Dynamic, Open Inquiry in Biology Learning

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ABSTRACT: In the new biology-learning curriculum for Israeli high schools, known as Biomind, students experience "open-inquiry." This paper describes a qualitative action research project that was performed in order to investigate the characteristics of the open inquiry learning process. Specifically, the research investigates this process in terms of the concepts of evidence, affective aspects, and other aspects that may emerge by following the open inquiry process. This paper also discusses how the findings from the open inquiry process can be used for further curriculum improvement.

This research characterized the open inquiry as a *dynamic inquiry* learning process. The main criteria for characterizing the dynamic inquiry are learning as a process, changes occurring during the research, procedural understanding, and affective points of view. The paper further suggests methods of documenting the dynamic inquiry process. This documentation can assist in understanding the inquiry process from both the cognitive and metacognitive points of view. The educational and research processes described here contributed both to improving the curriculum and to establishing an infrastructure through which the science education community can emphasize dynamic aspects of science in open inquiry learning.
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INTRODUCTION

Inquiry is more than a method of science, inquiry is science (Suchman, 1968). Thus, recent science education reforms (American Association for the Advancement of Science [AAAS], 1994; National Research Council [NRC], 1996, 2000) advocate the design of instructional environments that involve students in learning about the nature of science via scientific inquiry. Through development of inquiry skills, students are expected to gain an understanding of concepts and content, an understanding of the process of scientific inquiry, and an understanding of the nature of science (NOS), in addition to positive attitudes toward science (Abd-El-Khalick, Bell, & Lederman, 1998; Ogens, 1991). Inquiry learning is compatible with the constructivist approach, which emphasizes the idea that knowledge is not transmitted directly from one knower to another, but is actively developed by the student (Driver et al., 1994; Tobin & Gallagher, 1987; Yager, 1991), who is responsible for his or her own learning (Osborne, 1996; White, 1988). Inquiry involves activity and skills, but focuses on the active search for knowledge or understanding to satisfy curiosity (Haury, 1993; Tilgner, 1990).

Based in part upon the writings of Schwab (Schwab, 1964), Herron's Scale describes four levels of inquiry, each differentiated by the information and support provided to students prior to the completion of a learning activity: Confirmation, Structured, Guided, and Open Inquiry (Herron, 1971). Science inquiries that were part of the science curriculum resulting from the 1960s curriculum reform efforts were either confirmation, structured, or guided inquiries, with few, if any, open inquiries (Gabel, 2001). Teachers perceive inquiry activities as "assurance" for textbooks, or as preparation for final exams, and these activities are teacher-centered rather than students-centered (Mendelovici, 1996). When open types of inquiries were administered, results indicated that students did not usually progress to a higher level of process skills (Gabel, 2001). In the USA, UK, and Australian schools, science laboratories are being used less and less in the acquisition of genuine practical inquiry skills (Fensham, 1981; Finn, Maxwell, & Calver, 2002; Sanson & Pears, 1995; Solomon, Duveen, & Hall, 1994). Students work too often in the laboratory as technicians following "cookbook recipes," and they are unable to meaningfully summarize the important aspects of an experiment they have just completed (Bell et al., 2003; Germann, Haskins, & Auls, 1996; Tamir & Lunetta, 1981). Although students enjoy practical activities, such as lab or field activity, they do not necessarily internalize concepts and principles, and do not necessarily develop positive attitudes to science (Ogens, 1991). Penner and Klahr (1996) found that students failed to perceive the essence of inquiry as a process that combines an experimental and an intellectual aspect, a process whose aim is to suggest and examine explanations for natural phenomena. Students do not see science as scientists' efforts to construct explanations for phenomena in the "real world," and do not understand that knowledge is the product of a never-ending process by which it is reexamined and updated. Students work according to the "engineering model," instead of a "scientific model" (Schauble, Klopfer, & Ragghavan, 1991), that is, they see scientific assignments as an experience aimed at anticipated results and plan their experiments accordingly. In addition, Chinn and Malhotra (2002), who defined the characteristics of the authentic inquiry process, claimed that performing inquiry tasks according to the curriculum does not enable students to experience cognitive processes that characterize authentic science. Thus, teaching through inquiry has a limited influence on high-school students (Bell et al., 2003; Germann, Haskins, & Auls, 1996; Ogens, 1991).

In recent years, science education professionals have recognized the importance of developing high-level cognitive processes in concert with practical skills (Roberts, 2001). These professionals also expressed the belief that an inquiry-based approach to learning and scientific research is too valuable for the development of scientific literacy and should not be compartmentalized in curricula (Finn, Maxwell, & Calver, 2002). The goal is to help students negotiate the complexities of scientific inquiry so that they will be able to engage in independent open inquiry as soon as they are able (Germann, Haskins, & Auls, 1996). The combination of these ideas and the difficulties in teaching inquiry in Israeli classrooms (Dvir & Chen, 2000; Tamir, 1998; Tamir, Stavy, & Ratner, 1998) led to the establishment of the Biomind curriculum (Mendelovici & Nussinowitz, 2002).

The Biomind curriculum (program) was developed by a group of 30 biology teachers, and aimed at responding to the need for developing an innovative curriculum for teaching inquiry. This curriculum was designed to emphasize the students' search for knowledge through inquiry, and recognized the importance of learning both in the laboratory and in the field (Israeli Ministry of Education, 1991). The Biomind curriculum, in which students have to demonstrate self-direction, personal initiative and teamwork, is structured around students' active learning processes. During the Biomind learning process, students are expected to be involved in an open inquiry process and must address *three* logically connected inquiry questions. This open inquiry process emphasizes a new way of thinking, unfamiliar to the teachers who developed the curriculum. This inquiry process goes beyond both structured inquiry and guided inquiry, whereby the teacher performs certain parts of the work. Students in Biomind experience an open and authentic inquiry process in which the beginning and the end of the process are not predetermined, and not known beforehand, either to the students or to the teacher (NRC, 2000; Zion et al., 2004).

If we are to avoid the failure of the past related to giving teachers teacher-proof curriculum, we need to turn our attention to how best to support teachers in embracing the essence of inquiry (Crawford, 2000). In recent years, teachers' knowledge has been recognized by increasing numbers of educators and curriculum experts as the major factor in curriculum development and successful implementation (Barnett & Hodson, 2001). Moreover, significant curriculum development clearly would not occur unless teachers' professional knowledge and understanding were the primary focus of curriculum developers (Barnett & Hodson, 2001). One of the major forms of professional development is action research. Action research may serve as an opportunity to engage in life-long professional development through the support, collegiality, and collaboration of professional researchers (Hofstein, 2001). This professional development can provide an instant challenge of comparison and contrast that overcomes the limitations of teachers' previous experiences. In addition, this development enables group members to construct a clearer understanding of the distinctive features of the novel teaching through inquiry curriculum in which they participated (Barnett & Hodson, 2001).

Action research may provide teachers with strategies that will facilitate new ways of teaching and thinking about the Biomind curriculum. We formulated our research in qualitative terms because, as Eisner (1991) says, "To know what schools are like, we need to be able to *see*; what occurs in them, and we need to be able to tell others what we have seen in ways that are vivid and insightful" (p. 22). Our goal was to examine the educational reality of Biomind concerning the concept of open inquiry, with the intention of both improving the quality and extending the thinking of participants. The research questions were (1). What are the characteristics of the open inquiry learning process, in terms of the concepts of evidence, affective aspects, and other aspects that may emerge by following the open inquiry process? (2). How can the findings from the open inquiry process be used for further curriculum improvement?

RESEARCH METHODOLOGY

The Biomind Curriculum

The Biomind curriculum was designed for high school students studying toward matriculation in biology, and it is used as an alternative to the practical part of the previous curriculum (laboratory and ecology work), which equals 40% of the total grade. In the Biomind curriculum, the student is expected to function autonomously, while the teacher functions as a facilitator, who directs and focuses the learning throughout the entire process. The Biomind curriculum emphasizes both student's learning outcomes and the learning process that the student experiences. Different training methods attempting to develop inquiry skills have failed because they had not emphasized the metacognitive skills of reflection, self-control, and decision making in the inquiry problem solving process (Blank, 2000; Sternberg, 1998). Thus, different stages of the Biomind work offer opportunities for correction and improvement and Biomind students experience reflective thinking, and are expected to acquire metacognitive skills. The core of the curriculum is a self-directed and authentic open inquiry (Zion et al., 2004). The open inquiry relates to a biological phenomenon that can be observed in the field, and can be checked by controlled lab and controlled field observations. The students, who study in teams, submit a research proposal that includes three research questions, at least one of which is examined in an experiment, and another through field observation. The formulation of these questions at the beginning stages of research requires students to think of the logic connecting the three questions. The students conduct the research, summarize it, and submit the summary as part of a portfolio. The portfolio includes reports of inquiry experiments and excursion reports that demonstrate the acquisition of research skills in both the laboratory and in the field. All of these reports serve as a preparation for conducting the open type research (Zion et al., 2004). The 30 teachers who developed the Biomind curriculum met once every 2 weeks for 8-h meetings, starting 2 months before the beginning of the school year. Thus, the curriculum preparation began 2 months prior the onset of Biomind, and each Biomind cycle lasted 2 years. Constructing and implementing the first version of the curriculum lasted 3 years, and the curriculum was completed after the first two cycles of Biomind (see Figure 1).

Participants in the Study

Six biology teachers and the 16–18-year-old students in their intact classes (grades 11 and 12), who selected to study biology for their matriculation examination, participated in the study. Table 1 presents demographic and other characteristics of both teachers and their respective students.

Data Collection

The research applied the model of practical-cooperative action research (Elliott, 1997). In this model, collection and analysis of data is performed cooperatively among classroom teachers and university-based academic staff. The teachers participated in the process of planning the research and determining the research goals, preparing the research, and examining the ways in which significant change could be implemented (Elliot, 1997). The research focused on collecting evidence of learning in the Biomind curriculum in order to disclose theories, beliefs, and students' hidden attitudes in qualitative terms (Elliott, 1991; Rudduck & Hopkins, 1985; Stenhouse, 1975). Data collection, coding, and analysis were performed, and conclusions were drawn in an extended group activity, which included the six teachers (one of whom is also an academic researcher), the Biomind supervisor and the

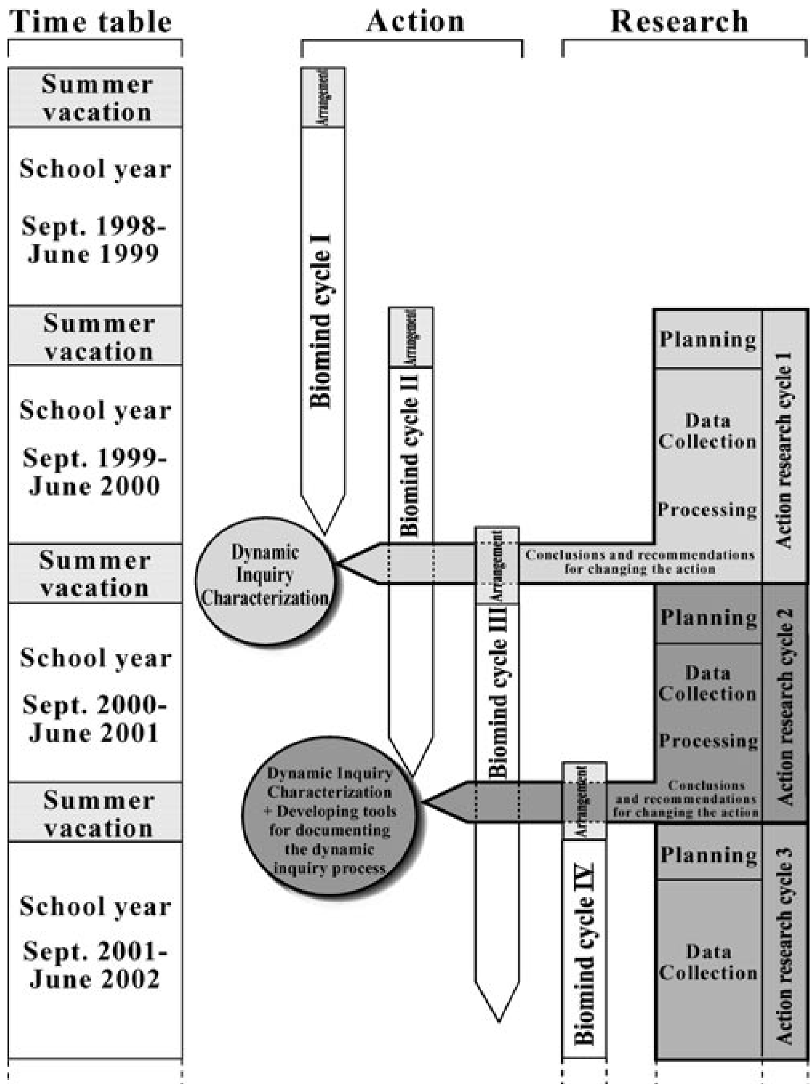

Figure 1. Depiction of Biomind cycles and action research cycles. The Biomind cycles are presented by years. Each cycle starts with the preparation of the teaching team in the summer vacation and continues for 2 years. Each action research cycle lasted 1 year. The horizontal arrow marks the Biomind cycles in which recommendations made during the activity cycles were implemented.

assistant supervisor, the chief supervisor of biology studies in Israel, and the manager of the National Biology Teachers Center. Adding people to the team in these stages of the research contributed to extending the reliability of the data analysis and conclusions, which were based on qualitative methodologies. The action research consisted of two complete cycles (Figure 1). Each action research cycle continued for 1 year, while each Biomind program cycle continued for 2 years. Action research cycle 1 included data collection about Biomind cycle I,[1] and about the first half of Biomind cycle II. Data analysis and conclusions were

[1] Biomind curriculum cycles are numbered by Roman numerals, while action research cycles are numbered by Arabic numerals.

TABLE 1
Teachers' and Students' Characteristics

Teacher No.	Academic Degree	Teaching Experience (years)	No. of Students in the Biomind Class	Biomind Cycle for Data Collection	Description of Israeli School
1 Action research supervisor	PhD in molecular biology	6	22 (15 girls, 7 boys)	I	Public school in the center of a large city
2	BSc in biology	20	40 (22 girls, 18 boys)	I	Large public school
3	MSc in biology	13 (The head teacher of her school's biology department)	7 (4 girls, 3 boys)	I	Special public school that emphasizes values education and contribution to the community. Located in a lower class neighborhood and the students come from lower and upper classes.
4	MSc in microbiology	17 (The head teacher of her school's biology department)	20 (11 girls, 9 boys)	II	New public school in a town established in 1996
5	MSc in science education	25	12 (girls)	II	Orthodox religious school for excellent students from upper socio-economic backgrounds
6	PhD in ecology	32	34 (17 girls, 17 boys)	II	Public school located in a large northern city. The students possess high cognitive abilities and come from the middle socio-economic classes.

used as a springboard for recommendations. The recommendations, which were accepted by the Biomind teachers, were implemented as of the second half of cycle II. In action research cycle 2, data were collected about the learning activity occurring in the second half of Biomind cycle II. The conclusions and recommendations resulting from this action research led to changes in the Biomind curriculum. These changes will be implemented as of Biomind cycle III.

The data was gathered from the following sources: student and teacher questionnaires, students' and teachers' journals, and interviews of students and teachers. Leading questions in both the questionnaires and interviews encouraged students and teachers to explain in detail the learning process they experienced during the open inquiry, in terms of concepts of evidence and affective aspects. Research tools were administered to direct students and teachers to recount of events and developments that transpired in the course of the inquiry learning process. A rich description was the basis for both characterizing the open inquiry learning process and considering curriculum improvements. The following text details the different approaches used to collect data:

1. Content analysis of the following documents:

   1.a) Students' reflections which were recorded in their Biomind portfolios. Students answered the following six questions: (i) Why did you decide to research this biological phenomenon? (ii) What did you learn from your experience in conducting scientific inquiry? (iii) What did you learn from writing a report? (iv) How did keeping a personal journal contribute to your learning process and your sense of responsibility towards your work? (v) How has teamwork contributed to your inquiry? (vi) In retrospect, what would you do differently if you began your inquiry again, and why?

   1.b) A questionnaire that students completed after submitting their research proposal. The questionnaire consisted of 10 open-ended questions related to the inquiry process. For example: (i) At what point in the research did you turn to these literary sources and why? When do you usually consult the teacher? (ii) Give an example of a helpful remark from a friend that advanced your studies. If you have changed the research question or some of its processes, what was the rationale? (iii) Give an example of how your personal initiative was expressed in this stage of the Biomind work.

   1.c) A questionnaire that students completed at the end of the Biomind program, after they submitted their portfolios to their teachers. This questionnaire consisted of five open-ended questions focusing on the teacher's role, team work, and student autonomy. For example: (i) Compare the Biomind research with other schoolwork, in regard to your enjoyment, acquisition of skills, and the cooperation with your teacher. (ii) How did you learn to think critically and readjust as you work, basing conclusions for continued work on your results?

   1.d) Events and activities documented in the teacher's journal, such as description of learning and teaching processes that occurred during the course of the inquiry project, student-teacher contact, and students' and teacher's reactions and affective responses.

   1.e) A questionnaire completed by each teacher at the end of a Biomind curriculum cycle. This questionnaire consisted of open-ended questions related to students' experiences of the inquiry process. Examples: (i) During the course of the research, did the team need to survey more literature, in addition to what was originally stated in the research proposal? Provide examples. (ii) At what stage was most of the literature collected? In your reply, consider your answer to the above question (i). (iii) Has the group brought up any new ideas during work? Note in which cases. (iv) Have these new ideas caused a change in the research question? Provide examples. (v) Have these ideas altered the direction of the research? Provide examples. (vi) Provide examples of the students repeating an experiment as a result of rethinking issues of control, repetition, and measurement and change of the independent variable, and measurement of the dependent variable.

1.f) A real-time journal reporting students' work activities. These activities included thoughts, planning, experimentation, results, temporary summaries, decision making, and hypotheses.

2. Interviews

2.a) Interviewing students—the students were questioned in semi-structured setting. Interview topics derived either from an analysis of students' reflections, or questions that arose during the interview.

2.b) Interviewing teachers—the teachers were questioned in the forum of an action research group. These interviews were conducted every 3 months throughout the 2 years, and included questions about events and activities, which arose during the operation of the Biomind curriculum. Teacher No. 1 initially moderated the interviews. As the course of the interviews progressed, the teacher's role changed from moderator to participant.

Procedure of Data Analysis

Data analysis occurred parallel to their collection, and included the following stages:

1. An analysis based on sensitizing concepts, which were identified in the literature on inquiry: concepts of evidence (Gott & Duggan, 1995) and as inquiry-based skills, such as, the ability to ask questions, to phrase a hypothesis, to isolate variants, to identify controls, to process data, and to make conclusions (Tamir, Friedler, & Nussionwitz, 1982; Tamir et al., 1998).
2. Coding—all the data were classified and divided into categories during the analysis. A category was formed only when the action research team found at least 30 quotations to support the category from the different archives. The research team referred to these categories only when a category was supported by at least five teachers' 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 characterization was developed (Glesne & Peshkin, 1992, pp. 131–134).
4. Multiple sources of data collection, as well as multiple voices of teachers, researches, and administrators were used to triangulate the data for this study. Any category that was not supported by evidence from at least documents of three different approaches, and was not authorized by the entire research staff, was omitted from the analysis. 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; Sagor, 1993).
5. A characterization of the learning process was constructed according to the grounded theory approach (Glaser and Strauss, 1967). The results of the data analysis were presented to the extended action research group, and criteria definitions were drawn

collaboratively through discussion. Recommendations for the future operation of the curriculum were also generated by this method.

RESULTS AND CONCLUSIONS

Analysis of all the action research data shows that the process of open inquiry is characterized by the following criteria: learning as a process, changes occurring during the research, procedural understanding, and affective points of view. Each criterion included several defined categories. Each category was based on examples from at least three different data sources. Several examples from these sources were selected to illustrate each category described in this paper. Members of the action research team, who are the authors of this article, selected examples from their archives. The team members selected examples that would be understandable to most readers, in addition to biologists or Biomind teachers. The student code, teacher reference number (Table 1), and data collection approach are indicated next to each example.

Learning as a Process

This criterion included the student's knowledge of the nature of a process, in which one stage leads to the other. In an inquiry process, the student proceeds through different intermediate steps from question to conclusion. However, the Biomind student, working with three interconnected research questions, experiences additional aspects of inquiry learning.

Understanding the Importance of Documentation Throughout the Research Process. During the Biomind project, students were required to keep a journal, documenting all the stages of their inquiry. Students understood the importance of documentation throughout the research process. Documentation contributed to the organization and the management of the research, and aided in providing a written record of the research:

> Although in the beginning we did not really see the need for documentation, we came to sense and understand that only if we gather all the planning, the results and the conclusions in one place, we can use them in the last stages of the work (Nadav, No. 1, 1.a).[2]

On the other hand, most of the students found it difficult to manage a journal. At the time of writing the research report, these students faced many problems, such as disorganization. One of the students reported that

> I can manage with most of the items in the portfolio except a certain item—the journal . . . I found it difficult to document my work. My journal consists of ideas, thoughts and decisions that were raised during discussions with the teacher who helped us greatly and with my partner Moti, and of results of experiments we did and drafts we wrote. I guess it is not good enough, but I did not have the internal capability to write down a detailed documentation of the work I did (Guy, No. 1, 1.a).

Renewed Thinking Occurs in the Course of the Research: Is There a Connecting Thread Between the Research Questions?. In the first cycle of Biomind curriculum, the students were required to identify the connecting thread between their three research questions. In those cases in which students performed the experiments according

[2] Nadav—Students' personal name, No. 1—Teacher's number, 1.a—document number—see research methodology/data collection approaches/content analysis.

to their original plans, students identified the connecting thread in the research report and did not refer to it during practice. For example: Teacher No. 1 was an examiner in the first two Biomind cycles. As she claims,

> Many times the connecting thread between the three research questions was the name of a certain organism. As the teachers and pupils commented, this merely fulfilled the technical requirement for a connecting thread in the research proposal and in the actual research. In addition, students obtained ideas for experiments from their peers' research, and they adjusted their own experiments, thereby "forcing" the connecting thread (No. 1, 2.b).

Understanding the Importance of Researching Additional Professional Literature Throughout the Process. The inquiry process in Biomind is a constructive one; a process in which the teacher does not supply information to the students. Here, the students construct the knowledge by themselves. Appropriate to a constructivist process, the students and teachers surveyed professional literature throughout the stages of the research. The students understood that literature could contribute significantly to planning the research. For example:

> It might be that in the experiment with the Rosemarine a control material should have been used . . . we did not find such a material in the literature and we were frustrated . . . if we had found material (in the literature), we would have based the research better (Adi, No. 2, 2.a).

In addition, the students recognized the contribution of literature to the solution of technical problems. Furthermore, they saw that literature enriches the discussion by enabling the students to connect their results to other research. For example: "The group needed additional material, which was helpful especially in writing an interesting discussion about the relation between homeopathy and the organisms' living mechanisms" (No. 1, 1.e).

Understanding the Importance of Dedicating Time Throughout the Course of the Research. The most prominent sentence, which appeared in all the students' reflection pages, addresses the importance of dedicating adequate time in performing the process of learning in Biomind.

Figure 1 shows that a learning cycle takes 2 years; it seems this is enough time for students to learn the principles of inquiry, and conduct open inquiry. But, it also seems that learning as a process, such as the Biomind approach, requires time. Many students procrastinated, did not plan their time efficiently, and probably thought that once the research was planned, it simply needed to be implemented. The students understood the difference between the theoretical design of a study and its actual performance, as follows: "I learned that doing the work might look easy on paper but very quickly I understood that it requires a lot of time and thinking" (Moshe, No. 1, 1.a). Students also identified those procedures that take more time, for example: "The time required for the research proposal, its performance, and writing it is very long" (Ayala, No. 1, 1.a). In addition, the importance of adhering to the timetable was understood: " . . . a problem in the timetable caused unnecessary delays which finally made the work much more difficult" (Orly, No. 4, 1.a).

Changes Occurring During the Research

This criterion includes changes made by the students during their inquiry work. The changes listed below emphasize that the Biomind inquiry learning enables open inquiry in which the amount of student self-direction is maximum, and the amount of direction from the teacher in planning and performing research is minimal.

Changes in the Course of the Research as a Consequence of Either Field Conditions or a Literature Search. Information from the literature which was found in the course of the research (and not just during the primary literature review) helps to overcome some research junctions, in which students wavered as to how to continue their research process. For example:

> A couple of students, Nadav and Liron, decided to examine the influence of air pollution on the intensity of plant photosynthesis, in the field and in the lab. In one lab experiment, students simulated air pollution in a plant's environment using cigarette smoke. Measuring the rate of oxygen emission, students observed that, in contrast to what they had expected, the cigarette smoke intensified the activity of plant photosynthesis. The students changed the simulation method thereafter and created air pollution with the help of SO_2. The idea for this change was developed from a scientific article found by the students (Achiron-Frumkin, 1994). In constructing this system, a plant chosen by the student, was crumbled due to the presence of the material. Therefore the students chose another species of plant (No.1,1.d).

An Answer to an Inquiry Question Can Change the Direction of Thinking. The Biomind students planned a constructed research plan that included three research questions. These questions had a connecting thread between them and also with the research subject. In addition, the students raised hypotheses, and checked how an answer to one question may help understand an answer to another one. Sometimes, a result completely changed the direction of students' thinking. For example, two students, Linur and Yael, obtained a result, which did not support their research hypothesis. As a result, they put a lot of thought into their discussion section, and also consulted with a biologist in order to explain their result. They understood that each result must have an explanation. In addition, the students understood that there is a place for hypothesis and for the creation of an infrastructure for a new theory. The students reported on this:

> Our hypothesis was that most of the Littorina of both kinds (striped and dotted) would gather in the closed and protected pool, and especially the young Littorina which are more exposed to danger. The results disproved this hypothesis. We found that striped Littorina, gather mainly on the side of the pier that faces the drier side of the beach. Surprisingly, dotted Littorina gathered on the side of the pier open to the sea. A marine ecologist explained to us that the Littorina are in an evolutionary developmental process. At the end of this process, we may assume that the beach will be the main habitat for both species of Littorina. That is how we understood that the more evolutionarily advanced, striped Littorina, which are found mainly on the side of the pier that faces the drier side of the beach. The less evolutionarily advanced, dotted Littorina, are still gathered on the side of the pier open to the sea (Yael and Linur, No. 1, 1.d).

After the students obtained results that contradicted the original hypothesis, the students understood that the evolutionary aspect of the Littorina plays an important part in the organism's ecosystem.

Additional Ideas Emerged and the Original Research Questions Were Modified. During research, students obtained some surprising results. The students were so intrigued that they raised new questions on their own initiative. An example is related to the extension of the research object: “In examining the influence of Rosemarine etheric oil on seed sprouting, the students raised the question whether the oil would also influence animals. For this reason, they examined its influence on snails’ breath” (No. 2, 1.e). Life processes related to animals depend on suitable seasonal timing. Therefore, the students often had to change their research question:

> A student group wanted to examine the metabolism of snails in their vernalization. Summer passed before the students were organized to begin their experiments. Therefore, the students started their work when the snails were already active. Consequently, the research focus was changed and the influence of different temperatures on the snails’ metabolism was examined (No. 2, 1.e).

Understanding the Need to Solve Technical Problems and to Suggest Practical and Creative Ideas. During the execution of the students’ experiments, unexpected technical problems arose. Most of these problems occurred because the students learned how to design and conduct experiments, instead of working from previously developed material. Teacher No. 4 describes the students’ difficulty in measuring the variants of the experiment:

> There was a problem in measuring breath pulse or the pulse of oxygen consumption of ants. Any experimental set they built up was not sensitive enough for measuring (No. 4, 2.a).

> In the beginning of our research we made an extract from a fixed number of leaves. This extract wasn’t exact and identical during all the times we made it, because the different number of leaves caused a different concentration. We therefore decided to prepare an extract from a fixed weight of hyssop leaves mixed with water (Liel, No. 4, 1.a).

Teacher No. 1 describes in her journal a difficulty and a solution devised by students in examining the heart beat of Daphnia sp.:

> Moshe and Yair wanted to examine the influence of water pollution by detergent on the heart beat of Daphnia sp. (a minute aquatic organism). It seems that the natural heartbeat of Daphnia sp. is fast and impossible to measure precisely. For this reason, the students added Acetylcholine to all the experiment’s tubes. This substance slows the heartbeat of Daphnia sp. (No. 1, 1.d).

Procedural Understanding

> Procedural understanding is the understanding of a set of ideas which is complementary to conceptual understanding, but related to the “knowing how” of science and concerned with the understanding needed to put science into practice. It is the thinking behind the doing (Gott & Duggan, 1995, p. 26).

This criterion refers to the concepts of evidence and research reliability, including categories that reflect the students’ understanding of the need for reliability in conducting scientific research. Following are categories and their corresponding examples:

Understanding the Importance of the Control of Variables. The importance of the control of constant variable became obvious when different students performed the same experiment, and when the repetitions of certain experiment were performed on different days:

> Ricka checked the beat of plasmolisa on the petals of red anemones compared to other colored anemones in different salt concentrations. The first few times, she did a microscopic

> preparat and immediately observed through the microscope, placing the leaf in the solution for one minute. Then, when her confidence in observing through the microscope increased, she placed in all the preparats (of different salt concentrations) at once. The preparats remained too long in the salt solution until she observed them under the microscope (more than one minute). The leaves then went through too much plasmolisa, much more than the one when the student observed all the preparat upon its preparation. The disruption in the results taught Ricka that an experiment should be repeated accurately under the same conditions (No. 1, 1.d).

Furthermore, students understood the importance of the method of measuring the dependent variable. The students wavered in choosing the method of measurement and determining the measured indicators. For example:

> The extraction for the first experiment we did by counting the number of leaves; however, we found that in order to make an accurate extraction we should weigh the leaves so that the concentration/amount of the extract would be accurate (Anat, No. 4, 1.b).

Learning How to Approach Each Question from Different Research Perspectives/ Working Methods. Students "tackled" research questions from different methods of work. For example:

> I also learned that writing a research report and conclusions should be based on results which are not measured merely in one way, but through different points of view and through repetitions, in order to have a wide and reliable base of conclusions (Irit, No. 1, 1.a).

Understanding the Importance of Control, Repetitions, and Statistics. The students understood the importance of control and its influence on reaching conclusions from the experiment, especially when they obtained unexpected results:

> A group of students assumed that the higher the percentage of detergent in the water the more the intensity of photosynthesis would decrease. However, the results of their experiment revealed that the detergent increased the intensity of photosynthesis. The students forgot to set up a system in which there was a detergent without a photosynthesis producing plant. Therefore, it was not possible to understand whether the presence of the detergent disrupted the method of measurement. So, the students should search for a different technique of measuring photosynthesis which is not influenced by a detergent (No. 1, 1.d).

The students understood the contribution of repetitions to the reliability of results. For example:

> "I learned the importance of repetitions mainly when we saw that the results do not always repeat accurately and that is why it is important to do repetitions" (Alon, No. 2, 2.a). "From writing the research report, I learned how to use statistic in order to process data" (Avi, No. 6, 2.c).

Affective Points of View

> Science is more than a body of knowledge and a way of accumulating and validating that knowledge. It is also a social activity that incorporates certain human values. Holding curiosity, creativity, imagination, and beauty in high esteem are certainly not confined to science, mathematics, and engineering . . . .In learning science, students should encounter such values as part of their experience, not as empty claims (AAAS, 1994, Ch. 13, p. 5).

This criterion consists of categories that describe the students' affective points of views throughout the course of the research, such as the following:

Curiosity, Frustrations, Surprises, and Disappointments Occur Especially Upon Obtaining Unexpected Results. Curiosity is one of the salient characteristics of students who practice inquiry learning. Just as a Biomind's student reported:

> "We were curious, especially when we obtained opposite results" (No. 2, 2.a).

Furthermore, in the following example, students express frustrations, but also the excitement that characterizes the world of research.

> "Yael and Linur disturbed me when I was in the middle of a different class. They burst in: 'Yes! We got what we wanted"' (No. 1, 1.d).

Wherever there is uncertainty in research, there will be some surprises, as well as some disappointments.

> There were many points of crisis, there was no strength any more . . . the second crisis was when we went to the shore and did one observation, and when we came the second time there was nothing. We didn't know what to do (Yael and Linur, No. 1, 2.a).

The Student and the Teacher Initiate Research Activities. In open inquiry learning, the student functions as a self-directed learner. By taking initiative, the student guides the research to produce results that prompt discussion.

> Initiative groups adhere to the timetable, initiate meetings with the teacher and the lab technician, suggest changes, brainstorm ideas (theoretical and technical), find helpful literature, try repeatedly until the system is built up, remember to observe the results of the experiment, use critical thinking in all stages, especially during the stage of writing the research proposal, analyze the data and make conclusions. Moreover they "dive into the water" although the intention is not clear enough, especially in asking the research questions and writing the discussion (No. 1, 2.b).

Persistence and Perseverance Help Ensure the Attainment of Experimental Results. Open inquiry is a process that requires the construction of an experimental system. Constructing such a system is not a simple, one-time action—it is a task that requires persistence until an appropriate system is achieved. For example:

> The group that examined the influence of the Aloe-vera plant on the development of germs did not obtain results, meaning there was no delay. For this reason, they repeated the experiment many times preparing extracts from new leaves of Aloe-vera (No. 2, 1.e).

Learning to Cope with Unexpected Results. Students learned to expect that the results may differ from the original hypothesis. For example:

> "We were very curious, especially when we got opposite results" (Beni, No. 2, 2.a).

> "Building up the different experiments . . . I learned that even when the results apparently do not fit the hypothesis; it is possible to make conclusions and even to build up a continuous experiment" (Michal, No. 5, 1.a).

Dynamic Nature of Scientific Inquiry in Class

This research aims to characterize the open inquiry learning process from different aspects. Students themselves claimed that the inquiry process that they have participated in may be characterized by dynamic features. As some of the students expressed this idea: "Only when experiencing inquiry work you actually find out the extent to which work of this type is dynamic and how difficult it is to stick to the original plan" (Ira, No. 3, 1.a); "After we finish an experiment, we summarize its results and then decide whether we want to continue... it is real research, because we thought about the questions and there are no right or wrong answers" (Itai, No. 6, 1.a). In reviewing the inquiry characteristics consolidated in this research, we realized that the term *dynamic inquiry* can be adopted as a general reference to an open inquiry process. The criteria of dynamic inquiry can generally be characterized as follows:

Learning as a Process. Every stage of the inquiry activity is based on the previous stage. One stage does not stand on its own, as inquiry is a flowing process. The procedural essence of inquiry learning enables changes to occur throughout the process.

Changes Occurring During the Research. The learning process is not linear, beginning with a question and ending with an answer. The process begins with initial planning. As the process progresses, changes occur in different stages of research, leading the researcher in new, previously unconsidered directions. A reflective and critical ability, and intellectual flexibility, may assist in making decisions that alter the course of research.

Procedural Understanding. Biology-based investigations depend on a procedural understanding of the concepts of evidence (Roberts, 2001). According to this criterion, the Biomind students exhibit an understanding of the importance of the concepts of evidence; when asked to improve research processes linked to concepts of evidence, they did. Their procedural research was more than technical work.

Affective Points of View. Table 2 presents the criteria of dynamic inquiry. The first three criteria emphasize the cognitive aspects of learning; the fourth emphasizes affective aspects, resulting from the dynamic and eventful character of the inquiry process itself. All of the affective aspects are characterized by an emotional state of mind needed in situations of changes and uncertainty.

Based on dynamic inquiry characterization, the action research team began developing tools for documenting the dynamic inquiry process and expressing its nature. A flow chart was the first tool by which students may take the opportunity to reflect the dynamic process of the research, as seen in Figure 2. The flow chart boxes indicate different inquiry stages, with a headline characterizing the stage and a short exemplary description. Arrows connect these stages and emphasize the direction of thinking and performing throughout the inquiry process. The flow chart shows direction and crossroads (divergence and convergence) of thinking and doing. However, most of the movements between stages could not be expressed in their entirety by the graphic presentation in the flow chart. This is where the "reasons for change" table (Table 3) plays a role. This table provides students the chance to articulate the thoughts, on which the practical steps of the flow chart are based, to elaborate the reasons for advancing from one stage to another, and to attribute these moves to aspects of dynamic inquiry. The following example (Figure 2 and Table 3) depicts one of the Biomind researches, entitled "The Influence of UV Radiation on Seed's Sprouting." The steps that were taken during this open inquiry reflect the criteria of dynamic inquiry as they were characterized by this action research. Stage E (Figure 2 and Table 3) provides a good example of an interesting

TABLE 2
The Criteria of Dynamic Inquiry

Criteria	Categories
Learning as a process	This stage requires the students to understand the importance of • documentation throughout the research process. • the connecting thread between research questions throughout the research process. • researching additional professional literature throughout the process. • dedicating time throughout the course of the research.
Changes occurring during the research	• Changes in the course of the research as a consequence of either field conditions or a literature search. • An answer for an inquiry question can change the direction of thinking. • Additional ideas emerged and the original research questions were modified. • Understanding the need to solve technical problems and to suggest practical and creative ideas.
Procedural understanding	This stage requires the students to understand the importance of • understanding the importance of the control of variables. • learning how to approach each question from different research perspectives/working methods. • control, repetitions, and statistics.
Affective points of view	• Curiosity, frustrations, surprises and disappointments occur especially upon obtaining an unexpected result. • The student and the teacher initiate research activities. • Persistence and perseverance help ensure the attainment of experimental results. • Learning to cope with unexpected results.

inquiry crossroad in which the students obtained a surprising result. By advancing in three different directions, the students were able to lead the research in a promising direction. The students were required to improve the experiment's credibility by adding control variables. In addition, students expanded the theoretical basis of the experiment, and increased the range of the independent variable according to the redefined biological basis. These steps demonstrate dynamic thought and action.

Recommendations and Changes of the Curriculum

The second objective of this research was to use the main aspects that characterize the open inquiry process in improving the curriculum. Table 4 summarizes several recommendations for action research cycles 1 and 2. The first recommendation related to the characterization of the learning process in Biomind, which revealed a dynamic inquiry process. A formal change accepted in the Biomind curriculum beginning at the second Biomind cycle was the addition of a reflection question that was assigned to describe the dynamic inquiry:

> Scientific research is considered a "dynamic process." The original plan often changes in the course of the research. Give an example of such a dynamic in your research: describe

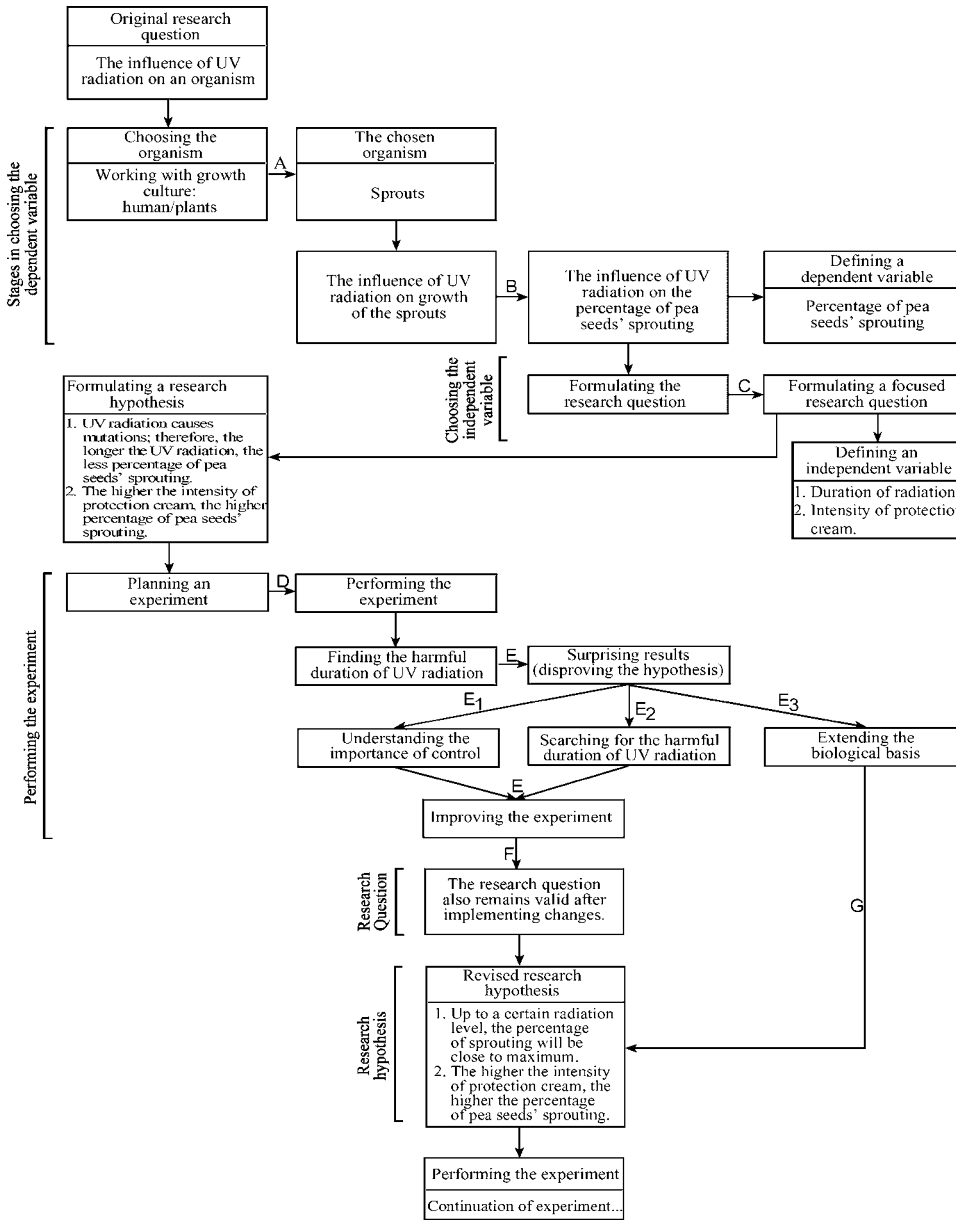

Figure 2. Flow chart (written by teacher No. 5 according to the teacher's journal) of a research conducted by Biomind students. The research quantifies the Influence of UV Radiation on Seeds' Sprouting. (The stages of inquiry are depicted in boxes, while the different steps are marked by the letters A–G, detailed in Table 2.)

the original plan, the reasons for changing it, and the change (Mendelovici & Nussinowitz, 2002).

Based on analysis of the students' reflection pages during the second Biomind cycle, students wrote deep and rich reflections (Appendix). This difference might be a consequence of changes in formulations of the instructions for reflection. One also sees that the students understood individual events in the learning process, but they were unaware of the entire

TABLE 3
A Table of Stages of Dynamic Inquiry That Emphasizes the Reasons for Changes[a]

The Move	The Criteria of Dynamic Inquiry	The Original Idea	The Reasons for the Change	The Change
A	Changes in the course of the research as a consequence of a literature search.	Choosing the organism: working with human or plant tissue culture.	Reading a paper: the technique of culturing tissues is problematic in school laboratory work.	Working with sprouts.
B	Additional ideas emerged and the original research questions were modified.	The influence of UV radiation on the growth of sprouts.	Technical difficulty: The location for performing the experiment was transferred from the school to the laboratories of Youth Doing Science at the University, because there wasn't a source of UV radiation at the school. Because use of the labs was limited, it was decided to radiate the sprouts once and then examine the percentage of their sprouting.	What is the influence of UV radiation on the percentage of pea seeds' sprouting?
C	Additional ideas emerged and the original research questions were modified.	Formulating the research questions: What is the influence of the 1. duration of radiation? 2. intensity of protection cream on pea seeds? 3. intensity of protection cream on the sprouting of UV radiated pea seeds.	Technical difficulty: examining the influence of time from spreading protection cream until washing the cream, on UV radiated pea sprouts, was cancelled because use of the labs was limited	1) What is the influence of the duration of radiation on the sprouting of pea seeds radiated with UV? 2) What is the influence of the intensity of protection cream on the sprouting of pea seeds radiated with UV?

D	Changes in the course of the research as a consequence of a literature search.	Planning an experiment: spreading protection cream on the seeds.	After submitting the experiment plan to the teacher, the teacher knew from reading articles on other subjects that this treatment will drastically harm the seeds.	Performing the experiment: The seeds were placed in closed Petri dishes, and the students spread protection cream on the dish covers.
E	Affective points of view 1. Learning to cope with unexpected results. 2. Surprises are created especially upon obtaining unexpected results.	Determining a period of time in which radiation harms the seeds. The seeds were exposed to 0, 30, 60, 90, and 120 min of UV radiation.	Surprising results (which disprove the hypothesis): the percentage of pea seeds sprouting was 95% to 100% during the period under examination. Doing thinking about the unexpected results: 1. Understanding the importance of control (E1). 2. Duration of UV radiation was shorter (E2). 3. Extending the biological basis (E3).	Improving the experiment: extending the duration of radiation while shaking both the control and experimental seeds.
E1	Understanding the importance of the control of variables.	The control seeds were not shaken and the treatment seeds were shaken (shaking was done when seeds were taken for radiation in the university lab).	Thinking about unexpected results: the conditions of the control group and the treatment group were not equal.	Shaking both the control and experimental seeds (shaking occurred when seeds were radiated in the university lab).
E2	Changes in the course of the research as a consequence of field conditions.	Determining a period of time in which radiation harms the seeds. The seeds were exposed to 0, 30, 60, 90, and 120 min of UV radiation.	Thinking about unexpected results: Perhaps the duration of UV radiation was too brief.	Extending the duration of UV radiation: from 30–120 min to 4 and 16 h.

Continued

TABLE 3
A Table of Stages of Dynamic Inquiry That Emphasizes the Reasons for Changes[a] (*Continued*)

The Move	The Criteria of Dynamic Inquiry	The Original Idea	The Reasons for the Change	The Change
E3	Researching additional professional literature throughout the process.	The existing biological basis: UV radiation causes mutations and decrease growing.	Thinking about unexpected results: An article stated that UV radiation causes hyperactivity of embryos' meristems.	Extending the biological basis: UV radiation encourages the development of embryos' meristems in sprouts up to a level in which mutations that slow the growth are accumulated.
F	Additional ideas emerged and the original research questions were modified.	Research question: the influence of the duration of radiation and intensity of protection cream on the sprouting of UV radiated pea seeds.	Extending the biological basis (see E3).	The research question also remains valid after implementing changes.
G	Changes in the course of the research as a consequence of either field conditions or a literature search.	1. The longer the duration of UV radiation, the greater the percentage decrease of pea seeds' sprouting. 2. The higher the intensity of protection cream, the higher the percentage of pea seeds' sprouting.	A new extended biological basis led to changing the hypothesis.	1. Up to a certain radiation level, the percentage of sprouting will be close to the maximum. 2. The higher the intensity of protection cream, the higher the percentage of pea sprouting.

[a]The table contains details of the dynamic research of the influence of UV radiation on seeds' sprouting. The table includes the move (moves A–G are also marked in Figure 2), the criteria for dynamic inquiry (Table 2), the original research idea, and the change performed (Figure 2). The reasons for the change are detailed here.

TABLE 4
Recommendations for Changes in the Biomind Curriculum[a]

An Element of Biomind Revealed in the Action Research	A Recommended Change	Implemented
	Action research cycle I	
The students conduct a dynamic research	Adding a reflection question.	√[b]
Dynamic inquiry learning requires time.	Giving a detailed timetable.	*[c]
Procedural understanding is an important element of an open inquiry.	A teacher colleague checks the research proposal.	√
	Action research cycle II	
Students understand individual events in the course of the research, without understanding the entire dynamic process.	1. Prepare a flow chart of the dynamic inquiry process as a basis of reflecting upon the inquiry process. 2. Prepare the table that details the basis for changes and the characteristics of dynamic inquiry.	*
Forced logical thread as a consequence of the requirement to formulate 3–5 questions at the beginning of the student's researches, does not fit a dynamic open inquiry model.	Formulating one question at the beginning of the work, while the remaining questions are posed during the course of the research. Student may plan two research questions at the beginning of their research, but must ensure that each answer contributes to an understanding of the other questions. Then, by doing the research and observing the results of the first and second part of the research, a third question is raised, and an open research plan is consolidated.	√

[a]The table includes a Biomind element which was revealed in the action research, a recommendation for change and a comment whether the recommendation was implemented.
[b]√: The recommendation was presented as an instruction to all the students of Biomind from cycle II, and onward.
[c]*: Left to the teacher's discretion.

learning process they experienced. A flow chart illustration such as the one presented in Figure 2 accompanying Table 3, can be used to illustrate the students' experience of their dynamic inquiry process.

In the first version of the Biomind curriculum, the research plan was built in advance upon three research questions, with a connecting thread between them. Through this action research, students' dynamic inquiry process could be constructed in two alternative ways. One way would require students to formulate one research question at the beginning, and the second question during the course of the research, based on the preceding results. Then, by performing research and observing the results of the first and second phases of the research, a third question would be formulated, and an open research plan consolidated. Another way would require students to plan two inter-related research questions at the beginning, ensuring that each answer contributes to an understanding of the other question.

DISCUSSION

The Significance of Dynamic Inquiry Learning

During the last 40 years, much has been said and written about the importance of learning through inquiry. This article tries to present new insights into this familiar learning process. As a consequence of the triple role of the writers of this article, as researchers, teachers, and curriculum developers of the new Biomind curriculum, hidden elements of learning inquiry process were characterized and integrated into the curriculum. Most science curricula focused only on learning a great deal about the problem and performing the experiments, observations, and calculations (Gallagher et al., 1995). Gallagher et al. (1995) presented a problem-based learning innovative curricular and instructional model which focused on the above elements, and also on a track in which formulation of the question and planning the experiment are conducted for more than a single trial or a specific direction. The present action research clarified the dynamic inquiry process elements which are related to the circular track mentioned above. The elements of dynamic inquiry were grouped into four main categories: *Learning as a process* emphasizes continuous thinking throughout the inquiry process, while trying to find a way to arrive at a reliable answer to a problem. *Changes that occur in the course of the research* are characterized by flexibility in thinking, judgment, and "contemplation" about and throughout the process. Learning as a process and changes that occur in the course of the research correspond to the NOS definition, "scientific knowledge is tentative" (Khishfe & Abd-El-Khalick, 2002, p. 556). *Procedural understanding* emphasizes elements that bring inquiry teaching closer to understanding the scientific approach as it was formulated by Davis (1935). That is to say, terms such as without prejudice, concept of cause, judgment on the basis of, distinguishing between fact and theory, are firmly entrenched in dynamic inquiry teaching. Procedural understanding meets another NOS definition that "scientific knowledge is empirical" (Khishfe & Abd-El-Khalick, 2002, p. 556). Affective points of view add the emotional dimension needed when conducting a dynamic process that involves many changes and intellectual crossroads. While the first three categories of dynamic inquiry emphasize cognitive learning points of view, the fourth category emphasizes the affective points of view which stem from the character of the inquiry process, as dynamic and consisting of many changes and events. By NOS definition, "Scientific knowledge is partly the product of human imagination and creativity" (Khishfe & Abd-El-Khalick, 2002, p. 556). Curiosity, for example, is expressed distinctively both while seeking an answer to a question, and upon obtaining unexpected results.

In the Biomind curriculum, the characterization of dynamic inquiry learning was performed through teaching biology and science, but the principles of dynamic inquiry may be emphasized in any field of knowledge and in any subject. The principles are not content dependent, but learning process dependent. Journet (1985) said that, "You can teach science in two ways: as a dynamic, exciting search for the understanding of patterns, regularities, and principles, or as a body of information, facts, knowledge, definitions of truth about the world (p. 236)." When we characterized the inquiry process, we showed that in Biomind students learned science as a dynamic process in which there simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge (AAAS, 1994, Ch. 1, p. 3).

According to Haury (1993), there is no authentic investigation or meaningful learning if there is no inquiring mind seeking an answer, solution, explanation, or decision. We assume that by experiencing dynamic inquiry learning, the student can emphasize a process in which, as in science, knowledge of nature is gathered and scientific thinking is developed by steps that combine into a coherent whole (Gable, 2001; Hardin & Bajema, 1978). More open inquiry will afford the best opportunities for cognitive development and scientific reasoning (NRC, 2000). We posit, therefore, that teaching through inquiry, in which a dynamic process is conducted, will develop critical thinking (minds on) and not merely the practical part of learning (hands on). We propose that future research investigate our assumption that the scientific knowledge, termed "knowledge in action," which may be acquired through dynamic inquiry, will function as appropriate functional knowledge (Kass & MacDonald, 1999). Learning to cope successfully with broadly specified complex and extended tasks within shifting and dynamic contexts, as a result of building experience, may prepare and encourage students to take on more complex tasks.

Documentation of the Dynamic Inquiry

During the inquiry process, Biomind students plan the research and make many changes during the course of the research. Because most students can assimilate complex data much more easily in graphic format, having students generate diagrams can improve their comprehension of targeted material (Gobert & Clement, 1999) and enhance students' participation in their own learning (Wilkes et al., 1999). The following methods for writing the protocol were suggested here:

- A graphic flow chart (Figure 2), emphasizing the process orientation.
- A table of stages of dynamic inquiry (Table 3), emphasizing the reasons for changes. Table 3, should include characterizations of dynamic inquiry (detailed in Table 2) which will correspond to the different stages of the process.

We think that the use of each one of the two methods cited above—both individually and especially in combination—could also serve as a solid basis for students' identification of the inquiry process learning, reflection on their learning process and development of metacognitive and scientific skills (Gallagher et al., 1995), acquisition of "ownership" of some of science requirements in order to solve the problem (Gallagher et al., 1995), and understanding the significance of inquiry, just as the V diagram does (Novak & Gowin, 1984).

A Learning Change

Much work remains in order to transform schools into places that nurture epistemologically authentic scientific inquiry (Chinn & Malhotra, 2002). Implementing dynamic open inquiry processes requires several stages. Teacher workshops should be conducted, demonstrating how students can implement the dynamic inquiry process and use documentation tools. There is also a need for a methodical study of students and teacher interaction during the dynamic inquiry process, and of the professional development of Biomind teachers. In our opinion, characterizing the concept of dynamic research for the first time and providing ways of documenting this research, may bring inquiry learning a step closer to the dynamic nature of scientific inquiry. A large scale quantitative research study based on both the characteristics of dynamic inquiry and the tools for documenting this inquiry may prove the following hypothesis: inquiry learning which emphasizes dynamic aspects, develops logical and critical thinking skills in general, and inquiry skills in particular, and develops NOS definitions. The likelihood that a new approach developed here is a refreshing and promising approach in learning through inquiry. There is also the likelihood that teachers and educators will implement this approach in school settings and progress beyond the limitations of previous inquiry learning.

Social and educational phenomena are complex, and their elucidation requires long-term immersion in the field as well as rich data—gathering through multiple means (Glesne & Peshkin, 1992, pp. 6–7), and a commitment of considerable time and resources. The decision to conduct a large-scale qualitative study proved fruitful. The results of this action research allow reorganization of the concept of inquiry around new emphasis. While this study focuses on the processes of *student* learning, revitalizes learning through inquiry, and serves as a significant contribution to the field of inquiry learning, it is important to stress that there were also benefits for the *teachers*. Through participation in the process of characterizing the concept of open inquiry in this action research, teachers created a "culture of inquiry."

APPENDIX

Students' Reflections About the Inquiry Process

The following paragraphs are from two reflections of excellent students in the first two cycles of Biomind. These reflections refer to the inquiry process. A student from the first cycle of the Biomind curriculum wrote:

> I have learned that scientific research is not like a normal assignment, where you know more or less what to write in advance, how to use bibliography material and summarize it. During the experiments and the research writing a few things changed for us, the research questions became more and more focused; we invented the experiments and made all kinds of decisions. Actually we learned to think, initiate things and not receive them as readymade (Irit, No. 1, 1.a).

A student from the second cycle wrote: "In my opinion dynamic inquiry is a process in which the research changes according to the changing conditions, to emerging needs and ideas." For example in one of the inquiry questions, we wanted to investigate the inhibition mechanism for germination. After reading the theoretical background we discovered that the mechanism is still unknown to professional investigators. Therefore we made the research question more relevant. We decided to isolate the different stages of germination and to investigate in which stage the inhibition occurs.

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