her reasons for doing so, and she tried to persuade her partners. When she thought that it was the right thing to do, she suggested that the experiment be repeated:

Gal: ... But the gas pressure has influence, too. It is not standard pressure of 1 atmosphere at the beginning of the experiment. I think we should start from the beginning.

Later, Gal understood that there was a problem with the formulation of the question and she suggested that it should be changed in a way that will allow them to directly measure the dependent variable. Ravit suggested an improvement in the experiment: instead of using a water bath in which the temperature decreased during the experiment, she suggested that the vessel should be heated with a stream of hot water. Gal remembers that there are some variables that were not taken in consideration:

Gal: We had not thought that as we heat, the water evaporates- not only the rate of CO_2 increases, also the rate of the water evaporation.

Later on, when one of the observations seemed to be abnormal, she asked to repeat the experiment. During this time the students discussed the best way of performing this experiment. When they presented the results in a graph, they connected it to the mathematics lessons:

Gal: Listen to me, it reminds me of the function of....

Liran: Sure, a quadratic function

Gal: No, a logarithmic one. It looks like this a little... right?

Ravit: Stop. The fact that we had just studied it does not mean that it is.

Liran: It is a quadratic function.

Gal: No, look, because it starts straight and then up...

This connection is the result of *metacognitive* declarative and conditional knowledge. The students are aware of their mathematics knowledge and their need to use it now, while representing the results of the experiment.

In the above-quoted discourse we identified *metacognitive* activity concerned with the regulation of cognition and *metacognitive* activity that is related to the procedural *metacognitive* knowledge. The conversations that deal with the inquiry question, the possibility of changing it, and the variables that need to be isolated indicate that the students engaged in *meta-procedural* knowledge related to the inquiry process. They controlled the inquiry phases and knew how to do it. *Metacognition* is reflected when they carefully check their actions, test themselves regarding the results, and then change the question and make more measurements. We can identify here the monitoring and evaluation components of the cognition's regulation, which are indicated when the students are aware of the way that the experiment is performed, and during the activity, by checking themselves and asking: does the experiment answer the question? Do we do everything correctly? Do the results make sense?

TABLE II

Examples of discourse segments that fit the *metacognition* components according the model that is illustrated in Figure 1 (N=3)

The student's quotation	Our interpretation	The *metacognition* component that is represented
"..it reminds me of a function of.... a logarithmic one...."	The student remembers knowledge that had been acquired in the mathematic lessons. This indicates the existence of the student's knowledge about his own knowledge	The student's *metacognitive* declarative knowledge about himself
"What about waiting time?"	The student understands that his partner's thoughts differ from his own and therefore she suggests a question that she had not thought about	The student's *metacognitive* declarative knowledge about others
"You need something.... Think about a graph, something that you can represent with a graph."	The student explains that she suggests this particular question because of the type of answer. She understands that the inquiry process has to lead to conclusions about the phenomenon; therefore, she searches for a suitable question that enables her to represent the results in a graphic way that helps to arrive at conclusions	The student's *metacognitive* procedural knowledge

Gal: “Listen to me; it reminds me of a function of....” Liran: “Sure, a quadratic function.”	The students use their knowledge of mathematical functions to describe the dependence between the variants in the experiment. They know how to use the appropriate strategy in spite that it was learned in an entirely different context	The student’s *metacognitive* conditional knowledge
“We want the gas to stay. So, maybe we will cool it? We do not need heating; we need ice and another big bowl for cooling....”	The student suggests another plan for the experiment	The planning component concerned with regulation of cognition
“... But the gas pressure has an influence too. .... I think we should start from the beginning.”	At each stage of the experiment the students examine the results of their observations in order to decide whether they are logical	The monitoring and evaluating components of the regulation of cognition

In Table II we matched students' quotations and actions to the model of metacognition that was chosen for the data analysis.

We can conclude that the inquiry activity provides the student with an opportunity to discuss in small groups and to develop *metacognitive* activity, as was indicated in the previous description.

Metacognitive Aspects that were Demonstrated in the Interviews

As was mentioned above, twenty 12th grade students that participated in this program were interviewed. While reading carefully the text of the interviews, we found many phrases used by the students related to their learning and exploring processes. Talking about thinking and learning processes indicates that *metacognitive* processes exist. The interviews enabled us to expose the *metacognitive* thinking and to characterize it regarding a theoretical framework.

Since the interviewees talked about their studies, we assumed that we have to search for *metacognitive* knowledge and therefore the theoretical framework that was chosen (Flavell et al. 2002) suggests a detailed description for the structure of the *metacognitive* knowledge, as is shown in Figure 2. In the following section, we match the students' phrases to metacognition components in relating to this model.

Metacognitive Knowledge about People

The students talked about their personal knowledge that had been created in their mind after observing a phenomenon. They claimed that it was important for them to know what was happening during the performance.

> The laboratory causes me personally not to accept things as obvious but to try to understand it deeply.... It also opens up new horizons.

The students are aware of the way that the knowledge had been created in their mind during the inquiry activity and they distinguished between construction of knowledge during active learning and passive learning, when the teacher supplies the knowledge.

> Here you build it, see it, and understand it.

They described the way in which their knowledge had been changed after the inquiry laboratory activity.

> For me this whole subject was not so bad and the laboratory came and shaped it and made it better.

The students are aware of the fact that every person has his own knowledge and they enjoy using the knowledge that they had acquired in the laboratory to explain to other people about certain phenomena.

> After I experienced the laboratory or the chemistry learning I can explain phenomena that other people that did not experience chemistry cannot explain.

Metacognitive Knowledge about Tasks

The Nature of the Information that is Encountered in the Cognitive Task. In their conversation, the students display their awareness of the information that is needed to perform the task. They know that they should connect the experiment that they do in the laboratory to the theory that was taught in the class. They understand the importance of the theoretical knowledge and they search for it when needed.

> We want to understand what happened there ..... and when we read books, we want to check the relation between the experiment and the subject matter.

Metacognitive Knowledge about Task Demands

The students' oral reports are related to four main demands of the tasks: to understand what happens in the experiment, to perform all the inquiry stages properly, and to write the final report – an activity that demands understanding, and relating to relevant and correct scientific knowledge in all the inquiry phases.

Metacognitive Knowledge about Strategies

The students' talks include phrases related to suitable strategies for performing the different tasks that are integrated into the inquiry activity. The students relate to the learning types and to particular strategies that are used by them during the activity. They mention specific ways of learning: cooperative learning that is based on collaboration between their classmates and how this encourages the innovation of good ideas:

> There is a diversity of thinking types. Everyone asks a question, makes an assumption for each question, and then we arrive at a central question...

They mention learning from colleagues, which is possible when the students are given enough time for discussion:

> ...when we sat together, it really helped me to understand. She contributed from her knowledge and I contributed too, and when we combined our efforts, we arrived at things that most of the class did not arrive at.

The students emphasized the importance of the personal attention that the teacher gives to each student during the laboratory activity, and the good feeling that they have when the inquiry subject is of interest to them:

> The teacher sits with us. She passes between the groups..... and this is more than when she just speaks there (in front of the whole class).....here you want to know why, you want to continue your report, and she explains things to you; it's nicer.

The students remember some personal strategies that they use in order to achieve better results. These strategies include checking the data and looking for mistakes:

> When we conduct the inquiry laboratory, there is a chance to check for mistakes.

They also concluded that they learn from their errors:

> When you do it, you understand your errors and you learn from them.

In the students' speeches we found all the components of *metacognitive* knowledge, which were chosen for the data analysis and are presented in Figure 2. In Table III we matched students' quotations from the interviews to this model of *metacognition*.

When the students were interviewed, they presented all this *metacognitive* knowledge. *Metacognitive* activity is presented during the inquiry activity when the students act according to the above-mentioned strategies - when they check their work and look for errors, and when they learn from the errors that they have found.

CONCLUSIONS AND IMPLICATIONS

In this research, we realized that the inquiry laboratory supplies the students with an opportunity to practice *metacognitive skills*. We found that while performing the inquiry activity, the students, whose activity was described above, practiced their *metacognition* in various stages of the inquiry process. This was expressed particularly in the following stages: (a) while asking questions and choosing an inquiry question, the

TABLE III

Examples of students' quotations from the interviews that fit the *metacognition* components according to the model illustrated in Figure 2 (*N*=20)

The component of the *metacognitive* knowledge		Quotations made by the students
Knowledge about people	About the person himself	For me this whole subject was not so bad, and the laboratory came and shaped it and made it better
	About the difference between people	After I had experienced the laboratory or the chemistry learning, I could explain phenomena that other people that did not experience chemistry could not explain
Knowledge about tasks	Information that is required for the task	We want to understand what happened there in..... and when we read books, we want to check the relation between the experiment and the subject matter
	Task demands	When you write the report, you have to understand it...
Knowledge about strategies	Cooperative learning	There is a diversity of thinking types. Everyone asks a question, makes an assumption for each question, and then we arrive at a central question...
	Learning from classmates	...when we sat together, it really helped me to understand. She contributed from her knowledge and I contributed too and when we combined our knowledge, we arrived at things that most of the class did not arrive at
	Individual learning	The teacher sits with us. She passes between the groups..... and this is more than when she speaks there (in front of the whole class)..... here you want to know why, you want to continue your report, and she explains to you; it's nicer
	Searching for mistakes	When we conduct the inquiry laboratory, there is a chance to check for mistakes
	Learning from mistakes	When you do it, you understand your errors and you learn from them
	Relying on common-sense	...if you know that it should be like that... it maybe seems illogical, so you check again and see what was going on there

students revealed their thoughts about the questions that were suggested by their partners and about their own questions. In this stage, the *metacognitive declarative knowledge* is expressed. (b) While choosing the inquiry question, the students expressed their *metacognitive procedural knowledge* by choosing the question that leads to conclusions. (c) While performing their own experiment and planning changes and improvements, the students demonstrate the *planning* component of *regulation of cognition*. (d) At the final stage of the inquiry activity, when the students write their report and have to draw conclusions, they utilize *metacognitive conditional knowledge*. (e) During the whole activity the students made use of the *monitoring* and the *evaluating* components concerned with *regulation of cognition.* In this way, they examined the results of their observations in order to decide whether the results are logical. The fitting between the inquiry stage and the *metacognitive* component that is shown is shown in Table IV.

As was previously mentioned, *metacognition* is an inner awareness or process (White, 1986) and therefore it is not constantly shown. To discern it during the activity, the students under observation should be verbal and willing to reveal their thoughts. In the described activity there was a unique combination of talkative students and a situation where a new student was trying to understand what had been going on in the group in the past, and therefore their thoughts were revealed to us. The fact that other observations lacked prominent expressions of *metacognition* does not mean that the students did not use their *metacognition*. We concluded that there are opportunities for *metacognitive* activity in the inquiry laboratory, but it is revealed in observations that demand special conditions, as mentioned above. A further investigation should be conducted in order to determine the factors that influence *metacognitive* activity in the inquiry laboratory: is this activity dependent on external conditions such as the teacher's behavior, the experiment type, the class, etc?, or does it depend only on the student's mentality?

In the interviews, it is easier to find *metacognition* aspects, because when a person talks about his/her knowledge and learning, he reflects his knowledge about his own cognition and this reflection is actually *metacognition* (Georghiades, 2004). All students that were interviewed demonstrated *metacognitive knowledge*. All the components of *metacognitive knowledge*, namely knowledge about people's knowledge, knowledge about strategies, and knowledge about tasks, exist in the students' conversations. The students mentioned *metacognitive* activity that took place during the performance of the inquiry and was the focus of the activity, according to them, in checking, searching for logical expla-

TABLE IV

Matching *the metacognitive* components that were observed with the various inquiry stages (N=3)

The *metacognitive* component that is expressed	The students' *metacognitive* activity	The inquiry stage
Metacognitive declaration knowledge	The students revealed their thoughts about the questions that were suggested by their partners and about their own questions	Asking questions and choosing an inquiry question
Metacognitive procedural knowledge	The students choose the question that leads to conclusions	Choosing the inquiry question
Planning component of *regulation of cognition*	The students plan changes and improvements for the experiment	Performing their own experiment
Metacognitive conditional knowledge	At the final stage of the inquiry activity, the students use knowledge that was acquired in a different context to write their report and to draw conclusions	Drawing conclusions and writing the final report
Monitoring and *evaluating* components of *regulation of cognition*	The students examine the results of their observations in order to decide whether the results are logical	During the whole activity

nations, and correcting errors. Those actions involve monitoring and evaluation, which are important components of regulation of cognition (Flavell et al. 2002). Also Yore and Treagust (2006) suggested that strategic planning, monitoring progress and regulation actions are the 'real-time' executive control of cognitive operations central to science literacy involved in doing science and learning science.

The students' *metacognition* is also demonstrated in their reflection essays in which they refer to their learning processes and to the role of the inquiry activity regarding those processes. Most of the students indicated that the inquiry activities help them to understand the theoretical concepts:

> Without the inquiry we understand fewer subjects because we do not conduct activities and do not see what is happening.

> I understand what exists under the formula. I think that the inquiry program helped me very much regarding this point, because it gave me the opportunity to think by myself about things, and it helped me to understand them better.

According to the reflection essays, the help in understanding is expressed in several ways, such as realization:

> In the inquiry we learn from our experience and from the realization of many abstract concepts that become visible and connected to reality.

The inquiry activities also aid in remembering things:

> When we explain phenomena, we remember them better than when we hear the teacher's explanation.

They also provide an opportunity for students to make mistakes and to learn from them:

> Sometimes we hypothesize and conclude and later we realize that we made a mistake, but this is a part of the learning process

In addition to the literature sources that claim that the inquiry laboratory activity has the potential to enhance students' meaningful learning, their conceptual understanding, their inquiry skills, and their understanding of the nature of science (Hodson, 1990; Hofstein & Lunetta, 1982; 2004), we can add that the inquiry laboratory provides the students with the opportunity for *metacognitive* activities. The utilization of this opportunity depends on many factors, such as the teacher's behavior, the inquiry activity, and the laboratory environment. It should be noted that the most important variable for the development of *metacognitive* abilities is the students' motivation to utilize the time and the activity for meaningful learning.

Since the results of the current research enable us to argue persuasively that the inquiry laboratory activity provides the students with opportunities to practice their *metacognition* throughout the different stages of the inquiry-type experiment, there is interest in further investigating the *metacognitive* aspect of inquiry activities.

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