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The Spectrum of Dynamic Inquiry Teaching Practices

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Abstract The Israeli high school biology curriculum comprises the Biomind program, in which students are engaged in an open inquiry learning process. The dynamic features of open inquiry often pose challenges to teachers in implementing the Biomind program. The current qualitative research shows that facilitating students in a dynamic open inquiry process is multidimensional. Teaching practices cover a wide range of methods, from structured inquiry through guided inquiry to open inquiry. An individual teacher's profile can be elucidated on the basis of this spectrum. In addition, we realised that teachers often encounter several difficulties in implementing open dynamic inquiry: A dearth of teachers' scientific knowledge, students' lack of scientific knowledge and skills, and a restrictive time-frame. This study suggests several areas which should be considered while implementing an on going professional development support for teachers who are engaged in open inquiry teaching.

Key words Biomind program · dynamic inquiry · open inquiry · professional development

Introduction

Inquiry Based Teaching and Learning Activities

Engaging K-12 students in inquiry-based learning is a cornerstone of ongoing science education reforms (American Association for the Advancement of Science (AAAS), 1993; National Research Council (NRC), 1996, 2000). Schwab (1962) led the way for these reforms by described inquiry as a way of teaching classroom science. Inquiry-based teaching helps students to learn science content, to master how to do science, and to understand the nature of

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science (NOS) (Krajcik, Czerniak, & Berger, 1998; Olson & Loucks-Horsley, 2000). Inquiry-based teaching motivates students when a puzzle confronts them, and they must take risks to try and solve it (Minstrell & van Zee, 2000). Minstrell (2000) states that during the inquiry process "we need to encourage and support personal curiosity when it occurs spontaneously and stimulate it when it doesn't occur naturally" (p. 472).

Inquiry based activities encompass a broad spectrum ranging from structured and guided inquiry (teacher directed) to open inquiry (student directed) and it is important to link the type of inquiry to the desired learning outcome (Olson & Loucks-Horsley, 2000). In structured inquiry, the teacher states the problem, formulates the question and hypothesis, and develops a working plan, while the students implement the plan, gather the data, analyse it, and draw conclusions. This is the most common type of exercise teachers impart to their students, and is typical of most exercises found in laboratory and field manuals. The next level of inquiry teaching is guided inquiry in which the teacher poses the problem and the students determine both processes and solutions. Both structured and guided types of inquiry are effective in conveying content because the teacher is able to lead the student into discovering a specific concept. Alternatively, in open inquiry, students state the problem, formulate the hypothesis, and develop their own working design. Open inquiry focuses on the inquiry process while its content depends on the aspect of the phenomenon that the student chooses to investigate.

However, students are not expected to cope with the challenge of open inquiry on their own, as teachers play a critical role in open inquiry learning. This role encompasses facilitating, focusing, challenging, and encouraging students to engage in this kind of activity. By assuming this role, teachers empower the learning community of teachers and students, to cooperate with each other and to promote an open inquiry process (Zion & Slezak, 2005). On the other hand, many teaching difficulties in implementing the open-inquiry teaching approach among science teachers have been reported. Teachers experience a lack of confidence while facilitating students in the pedagogically risky process of open inquiry, in which results are sometimes unexpected, cannot be predetermined, and lead to further investigations (Kennedy, 1997; Singer, Marx, & Krajcik, 2000; Windschitl, 2003). In addition, the dynamic nature of the open inquiry may cause teachers to feel out of control over what is going on in their class (Uno, 1997).

Open inquiry has been the focus of an ongoing debate whether it properly represents the nature of science and if it is a sound approach for teaching (DeBoer, 1991; Yerrick, 2000). Whether described as expository versus inductive, product versus process, instructional method versus nature of science, or guided versus open inquiry, those who claim that the open inquiry experience may deepen an understanding of the essence of science for future generations of students have called for further investigation that examine classroom teachers' use of open inquiry teaching practices (Berg, Bergendahl, & Lundberg, 2003; Crawford, 2000; Roth, 1999; Yerrick, 2000). The Biomind open inquiry program may serve as a vibrant case study for studying teachers' use of open inquiry teaching practices, particularly due to the fact the teachers participate in this program voluntarily. These teachers found the Biomind program as an opportunity to refresh, promote, and develop their inquiry teaching.

The Biomind Program

The practical part of the Israeli high-school biology syllabus includes structured inquiry activities in the laboratory and structured or guided ecological inquiry in the field. Since the

1980s, evidence has accumulated in Israel showing that practical learning in biology has become routine and repetitive, with the student not functioning as a self-directed learner and the teacher not functioning as a facilitator of inquiry learning (Shperling, 1999). In addition, a gap was found between the teaching of inquiry skills in laboratory classes, and the students' coherent integration of these skills, both in ecological field work and in the analysis of scientific articles and content topics taught in the classroom (Mendelovici, 1996). These findings regarding inquiry teaching, combined with the fact that in recent years, science education professionals have recognised the importance of developing high-level cognitive processes in parallel to developing practical skills (Roberts, 2001), have led to the development and implementation of an open inquiry curriculum in Israel known as the Biomind Program (Mendelovici & Nussinovitch, 2002; Zion et al., 2004a).

Biomind is a program offered to Israeli high school biology students as an alternative to the standard practical components of the biology curriculum (laboratory sessions and ecology field project). Within the Biomind program, 11th and 12th grade students practice authentic and open scientific inquiry (Zion et al., 2004a). Students start with observing a natural phenomenon in the field (such as: chemically induced growth inhibition affected by a specific plant on other plant species which grow nearby), generate inquiry questions and hypotheses, design and execute experiments, collect and process data, and draw conclusions. The Biomind program's open inquiry process is unique in terms of the logical thinking that is required during the development of the inquiry questions (Zion et al., 2004a, 2004b). Using several approaches, students are required to initiate and investigate three inquiry questions that are logically related to each other. For example, three inquiry questions may be investigated in parallel and lead to understanding different aspects of the phenomenon. In another approach, findings related to the first question may lead to the formulation of a second question, and findings from the second question may help formulate the third question. A combination of these approaches is also possible. For example, the first two questions examine different aspects of the phenomenon in parallel, and the third question may be formulated after examining some findings.

The Biomind Program is an Opportunity to Improve Teachers' Pedagogical Knowledge Regarding Inquiry Learning

Facilitating students in an open inquiry is a challenging endeavor for teachers (Windschitl, 2002). This is particularly true for Israeli biology teachers in the Biomind program. Teaching open inquiry is an opportunity for these teachers to refresh their inquiry teaching skills and enhance their professional development. An action research following the first 3 years of the Biomind program found that open inquiry in the Biomind program is characterised by four main criteria of learning in a dynamic inquiry environment: learning as a process, changes occurring during the inquiry process, procedural understanding, and affective points of view (Zion et al., 2004b). This dynamic open inquiry characterisation was performed applied by teachers operating simultaneously in three roles within the program framework: as teachers, program developers, and researchers. Their suggestions following the action research were designed to improve the Biomind program, so that the criteria for dynamic inquiry are more explicitly emphasised in the updated program manual (Zion et al., 2004b).

As teachers play a central role in the implementation of the Biomind program, successful teaching of open inquiry depends greatly on the comprehension of the essence of open dynamic inquiry by the Biomind teachers. This raises several questions: Are Biomind teachers aware of the principles of open inquiry? Are Biomind teachers aware of the dynamic nature of open inquiry? Are Biomind teachers applying the principles of open dynamic inquiry as they facilitate their students' through the inquiry learning process? These are vital and relevant questions because research has shown that teachers, who often lack experience in conducting authentic inquiry, also lack an understanding of inquiry procedural knowledge. They often do not understand the sequence of events in the inquiry process (Windschitl, 2002). In addition, teachers often have difficulty in shifting from a mechanical teaching approach, in which they see a simple series of events in experimenting, to "mastery" teaching, in which they understand the content, concepts, and processes of science (Roth, 1996; Vasquez & Cowan, 2001).

Teachers' conception of the essence of the inquiry process affects the implementation of curricula, especially when a certain curriculum emphasises open inquiry (Keys & Bryan, 2001; Tamir, 1983; Welch, Klopfer, Aikenhead, & Robinson, 1981). Crawford (2000) characterised the functioning of teachers implementing open inquiry teaching in class. Her research emphasised that pedagogical-content knowledge, deep comprehension of the essence of science, and understanding how to facilitate students in their inquiry process, are essential components of the teacher's inquiry teaching skills. Due to the multiple interpretations of inquiry-based teaching in science, Crawford (2000) and Keys and Bryan (2001) called for additional research on teacher beliefs, knowledge, and practice of inquiry to provide a more comprehensive description or characterization of this teaching mode. Because teachers actively construct their practice based on their beliefs about learning and understanding of inquiry, analysing their thoughts in the context of their practice may provide an enhanced description of inquiry teaching. Thus, it is worthwhile to follow the Biomind teachers during the implementation of this novel inquiry program. Furthermore, such a follow-up may serve as a basis for constructing appropriate open inquiry professional development programs for teachers (Harlen, 2004).

Research Objectives

The current research focuses on teachers involved in the Biomind program and the implementation of an open inquiry process in this program. Facilitating students as they conduct an autonomous inquiry is a new task for teachers, and requires a significant change in their teaching practices. The goal of this research is to characterise the teaching of dynamic inquiry by teachers implementing a new open inquiry program. This goal leads to two main research objectives:

1. To characterise the dynamic inquiry principles teachers emphasise during the teaching process.
2. To diagnose difficulties teachers experience in implementing open dynamic inquiry.

Research Methodology

The research methodology focused on collecting evidence of teaching in the Biomind program in order to expose theories, beliefs, and teachers' hidden attitudes in qualitative terms (Rudduck & Hopkins, 1985; Stenhouse, 1975). Arrangement and construction of information was used to interpret and understand the meaning of the data (Pidgeon, 1996).

Participants in the Study

Ten teachers from different schools teaching the Biomind program participated in this research (Table 1). The teachers vary in seniority and education. All teachers participated in the Biomind introductory workshops. In the workshops, the teachers learned the principles and goals of open inquiry teaching and the principles of the new program. The workshops also provided scientific and pedagogical support to assist teachers in facilitating their students' open inquiry processes. This research demanded cooperation between researcher and teachers, so only those teachers who expressed their consent to cooperate in an educational research were included.

Data Collection

We gathered data during two academic school years, in which each teacher supervised one class of Biomind students. Interviews were used as a primary tool for collecting research data. The interviews were semi-structured and lasted approximately one hour. Each teacher was interviewed privately, twice during the research: the first time after the students submitted their inquiry proposals, and a second time after the students finished writing their reports and constructing their portfolios. To maintain a quiet and comfortable surrounding, the teachers were interviewed in the school laboratory, the teachers' lounge, or in their homes.

Table 1 Teachers' characteristics

Reference number assigned to teacher-participant	Teaching seniority	Highest degree earned	Cycles of Biomind teaching	Type and location of school where the teacher works	Number of students in class
1	26	MA in Science Education	2	Urban school in northern Israel	10
2	15	MA in Jewish Studies	1	Religious school in northern Israel	22
3	15	M.Sc with thesis in Medical Sciences	1	Urban school in northern Israel	14
4	10	B.Sc in Biotechnology	1	Urban school in northern Israel	16
5	11	MA with thesis in Science Education	1	Rural school in northern Israel	16
6	7	Ph.D in Biology	1	Urban school in central Israel	16
7	30	Ph.D in Biology	2	Urban school in northern Israel	20
8	22	M.Sc in Biology	1	Rural school in northern Israel	26
9	28	M.Sc in Biology	2	Rural school in central Israel	26
10	23	M.Sc in Biology	2	Rural school in southern Israel	24

The first set of interviews was conducted while the students were in the initial stages of their inquiry process, in which the learning of inquiry skills is emphasised. The interview questions referred to aspects of inquiry design, difficulties experienced by teachers in facilitating students, and methods used by the teachers to overcome these difficulties (Appendix A). For the second interview, a set of questions was formulated to elicit teachers' conception of the essence of open inquiry and compare the Biomind inquiry process to inquiry process in science (Appendix A). In the second set of interviews, each teacher was also asked specific questions based on issues that surfaced in the first interview and required clarification, examination, or elaboratoryoration.

The following documents were used as data sources for analysis:

I. Students' inquiry proposals containing teachers' corrections.
II. Students' final Biomind portfolios, especially summaries of and reflections upon the inquiry process.
III. Students' logs containing teachers' remarks.
IV. An open-ended questionnaire administered to teachers near the completion of the research, entitled "The winding paths of inquiry" (Appendix B).
V. Biomind teacher discourse in online and face-to-face discussion groups in which pedagogical support was offered. Instructions were provided to teachers by the Biomind developers and by supervisors from the Israeli Ministry of Education.
VI. Protocol from a panel entitled "What is a good inquiry and what is the preferred association between inquiry questions?" The panel summarised lengthy discussions held over the years on various occasions among Biomind teachers (including participants of this research), program developers, and science education researchers. The panel discussions fueled additional debates within the Biomind teachers' discussion groups.

Data Analysis

Data analysis included the following stages:

1. An analysis based on sensitising concepts, which were identified in the literature on inquiry: concepts of evidence (Gott & Duggan, 1996), types of inquiry (Olson & Loucks-Horsley, 2000, pp. 175–176), and dynamic open inquiry (Zion et al., 2004b).
2. Coding – all the data were classified and assigned into categories during the analysis. A category was formed only when at least five quotations supported the category. In addition, the research team referred to a category only when a category was supported by at least three different archives.
3. During several cycles of coding the data, categories were generated, data 'scraps' were assigned to categories, and the categories were refined and integrated until a coherent characterisation was developed (Glesne & Peshkin, 1992, pp. 131–134).
4. Multiple sources of data collection, as well as multiple voices of teachers and researchers were used to triangulate the data for this research. Data collection through triangulation of sources, as well as the rich description of the phenomenon under review, contributed to the validity of the research (Anfara, Brown, & Mangino, 2002).
5. A characterisation of the open inquiry teaching process was constructed. During this stage, teachers' difficulties were described.

Results

The results will be presented in three sections according to the research goals. The primary objective of this research was to follow the teachers who implemented the Biomind program, and to identify the dynamic inquiry principles the teachers emphasised. The first section shows how the characteristics of dynamic inquiry can be identified in inquiry teaching and includes evidence for each of the characteristics of the dynamic inquiry process. While analysing the data, we realised that we can arrange the characteristics of dynamic inquiry teaching along a spectrum. One end of the spectrum characterises aspects related to principles of structured inquiry that teachers emphasised during the teaching process, and the other end of the spectrum characterises aspects related to open inquiry principles. The evidence regarding each characteristic of dynamic inquiry will be presented according to the spectrum. Evidence emphasising principles of open inquiry will be presented first, and evidence emphasising aspects of guided and afterwards structured inquiry will be presented. The findings are summarised in Table 2. Based on the spectrum presented in Table 2, we have constructed a personal profile of four teachers studied in this research. The personal profiles are presented in Table 3.

The second objective was to diagnose difficulties teachers experience in implementing open dynamic inquiry. Accordingly, the second and third sections present teachers' difficulties and how teachers cope with difficulties in facilitating dynamic open inquiry, respectively. The Discussion section synthesises the previous three sections and reflects upon the findings.

Dynamic Inquiry Teaching Spectrum

Learning as a Process

The Biomind program requires students to formulate three inquiry questions related to a biological phenomenon. In some cases, only the first question is formulated at the beginning of the inquiry process, while the other two questions are formulated during the inquiry process. For instance, the findings of one inquiry question can lead to a new inquiry question that could not be considered at an earlier stage. This process enhances the student's comprehension of inquiry as a dynamic experience. The issue of formulating questions is addressed in a substantial part of the evidence referring to inquiry learning gathered for this research. Most teachers participating in the research believed that the logical association among inquiry questions is a significant aspect of the Biomind inquiry process. Most of these teachers believed that a "good" inquiry project is characterised by an approach in which inquiry questions follow one another:

> The inquiry learning process is a dynamic inquiry process in which one inquiry question led the students in a certain train of thought. First, they formulated a question, and then they formulated another one (Teacher 8).

A teacher explained the importance of the dynamic nature of sequential formulating of inquiry questions:

> The questions should derive one from another, like in a detective work. Otherwise we just fall back on studying the same phenomenon from several aspects leading us back to the standard program. An inquiry process goes deeper when it is based on one question leading to the next question. (Teacher 10)

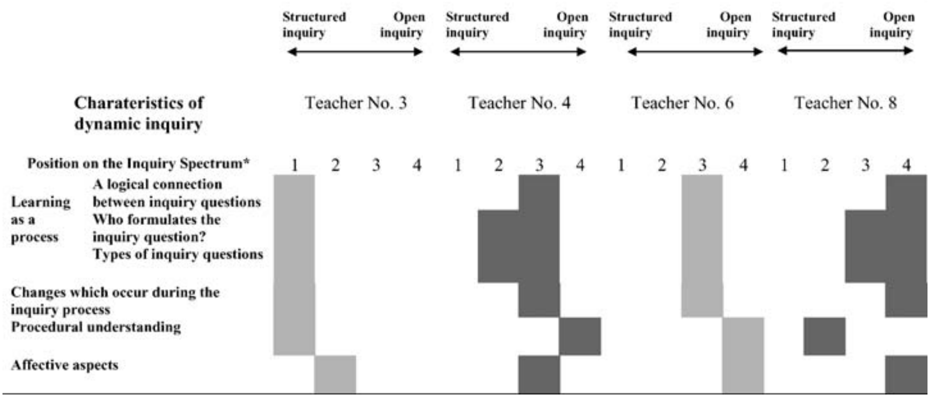
Table 2 Range of teaching practices in the biomind program

Characteristics of dynamic open inquiry		Structured inquiry	←→		Open inquiry
		Structured inquiry teaching – point of reference	Teaching inquiry in Biomind program – characteristics gathered in the current research		
	A logical connection between inquiry questions	Three questions are formulated at the same time. The questions are not necessarily connected to a challenging phenomena. Data is analysed only after findings for all three questions have been gathered.	A challenging phenomena is under investigation. Questions are formulated independently with no logical connection between them.	Inquiry questions are formulated in parallel and are logically connected.	Analysing findings relating to one question raises a new question.
Learning as a process	Who formulates the inquiry question?	Teacher formulates the inquiry questions.	Teacher formulates the inquiry questions.	Questions emerge during teacher-student discussion. For example: a student proposes a subject, the teacher comments, and together they formulate the remaining questions	The student raises the question, and the teacher helps to formulate and focus it.
	Types of inquiry questions	Questions that have been formulated in previous inquiry projects. "Safe" and not challenging questions have a greater chance of obtaining answers. Questions to which the teacher knows the answers. Preference for questions that can be answered in a short time.	Questions asked by previous inquiry learning project teams. Questions the teacher finds challenging. Questions whose findings are predictable by the teacher.	Questions which both teachers and students find challenging, and have emerged during mutual discussions. Questions whose answers may be partially known in advance for the teacher.	Questions which evoke students' curiosity while the teacher is not always knowledgeable about the topic these questions address and/or the expected outcome..

Table 2 (continued)

Characteristics of dynamic open inquiry	Structured inquiry	⟵	⟶	Open inquiry
	Structured inquiry teaching – point of reference	Teaching inquiry in Biomind program – characteristics gathered in the current research		
	Teacher foresees how the entire inquiry will progress.	Teacher partially understands the dynamic aspects of inquiry.	Teacher understands the dynamic aspects but: Prefers to navigate the inquiry so as to avoid unexpected problems.	The inquiry process takes a long time and is unexpected. Both the teacher and student understand that inquiry can take many paths and they control the process.
Changes which occur during the inquiry process	No place for changes.	Teacher views most inquiry dynamics as a result of technical problems.	Teacher does not facilitate the inquiry process properly. The inquiry process switches from subject to subject without focus.	
	Teacher is unable or unwilling to cope with the dynamic aspects of the inquiry process		Teacher is not willing to experience inquiry involving change throughout the process.	
Procedural understanding	Inquiry is procedurally structured in such a way that it achieves high levels of credibility based on the expected findings.	Great emphasis on planning experiment variables – defining, isolating, and measuring them. Findings depend on proper, reliable equipment.	It is important to know how to explain and connect the results to the biological basis of the inquiry. Understanding procedural aspects throughout the process.	It is important to know how to explain and connect the results to the biological basis of the inquiry. Inquiry development is not expected. Proper procedural aspects are reconsidered at every stage. If a procedural aspect turns out to be improper, the experiment is reorganized and predictions are reconsidered.
Affective aspects	Self-confidence	Sense of insecurity and uncertainty is not an integral part of inquiry.	Sense of uncertainty and openness to accepting change, problems, and mistakes.	A sense of insecurity and uncertainty follows the inquiry process. These feelings are accompanied by teacher-student cooperation and by the joy of discovery, curiosity, excitement, and wonder.
	Problems and changes during the inquiry process should not emerged	There is excitement and curiosity.	It is preferable to know the outcomes in advance, at least in regard to one inquiry question.	

Table 3 Teachers' individual profiles representing the range of teaching practices in the biomind program



The *shaded boxes* indicate the point along the spectrum, which represent the teacher's teaching style.

Table 2 served as a basis for the creation of this Table.

* Inquiry Spectrum: 1 = structured, 4 = open.

Another teacher supported the parallel approach:

> As a facilitating teacher I am not opposed to parallel questions. If the students study factors influencing a phenomenon, let them formulate parallel questions. The important thing is to link the inquiry questions, so that each one in itself and the association between them shed light on the phenomenon under inquiry. (Teacher 9)

At the structured end of the spectrum we find teachers who saw no importance in linking inquiry questions (Table 2). One teacher claimed: "The students performed experiments but have not yet analysed the findings. They will do it later. First they have to finish performing the entire design" (Teacher 3). This teaching orientation does not leave room for reasoning about the findings, throughout the inquiry process, and does not allow critical appraisal of the entire design, for example, relevance to the phenomenon and of the logical association between inquiry questions.

The data we have collected regarding teachers–students' interactions, enables us to place the teaching practices on a spectrum indicating each one's role in formulating the inquiry question (Table 2). Most teachers stated that students are unable to formulate the inquiry questions by themselves, adding that formulating questions is the most difficult stage of inquiry learning. The spectrum ranges between two extremes as described by one of the teachers:

> When asking them to choose an inquiry question, we gave them a list of questions that we had prepared from which they may choose. Alternately, we allowed students to come up with their own idea and helped them rephrase it into an inquiry question. (Teacher 4)

In the middle of this spectrum, teachers and students cooperate in phrasing an inquiry question during discussion:

> We sit and talk, formulate questions. Most students arrived with an initial idea that was unfeasible...Most students are not self-directed. They want someone else

to do the work, or at least support them and do the work together with them. (Teacher 1)

The critical role of the teacher in the inquiry process affects both the nature of the inquiry questions and the process of formulating questions as described above. We found that inquiry questions may also be characterized along a spectrum, at one end of which are questions for which the answers which can probably be expected by the teacher, and at the other end are questions the teacher may never have encountered before and therefore has no way of anticipating the answers. We found further that many teachers in our study tend to lead students to investigate issues in which these teachers are familiar and feel confident. One teacher illustrates this tendency: "I would lead them to inquiry questions I know how to handle, where I can clearly see the defined variables, and where I know I can support them and give them a hand in case they get lost" (Teacher 9).

Changes Occurring During the Inquiry Process

During dynamic open inquiry, changes occur as the inquiry design is implemented. These changes occur as unexpected findings are obtained from experiments or after reading additional relevant literature sheds new light on the inquiry topic. Other changes include new ideas which emerge during the inquiry process. The attitudes of Biomind teachers towards changes during the inquiry process can be placed along a spectrum (Table 2). Most teachers view changes and dynamic aspects of inquiry positively:

> When I facilitate students' inquiry, I don't know what the findings will be. That is, I don't know in advance what will happen. I can anticipate general outcomes but the inquiry process itself is an unknown. Possibly, all of the hypotheses will be proven wrong and the students would have to start over and examine new paths – that is a good inquiry. When you guide the student in a path familiar to you, where you know the outcome, that is to me a bad inquiry. (Teacher 2)

Some teachers were aware of the dynamic aspect and view changes positively: "These are the points that are important to me; encountering mistakes, designing and realizing that experiment doesn't work and why. Mistakes should be part of the experience of what-is-inquiry" (Teacher 4). But these teachers prefer the inquiry process to be semi-structured. For instance, they preferred that one of the inquiry questions should be "safe" so that students feel successful:

> I decided that I can't give them absolute freedom on every subject. They are not that strong in managing inquiry, and I can't guide them on subjects with which I am not adequately familiar. I can look for new methods but I felt I needed something which would be technically easier for me to facilitate them in doing. (Teacher 6)

On the other hand, some teachers expressed a negative attitude toward the dynamic aspect, looking at change as a failure of the inquiry process. These teachers strive to avoid change: "All the experiments changed... they all changed direction. I can't do anything, can't handle the technical problems. I try to cope with changes by instructing the students to perform other different simpler experiments" (Teacher 3). In addition, these teachers view the dynamic change as the abandonment of one inquiry subject for the adoption of another; not as changes that are an integral part of the inquiry process in a certain subject: "Things change all the time... subjects change" (Teacher 3).

Procedural Understanding

The teachers who participated in the research were asked to define a "good open inquiry." Their answers revealed a variety of attitudes concerning the emphasis of procedural understanding during the open inquiry process (Table 2). Some teachers considered strict methodical procedures at the inquiry design stage to be an essential component of the inquiry process:

> It is important to isolate variables. It is important to change just one variable while the others remain controlled. They won't know how to do it on the first experiment, but they'll learn later. When students conduct quantitative inquiry they must make sure the findings are accurate. It is important to control any factors that may affect the findings. In the findings section, it is important to support both the findings of the experimental treatment and the findings of the control treatment. (Teacher 8)

> A student must learn to isolate variables, design a proper control, analyse findings in a graphically appropriate presentation, and discuss the findings based on scientific data. The student must refrain from relying on personal expectations. (Teacher 10)

A teacher who was asked to define a 'poor' inquiry project picked one that "Did not include replications. The students conducted each experiment only once" (Teacher 7). The teacher added that in order to improve the project, the students should repeat each experiment. When asked to define a 'good' inquiry, this teacher stated: "There's a group that did a good job... and they did have replications" (Teacher 7).

Other teachers focused on procedural aspects of a certain experiment, and did not consider an ongoing inquiry process:

> The important thing is: What did I learn from the experiment? What did I design? How did I organize the experiment, and how did I reach the correct conclusions at both the biological and experimental levels? The experiment's structure and my ability to improve the experiment are also important. (Teacher 1)

Other teachers, when asked to define a "good inquiry", didn't attribute such paramount significance to the procedural inquiry aspects (e.g. replications). These teachers noted the importance of the overall structure and logic of the entire inquiry process. This structure comprises of the design of several experiments, data processing, critical evaluation of findings, explanation of the finding, and related inquiry questions. Teacher 2 claimed: "Discussion and reasoning are very important to me. That is, it's important to encourage reasoning and critical thinking so that one question leads to another. Designing one particular experiment is less significant than the inquiry structure as a whole." "The whole idea of designing inquiry, experiencing problems is also very important in my view" (Teacher 4).

Affective Points of View

The teachers indicated that the dynamic aspect of the inquiry process elicits different affective reactions (Table 2). Both teachers and students experienced disappointment, frustration, and sometimes despair:

> It works many times, but more often the experimental procedure fails, which brings about very intense reactions from the students, and many times from myself, and leads

> us to feel terrible. For instance, all the groups working on animals abandoned their projects. When we finally formulated an inquiry question, our animal disappeared from the research field. It was very disappointing and depressing for me too. (Teacher 2)

> I prefer that students obtain the expected findings the classic way, where we can see what was achieved... that is why I tried to lead them in such a way that at least one question will have a relatively expected answer. (Teacher 4)

> The students are affected by the fact that we're working on something for which I do not have the answers to in advance. In the laboratory, I know what is expected. In Biomind, we delve into the unknown. Uncertainty can be uncomfortable for the teacher, but can also be interesting and exciting. I'm not at the uncomfortable stage. I have enough practice to cope with uncertainty. But this coping does take effort. (Teacher 2)

Some teachers were aware of the dynamic aspect and viewed change positively, yet they preferred that at least one inquiry question was "safe," so that the students feel confident and successful:

> Of course I prefer to obtain findings in the "classical" manner, to be able to see things...that is why I tried directing my students to have at least one of the three questions, a "safe" question, which will result in the expected outcome. They should feel some success. (Teacher 4)

Some teachers emphasised uncertainty as an integral part of the inquiry process: Uncertainty is both difficult and enjoyable at the same time. I did not always know where to go... It was very interesting for me to investigate and learn new things. Sometimes the students shared knowledge that was new to me. It is a pleasure to discover new things, as a teacher. (Teacher 5).

> Many times, one interesting discovery led to another, unexpected discovery. We also worked through student curiosity. (Teacher 8)

The intensive cooperation, success, and failure helped to create a novel relationship between teacher and student (Zion & Slezak, 2005); teamwork, and mutual inquiry initiative were seen as legitimate:

> We were constantly considering how and in which directions to proceed, what steps needed to be performed, how we constructed an experiment, and how did we process the data. You studied with the student and some of the work was really performed out of the joy in doing it. (Teacher 8)

This teacher testified to the teamwork between herself and her students. She expressed a sense of a cooperative inquiry team: "There is very good discourse, I really like these open conversations. We and the students thought like a team conducting science" (Teacher 8).

Dynamic Inquiry Teaching Spectrum-personal Profile

The findings presented above led us to conclude that the attitudes of teachers to dynamic inquiry teaching are not homogenous and do not consistently reflect the open inquiry principles which are described in detail in the program's instructions. We realised that although teachers participated in an introductory workshop, their attitudes to dynamic inquiry teaching vary along a spectrum of attitudes, covering the entire range from structured inquiry to guided inquiry to open inquiry. Based on the teaching spectrum summarized in Table 2, we constructed personal teaching profiles of four teachers participating in the research. These profiles are presented in Table 3. Grey-colored cells in Table 3 indicate cases in which the teacher functions along the spectrum of dynamic inquiry characteristics. Sometimes the teachers function in more than one level, as the teachers report their interactions with students altered to match the students' learning abilities. The four teachers' profiles indicate there is no one uniform model by which inquiry is being taught. Teacher 3's teaching profile tends towards the structured end of the spectrum. Teachers 4 and 6 can be positioned at an intermediate level and Teacher 8 tends towards the open inquiry end of the spectrum. The spectrum enables us to identify the strengths and weaknesses points of the teachers. For instance, Teacher 4 exhibits difficulties in assigning her students an active role at the question phrasing stage and directing inquiry towards questions for which the teacher does not know the answer. On the other hand, Teacher 4 succeeds in facilitating her students in emphasizing procedural aspects throughout the entire teaching process, while Teacher 8 exhibits difficulties in emphasizing these aspects.

Difficulties of Teachers in Teaching Dynamic Open Inquiry

As we mapped the teachers according to the different attitudes in teaching dynamic inquiry, we also accumulated evidence detailing teachers' difficulties in teaching dynamic open inquiry. As described below, teachers' difficulties emerged due to three factors: teachers' lack of knowledge and skills, students' lack of knowledge and skills, and logistic limitations of conducting inquiry at school. This section presents evidence of difficulties according to these three factors.

Teachers Lack Scientific Knowledge and Understanding Regarding the Essence of the Inquiry Process

The teachers were not consistently proficient in their students' inquiry topic: "I decided I cannot allow them to choose freely any subject... I cannot facilitate my students in subjects that I am not proficient in" (Teacher 6). The teacher's lack of scientific knowledge might cause a shift in students' attitude toward them, and this made some teachers uncomfortable, expressing insecurity in facilitating the students: "First of all, I am not proficient in every subject of biology, and I want to learn with the students. But my lack of knowledge creates a feeling of total insecurity when the teacher doesn't know" (Teacher 8).

Many teachers never experienced actual scientific research process during the course of their academic studies and teacher training. Teacher 5 noted: "I have no pretensions to being an expert, as I have never conducted real scientific research" (Teacher 5). Likewise, teacher 1 also stated:

> Everything I do in this field is based on teaching experience and literature. That is, I read about what others have done... when I was a student at the university 'a hundred years ago'... practical inquiry skills were not taught. I would attend a lecture, pass a test, and that was it. Today, biology students are required to write an inquiry proposal during their academic studies.

Furthermore, teachers exhibited difficulties in understanding the concept of evidence such as, identifying and setting up controls, and designing a valid and reliable inquiry plan that included determining constant factors and the need for repeatability: "Concepts such as repeatability and sample size came up in this week's Biomind teachers' discussion. Group participants concluded that terminology regarding experimental planning was not clear to everyone" (Teacher 9).

Students Exhibit Low Levels of Biological Knowledge, Inquiry, and Scientific Writing Skills

Another problem that affects the open inquiry teaching emerged due to the lack of the students' knowledge infrastructure. Lack of knowledge can be observed in: different fields of biological knowledge, inquiry skills, and scientific writing skills. The students were expected to begin inquiry work in the middle of 11th grade, a period when many biological topics have not yet been taught. Sometimes, students chose subjects which they haven't learnt. "When they started out, their knowledge was almost zero" (Teacher 8). "I think their knowledge of biology is insufficient to develop ideas for open inquiry" (Teacher 1).

Students had difficulties in designing an experiment. Such students did not easily link a phenomenon to an inquiry question. These students identified an interesting phenomenon in the field and formulated an inquiry question that was indirectly, if at all, linked to what they saw. For instance: "Students noticed a field where only flowers of one color bloomed, while this flower is known to bloom in many different colors elsewhere. But, their inquiry question, by mistake, focused on something entirely different, flower plant germination" (Teacher 3). Often students developed ideas that were difficult to investigate in school laboratory conditions. "So far, I have not seen one student who managed to execute their initial idea. Students sometimes have grandiose ideas that are unrealistic" (Teacher 1).

Students exhibited difficulty also in locating suitable methods and handling equipment and overcoming technical difficulties that emerged during their work: Students do not have a repertoire of methods. When they obtain an unexpected result from an experiment, they have a difficult time deciding whether this is the correct finding, or whether the experiment went wrong for some technical reason and an alternative method is required. (Teacher 6) Another teacher stated: "The students themselves lack laboratory skills, and the laboratory lacks equipment" (Teacher 8). Experiment planning also created problems regarding the comprehension of procedural aspects of inquiry: "There were many problems with the inquiry plan, and also with measurements and the required controls. Internal control was not enough and external control was also needed" (Teacher 5).

Students also exhibited difficulties in processing data: "The students are having difficulties in processing information, focusing on the main points, and building data tables. Students find it very, very difficult to determine what the graph titles should be" (Teacher 8). In many cases, the teachers also emphasised that performing statistical tests was beyond their students' capability.

In addition, the students also exhibited difficulties in scientific writing: "The students' writing skills are lacking. They can't form a logical sentence using correct language. They can't discriminate between what is important and what is not" (Teacher 8). Some of the students' problems were not necessarily linked to scientific writing but to the ability to cope with written text in general: "They copy and paste together segments from the encyclopedia. The segments are not clearly relevant or linked to each other" (Teacher 2). Students who never experienced learning as a process integrating reflection, found it difficult to view the different work stages, keep a log, and consider alternative evaluations.

These students focused on the outcome of their experiments and on their grades. "I told them to keep everything in their work log. Some students found this very difficult, because they were not organized enough, and did not understand the need for documentation" (Teacher 5).

Limitations of Conducting Inquiry at School

Teachers claimed that a two-year time frame is unrealistic for acquiring inquiry skills, planning inquiry projects, implementing work and writing a final report:

> The work requires a lot of guidance which is difficult to maintain. I have to work closely with the students and be their partner in every step. It is possible, no doubt, but only if we put enough time into it. For this work to proceed optimally, we must meet. Meeting means time to spare for the teacher and the student. During the school year there is almost no time to spare. (Teacher 1)

One issue described as a difficulty in facilitating inquiry work is the limited timeframe for teaching inquiry skills, planning inquiry projects, and conducting and reporting them. Students who suggested inquiry subjects faced different difficulties and often switched subjects arbitrarily, prolonging their inquiry process. This phenomenon was described by a teacher:

> The program should be initiated at the beginning of 11th grade, with a set timeframe to which the teacher strictly adheres. On their part, each student group should also be required to detail their inquiry schedule as part of the inquiry proposal. (Teacher 1)

Teachers who have taught at least one teaching cycle apply their experience and lessons in structuring a timeframe for the next cycle:

> I have a complete picture now and can plan it differently. When you are unsure, you tend to postpone things. I performed many activities perhaps too late and was pressed for time. Today, I would schedule tasks in a different way. (Teacher 4)

How Teachers Cope with Difficulties in Facilitating Dynamic Open Inquiry

The various ways teachers cope with difficulties in open inquiry can be attributed to the same three factors upon which we mapped teachers' difficulties. We will first introduce how teachers focused on their own improvement in scientific knowledge and the essence of the scientific inquiry process. Subsequently, we will introduce ideas applied by teachers in order to facilitate students' biological knowledge, inquiry, and scientific writing skills. Finally, we will show how teachers handle the limitations of conducting inquiry at school. Some of the suggestions detailed in the following section were welcomed by the Israeli Ministry of Education and have already been incorporated into the Biomind program. Table 4 summarises difficulties and their proposed solutions.

Developing Teachers' Scientific Knowledge and Understanding of the Essence of the Inquiry Process

In light of teachers' difficulties in teaching open inquiry, the Israeli Ministry of Education decided that teachers who facilitate their students in the Biomind program must participate

Table 4 Dynamic inquiry teaching difficulties and related solutions

Difficulties of teachers in teaching open dynamic inquiry	How can teachers overcome difficulties in facilitating dynamic inquiry?
Teachers lack scientific knowledge and understanding regarding the essence of the inquiry process.	Teachers participate in professional meetings, which develop teachers' inquiry experience and enhance their biological and pedagogical knowledge
	Teachers develop inquiry experience and skills by performing actual inquiry process
Students exhibit low levels of biological knowledge, inquiry skills, and scientific writing	Train students in phrasing inquiry questions and link them to phenomena
	Allocate time during biology studies at school to improve learning habits, such as inquiry performances and scientific writing.
	Create a database of inquiry subjects and methods.
Limitations of conducting inquiry at school	Teach according to a tight schedule.
	Creating a data base of research methods suitable for school laboratoryoratories.

in several annual professional meetings to share ideas and solutions. The teachers also discussed and consulted with each other via an internet discussion group. Students' inquiry proposals were reviewed by Biomind teachers to help identify and solve problems that emerged during this early stage. One teacher stated: "It is a good idea. I sent the inquiry proposal to two other teachers in the colleague group, and they made their remarks" (Teacher 1). Other teachers positively viewed the workshops as contributing to enhancing their content and pedagogical knowledge. The workshops gave participants feedback regarding their teaching skills and improved their confidence: "The interaction with other teachers and their different points of view on inquiry teaching were very helpful to me. I found people who could offer constructive criticism of what I was doing" (Teacher 6). Another teacher said:

> I found out that the colleague support group brings together knowledge from very different directions. It opens your mind. Everyone sees things a bit differently. If you're open to what others have to say, it is very helpful. The group "helps when your student has a technical problem that you yourself may need help with" (Teacher 3).

One teacher suggested that the teachers themselves conduct an inquiry, so that they could acquire firsthand experience with the difficulties that arose during the inquiry process and improve their ability to cope with the difficulties their students encounter.

Scaffolding Students' Biological Knowledge, Inquiry, and Scientific Writing Skills

The formal instructions of the Biomind program do not explicitly require that students state in their inquiry proposal the phenomenon from which the inquiry question arose. Teachers claimed that describing the phenomenon would help students phrase the question relating to such phenomenon properly. Furthermore, students' lack of knowledge of inquiry methods inhibited their ability to plan an experiment according to the question they formulated. These students were not familiar with suitable methods, even if they knew what they wished to investigate. Teacher 7 said they must pass through the planning stage independently, with the teacher stepping in to suggest methods by which the students can perform their planned inquiry. The students may then continue independently:

> Students came to me and said, these are the avenues we want to take, help us plan the experiment because we don't know how to do it ... They could not do it by themselves, they lacked the requisite knowledge. We planned it together. I helped them with the first observation and measurement. They continued from there. (Teacher 7)

This teacher claimed the experiments should be simplified so that students could conduct them: "The issue should be simplified to achieve something that can actually be performed in school" (Teacher 7).

Creating a database of subjects appropriate for the Biomind program, including inquiry methods, can help teachers who are experiencing difficulties in suggesting inquiry subjects and methods. "Every year the teacher is required to be very creative and suggest new subjects. It was very difficult. If there was a subject database each teacher could select a topic" (Teacher 7).

How to Overcome Limitations of Conducting Inquiry at School

Time and resource limitations can suffocate even the finest of curricula. Biomind teachers believe that a teacher must adhere to a very tight and structured schedule and introduce an intensive work routine, in spite of students' tendencies to postpone their assignments. At a Biomind teachers' convention, one teacher presented the teaching schedule she now uses, which she had developed following several cycles as a facilitator. She detailed her schedule and said: "Intensive activity from day one is the big secret" (Teacher 9).

Discussion

Dynamic Inquiry Teaching Profiles

One of the greatest challenges in science is to keep an open mind. This may sound simple and rather commonplace, but it serves as the main driving force for teachers in selecting to teach an open inquiry program. In Israel, although teachers can opt to remain with the traditional and most widely used practical inquiry program based on guided inquiry, teachers choose to apply the Biomind program on their own initiative and motivation to cope with the challenge of teaching open inquiry.

Although the Biomind program centers on the open inquiry process, findings of this research point to a gap between the detailed written program rational and instructions, teachers' motivation, and the reality of teaching open inquiry in the class. To maintain the sense of openness during the open inquiry, as the Biomind program requires, is a complex task, especially because open inquiry is a dynamic inquiry learning process. The dynamic learning process emphasises perspectives of critical thinking and change, uncertainty, and reflective thinking about the process (Zion et al., 2004b). This research shows that facilitating students in a dynamic inquiry process is characterized by a spectrum of teaching levels, ranging from facilitating structured inquiry to facilitating the desired open inquiry. The functioning of each teacher, with regard to every characteristic of dynamic inquiry, is represented on a different point along the spectrum. For example, regarding a certain characteristic, the teacher's functioning is represented one end of the spectrum (e.g., open inquiry), regarding another characteristic, the functioning is represented the opposite end of the spectrum (e.g., structured and guided inquiry).

Several factors may be suggested in explaining the finding that teachers operate along a spectrum of facilitating characteristics, not all of which are appropriate for open inquiry. Teachers' difficulties and the way they cope in overcoming teaching dynamic inquiry, can shed some light on this issue. For example, enabling and encouraging the student to become self-directed takes a long time. But, teachers operate in a timeframe determined by the educational system, which often does not allow enough time for dynamic open inquiry. For this reason, teachers working with a large number of students per class are inclined to prefer structured and guided inquiry, enabling them to conclude the inquiry process within the imposed time limitations. In this context, a tight schedule provided by the teacher at the start of the academic year, may be a solution.

To engage in scientific inquiry, students need teachers who believe that open inquiry based teaching is the best instructional approach to support their students' learning and difficulties, and are also confident in their ability to teach open inquiry approaches (Damnjanovic, 1999; NRC, 1996). Teachers may feel insecure regarding the concept of dynamic open inquiry because of its strong element of uncertainty. Working with three logically related inquiry questions may also contribute to the feeling of teachers' uncertainty, and this idea emphasises the importance of documentation and reflection throughout the inquiry process. Our teachers also mentioned difficulty in encouraging students to document the process and reflect upon it as they progress. As the program is still in its initial stages we can assume that Biomind teachers do not fully understand the essence of the open inquiry process. Teachers lack the confidence or the time to develop new teaching strategies geared to improve students' understanding and use of the open inquiry process (Schauble, Klopfer, & Ragghavan 1991; White & Frederiksen, 1998). Alternatively, Biomind teachers find it difficult to change attitudes and teaching methods with which they are familiar, and have successful experience.

It is possible to draw a profile for every teacher, based on their ability to facilitate students. This profile may be used for several purposes: as a method for reflecting on teaching practices; as a tool for determining what aspects of dynamic open inquiry the teachers find easier or more difficult to cope with in their teaching; and as a research tool for either qualitative or quantitative studying of inquiry teaching and teachers' professional development. Future research may compare teachers' profiles in depth and discuss the significance of profile types. In some cases (e.g., Teacher 4), we marked two squares for one criterion; having obtained evidence that teachers changed their mode of teaching to match the developing abilities of their students. This finding emphasised that the spectrum represents an actual sequence of teaching strategies. This sequence can be interpreted in two ways, first: the teacher's own professional development, and the second, developing congruence between teacher and student taking into consideration students' cognitive capabilities and learning styles. The segments along the spectrum can be utilized for research purposes of teachers' practices and development. We realise that the spectrum presented here may need to be refined further as more teachers enroll in the program.

Teachers' Professional Development

Helping Biomind teachers cope with the difficulties of teaching dynamic open inquiry is essential to the success of the program. Tobin, Tippins, and Gallard (1994) reported evidence of a strong connection between teachers' beliefs about teaching and learning and their actions. It is likely that teachers who have difficulty in teaching inquiry, require restructured belief systems about the value of inquiry teaching and learning outcomes. According to this assumption, we advocate the design of two-year introductory workshops for new Biomind program teachers. In these workshops, teachers learn the principles of open inquiry teaching and the principles of the new program. The workshops also provide scientific and pedagogical support to assist teachers in facilitating their students' open inquiry processes. Results of this research show that although all teachers participated in the workshops, some teachers' teaching profiles vary greatly from the expected profile for open inquiry teaching. This finding emphasises that professional development workshops for teachers in the early years of implementing a new curriculum are not adequate in supporting open inquiry teaching. Long-term ongoing support for teachers is necessary, relating to the personal teaching profile of every teacher and working on their strengths and limitations from an open inquiry perspective. This type of support will address the difficulties and apply the solutions suggested in this article, and additional aspects that future research may reveal. Teachers bring different ideas, beliefs, experiences, concerns, interests, and feelings to professional development programs. Teachers have different starting points along the development process and might achieve different outcomes within the broad goals of the program, even though they have attended the same program (Bell, 1998; Luft, 2001). This finding may be a good reason to consider the reality that teachers facilitate students at different levels throughout the dynamic open inquiry process, and there is room for improvement. The key point here is to make teaching changes gradually, continually, and for the long-term.

Different researchers have suggested methods to assist the long-term professional development which may be suitable for adaptation in the Biomind program: Vasquez and Cowan (2001) listed a series of actions that hold implications for teachers' practice: reflection, self-examination, peer study groups, mentoring by master-level teachers, and time for developing a deeper understanding of the content and pedagogical knowledge of the curriculum. Engaging teachers in curriculum and pedagogical development is another way to help teachers overcome their difficulties (Parke & Coble, 1997). Lack of content and procedural knowledge is another significant aspect that should be considered. Bybee and Loucks-Horsley (2001) indicated that "Teachers need to know science as deeply, even more deeply, than their students" (pp. 4). Thus, an academic support system such as an inquiry-based course for teachers is required for the teacher in order to fill in the gaps (Bell, 1998; Crockett, 2002; Hogan & Berkowitz, 2000; Jeanpierre, Oberhauser, & Freeman, 2005; Trautmann & MaKinster, 2005). Teachers, who take such a science course, are able to share the same opportunities with their students in developing an understanding of the nature of science, and the essence of scientific inquiry (Lederman & Lederman, 2004; NRC, 1996). This opportunity is of value because a tendency to encourage and enable students to carry out student-directed, open-ended scientific inquiry projects appears to be associated with adherence to social constructivist views about science (Bencze, Bowen, & Alsop, 2006). Although teachers adhering to rationalist–realist and teachers adhering to naturalist–antirealist perspectives about science are both likely to effectively promote learning of products of science, teachers adhering to naturalist–antirealist views will be most likely to promote student-directed, open-ended inquiry activities (Bencze et al., 2006).

Further important professional support can be given by constructing asynchronous online discussion groups for teachers, and by arranging face to face veterans' continued teachers' workshops. Involving teachers in Biomind pedagogical support groups is beneficial for several reasons: These groups can assist teachers in understanding the essence of the inquiry process and supply them with constant scientific and pedagogical support regarding their students' inquiry projects. Understanding and making use of the existence of different facilitating teaching profiles can also be achieved in the context of these workshops. We suggest that future research will focus on two perspectives: One, finding pedagogical solutions to some of the restrictions and difficulties that interfere with teachers' application of dynamic inquiry characteristics at a level appropriate for open inquiry. Two, improving the ability to teach the inquiry process by enabling teachers to adapt their teaching profile to the learning capabilities of their students.

The current study helps fill the gap in understanding the nature of the classroom practice, of in-service teachers that challenged themselves by choosing to teach open inquiry. The current research shows that even though detailed instructions and a two-year in-service professional development training course accompanied the implementation of the Biomind program, facilitating students in a dynamic inquiry process occupies a spectrum of teaching practices that ranges from structured to open inquiry. An individual teacher's profile can be created upon the basis of this spectrum. We also realised that teachers often encounter several difficulties in teaching dynamic inquiry: A dearth of teachers' scientific knowledge, students' lack of scientific knowledge and skills, and a restrictive time-frame. These results suggest several areas which should be considered while implementing long-term professional development support initiatives for teachers who engage in open inquiry teaching. Teachers who have appropriate pedagogical knowledge and confidence in open inquiry teaching might serve as an effective vehicle for engaging students in thought provoking open dynamic inquiry. In this context, we propose that the results of this research may open a window for understanding the essence of open inquiry teaching.

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Appendix A

Questions which formed the basis of the interviews

The first set of interviews included six general questions addressed to all participating teachers:

1. What distinguishes the Biomind program from the standard biology program?
2. What difficulties did you encounter while facilitating the students and when? (Your own and the students' difficulties). How did you cope with these difficulties, and can you suggest solutions for them?
3. One problem discussed by teachers in the Biomind workshops is correcting students' inquiry proposals. Do you have any suggestions for teachers trying to meet this challenge?
4. How do you facilitate your students in choosing inquiry topics and in formulating inquiry questions?
5. Let us try and draw an outline of the inquiry process, beginning with the stage of choosing a subject. What activity was performed at each stage? Where did you encounter turning points and junctures? What decisions were taken? How did the first inquiry question lead to the second?

6. During the inquiry process, students often obtain findings which are unexpected or contradict the inquiry hypothesis. How do you assist students in such situations?

The second set of interviews also included six general questions addressed to all participating teachers:

1. Among the inquiry projects you facilitated, choose one that you think is good inquiry and adequately reflects the goals of the Biomind program. Why did you choose this specific inquiry project? How are the questions linked to one another? What difficulties arose when you facilitated this inquiry project?
2. Inquiry work in Biomind begins with a phenomenon, proceeds with the formulation of questions related to the phenomenon, and continues with investigations via controlled experiments. Why do you think the program was constructed around this protocol? Do you believe it is important to perform every component of the protocol? Explain.
3. Can you see any parallels between the Biomind inquiry work and the scientific inquiry process? What are the similarities and what are the differences?
4. Unlike structured inquiry learning in the laboratory, open inquiry learning in the Biomind program takes a long time. Yet the acquired inquiry skills may be similar. In what way(s) does the long time frame contribute to the Biomind inquiry process?
5. Biomind is an experimental program continuously developing and changing. Your experience is important in shaping future education. What was your primary difficulty in implementing the program? How would you suggest coping with this difficulty?
6. Do you expect that following their participation in the Biomind program your students will be more successful in solving theoretical inquiry problems, compared to students who have been taught in the standard practical inquiry program?

During the second interview, the teachers were asked specific questions according to the responses they provided during the first interview. Some examples appear below:

1. The Biomind program fosters investigation by means of three questions. One question refers to study by means of observation. Do you believe that it is important to include a field observation as part of an inquiry project?
2. What happened if a student workgroup neglected to document part of their process? How would you respond? Or "how would you convince the students to keep an organized log as required by the program guidelines?"
3. In the first interview you said: "inquiry as a concept is central to Biomind, unlike the previous program..." What do you mean by this statement?
4. Some teachers insist that the inquiry proposal includes the entire inquiry design, before the students begin the practical stage. Others claim that it's possible to approach the experimentation stage with a first draft of an inquiry proposal and complete the proposal throughout the course of the process. What are the pros and cons of each approach?
5. Changes occur throughout the Biomind inquiry process. Do you think this is a positive or a negative aspect of the Biomind program? Explain.
6. In the previous interview, you mentioned problems that arose and how you managed to overcome them. What have you learned from this experience about managing Biomind inquiry teaching for your future class?

7. Do you believe that you have changed in your comprehension of the essence of inquiry since you participate in the Biomind program? Please specify.

Appendix B

The winding paths of inquiry

Choose one of your student's inquiry subjects

- What was the phenomenon observed and studied?
- What were the inquiry questions?
- How are the questions linked to each other and how do they contribute to building contiguous data regarding the observed phenomenon? How were the questions generated?
- Give an example of an unusual method you implemented.
- What were the inquiry findings? What do you think was the most unusual result?
- Write down a resource (article/internet website/expert) that you came across and contributed new biological knowledge or inquiry methods.
- List some difficulties that emerged during the inquiry process and suggest possible solutions. What might your role be in applying these solutions?
- Why did you choose to present this specific inquiry project?
- Give an example of an interaction that occurred between you and the students.

References

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Anfara, V. A., Brown, K. M., & Mangino, T. L. (2002). Qualitative analysis on stage: Making the research process more public. *Educational Researcher, 31*(7), 28–38.

Bell, B. (1998). Teacher development in science education. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 681–693). Dordrecht, The Netherlands: Kluwer.

Bencze, L., Bowen, M., & Alsop, S. (2006). Teachers' tendencies to promote student-led science projects: Associations with their views about science. *Science Education, 90*(3), 400–419.

Berg, C. A. R., Bergendahl, V. C. B., & Lundberg, B. K. S. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education, 25*(3), 351–372.

Bybee, R. W., & Loucks-Horsley, S. (2001). National science education standards as a catalyst for change: The essential role of professional development. In J. Rhoton & P. Bowers (Eds.), *Professional development planning and design* (pp. 1–12). Arlington, VA: NSTA.

Crawford B. A., (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916–937.

Crockett, M. D. (2002). Inquiry as professional development: Creating dilemmas through teachers' work. *Teaching and Teacher Education, 18*, 609–624.

Damnjanovic, A. (1999). Attitudes toward inquiry-based teaching: Differenced between pre-service and in-service teachers. *School Science and Mathematics, 99*(2), 71–76.

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York: Teachers College Press.

Glesne, C., & Peshkin, A. (1992). *Becoming qualitative researchers*. White Plains, NY: Longman.

Gott, R., & Duggan, S. (1996). Practical work: Its role in the understanding of evidence in science. *International Journal of Science Education, 18*(7), 791–806.

Harlen, W. (2004). *Evaluating inquiry-based science developments*. Washington, DC: National Research Council. Retrieved June 4, 2006, from http://www7.nationalacademies.org/bose/WHarlen_inquiry_Mtg_paper.pdf

Hogan, K., & Berkowitz, A. R. (2000). Teachers as inquiry learners. *Journal of Science Teacher Education, 11*(1), 1–25.

Jeanpierre, B., Oberhauser, K., & Freeman, C. (2005). Characteristics of professional development that effect change in secondary science teachers' classroom practices. *Journal of Research in Science Teaching, 42*, 668–690.

Kennedy, M. (1997). *Defining Optimal Knowledge for Teaching Science and Mathematics (no. 10)*. Madison, WI: National Institute for Science Education, University of Wisconsin.

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essentional research for lasting reform. *Journal of Research in Science Teaching, 38*, 631–645.

Krajcik, J., Czerniak, C., & Berger, C. (1998). *Teaching children science: A project-based approach*. Boston, MA: McGraw-Hill.

Lederman, J. S., & Lederman, N. G. (2004, April). Early elementary students' and teacher's understanding of nature of science and scientific inquiry: Lessons learned from Project ICAN. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Vancouver, British Columbia, Canada.

Luft, J. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education, 23*(5), 517–534.

Mendelovici, R. (1996). *Teaching biology in high school in Israel in the* middle of the *1990s, emphasizing inquiry.* Unpublished masters thesis. The Hebrew University in Jerusalem, Israel. (in Hebrew)

Mendelovici, R., & Nussinovitch, R. (2002). *Biomind, an alternative for the* practical part of curriculum for Biology of 5 units for matriculations. Jerusalem, Israel: The Center for Science Education, The Hebrew University (in Hebrew).

Minstrell, J. (2000). Implications for teaching and learning inquiry: A summary. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 471–496). Washington, DC: American Association for the Advancement of Science.

Minstrell, J., & van Zee, E. H (Eds). (2000). *Inquiring into inquiry learning* and teaching in science. Washington, DC: American Association for the Advancement of Science.

National Research Council (NRC). (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council (NRC). (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

Olson, S., & Loucks-Horsley, S. (Eds.) (2000). *Inquiry and the National Science Education Standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

Parke, H. M., & Coble, C. R. (1997). Teachers designing curriculum as professional development: A model for transformational science teaching. *Journal of Research in Science Teaching, 34*(8), 773–789.

Pidgeon, N. (1996). Grounded theory: Theoretical background. In John T. R. Richardson (Ed.), *Handbook of qualitative research methods* (pp. 75–85). Leicester, UK: The British Psychological Society Books.

Roberts, R. (2001). Procedural understanding in biology: The 'thinking behind the doing. *Journal of Biological Education, 35*, 113–117.

Roth, W. M. (1996). Teacher questioning in an open-inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching, 33*, 709–736.

Roth, W. M. (1999, April). Scientific research expertise from middle school to professional practice. Paper presented at the annual meeting of the American Educational Research Association, Quebec, Montreal, Canada.

Rudduck, J., & Hopkins, D. (1985). *Research as a basis for teaching: Readings from the work of Lawrence Stenhouse*. London: Heinemann.

Schauble, L., Klopfer, L. E., & Ragghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28*, 859–882.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Shperling, O. (1999). Letter to the biology team about the ecology work. *The Bulletin of Biology Teachers, 159*, 10–11. (in Hebrew)

Singer, J., Marx, R. W., & Krajcik, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist, 35*(3), 165–178.

Stenhouse, L. (1975). *An introduction to curriculum research and development*. London: Heinmann.

Tamir, P. (1983). Inquiry and the science teacher. *Science Education, 67*(5), 657–672.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 45–93). New York: Macmillan.

Trautmann, N., & MaKinster, J. (2005, January). Teacher/scientist partnerships as professional development: Understanding how collaboratoryoration can lead to inquiry. Paper presented at the 2005 International Conference of the Association for the Education of Teachers of Science, Colorado Springs, CO.

Uno, G. E. (1997). Learning about learning through teaching about inquiry. In A. P. McNeal & C. D'Avanzo (Eds.), *Student-active science: Models of innovation in college science teaching* (pp. 189–198). Fort Worth, TX: Saunders College Publishing.

Vasques J., & Cowan, M. B. (2001). Moving teachers from mechanical to mastery: The next level of science implementation. In H. Pratt (Ed.), *Issues in science education series: Professional leadership and the diverse learner*. Arlington, VA: NSTA.

Welch, W. W., Klopfer, L. E., Aikenhead, G. S., & Robinson, J. T. (1981). The role of inquiry in science education: Analysis and recommendations. *Science Education, 65*(1), 33–50.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*(1), 3–18.

Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education, 87*, 112–143.

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education, 87*(1), 112–143.

Yerrick, R. K. (2000). Lower track science students' argumentation and open inquiry instruction. *Journal of Research in Science Teaching, 37*, 807–838.

Zion, M., Shapira, D., Slezak M., Link, E., Bashan, N., Brumer, M., et al. (2004a). Biomind – A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education, 38*(2), 59–67.

Zion, M., & Slezak, M. (2005). It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education, 21*, 875–894.

Zion, M., Slezak, M., Shapira, D., Link, E., Bashan, N., Brumer, M., et al. (2004b). Dynamic, open inquiry in biology learning. *Science Education, 88*, 728–753.