Biomind – A new biology curriculum that enables authentic inquiry learning

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In recent years, the science teaching community and curriculum developers have emphasised the importance of teaching inquiry and teaching science as inquiry. One way of developing learners' skills for planning and carrying out scientific research is by allowing them to perform independent research, guided by a teacher. It was recently discovered that there are considerable differences between experiments conducted by scientists and those conducted by students, with regard to the cognitive processes that the experimenters go through. Developing inquiry study activities that emphasise authentic inquiry was suggested in order to introduce students to cognitive activity that more closely resembles that of scientific professionals. This article describes the Biomind programme, intended for students of Grades 11 and 12 (ages 16 to 18 years) majoring in biology. The curriculum, developed by biology teachers, enables students to conduct independent research under teacher guidance. The curriculum emphasises the learning process, not just the outcome, and so students must reflect upon the work in progress. Moreover, the Biomind curriculum follows the principles of authentic inquiry. Biomind may improve students' scientific thinking abilities, expand the guidance aspect of teachers' work, and inspire curriculum developers to further emphasise inquiry.

Key words: Authentic inquiry, Curriculum, Full inquiry,

Introduction

If a single word had to be chosen to describe the goals of science educators during the 50-year period beginning in the 1950s, it would have to be 'inquiry' (DeBoer, 1991). 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 – an active learning process, in which students are supposed to develop critical and logical thinking skills (NRC, 1996; 2000). This active learning process suits the constructivist teaching approach and the idea that the knowledge is actively built up by the learner, who is responsible for his or her own learning (Driver et al., 1994; Osborne, 1996). During investigative work pupils have to make their own decisions either individually or in groups, while they are given some autonomy in how the investigation is carried out (Watson et al., 1999). Group learning is beneficial for inquiry learning, because it allows for the formation of a supportive climate for learning, organisation, responsibility and division of work (Tingle and Good, 1990) and also offers the option to test and correct ideas from among various reasonable opinions (Aho et al., 1993). Likewise, in inquiry learning according to the constructivist approach, the role of teachers is supposed to change from 'material transmitters' to 'guides' (Barnett and Hodson, 2001).

As part of this tendency, the biology curriculum for high schools in Israel emphasises the teaching of inquiry in its different perspectives: inquiry exercises are carried out in the laboratory; ecological research is performed in the field, and the analysis of a previously unfamiliar research paper contributes to theoretical learning. (Israeli Ministry of Education, 1991; Tamir et al., 1998). In one study, students specialising in biology, and learning inquiry through an explicit teaching method, acquired inquiry skills better than students who did not learn through an explicit inquiry method (Tamir et al., 1998). In spite of all the benefits of using inquiry in science lessons, inquiry has not gained prominence in most classrooms in recent years (Tamir, 1998). Ogens (1991) found that teaching through inquiry has a limited influence on high school students. In Israel it was found that students who carried out inquiry work in a conservatory acquired declarative and procedural knowledge of inquiry skills, but did not necessarily gain the conceptual or logical knowledge they might be expected to acquire during the problem-solving process (Dvir and Chen, 2000). In addition, it was observed that students had difficulty understanding the role of control and the proper planning of an experiment (Tamir et al., 1998). Teachers in Israel pointed out that it is impossible for students to carry out inquiry into a biology problem in laboratory classes, and hence
they do not come to understand the nature of science (Mendelovici, 1996). There have been attempts to involve external commercial entities in students’ science learning. For instance, The Society for the Protection of Nature in Israel was enlisted to guide students in their ecological research in the field. However, these attempts often produce a situation where the work becomes routine and repetitive, with the student not functioning as an autonomous learner and the teacher not functioning as a guide (Shperling, 1999). In addition, an artificial disconnection is created between, on the one hand, teaching inquiry skills in laboratory classes and, on the other hand, students’ coherent integration of these skills in ecological field work and in assimilation of research articles and material taught in classroom lessons. (Mendelovici, 1996). All of these difficulties in teaching inquiry, combined with the fact that in recent years science education professionals have recognised the importance of developing high-level cognitive processes parallel to practical skills (Roberts, 2001), have led to the establishment in Israel of the Biomind Programme (Mendelovici and Nussinovitch, 2002).

**Methods**

**The Biomind programme**

The Biomind programme is intended for high school students in Grades 11 and 12 (ages 16 to 18 years), specialising in biology and studying toward matriculation examinations in this field. The programme offers a different teaching approach for the practical part of the syllabus, which accounts for 20% of the matriculation examination: an alternative to laboratory work, and to the morphological description of plants and ecological work (Tamir, 1985). The Biomind programme offers an alternative conception and organisation of the biology inquiry process, in terms of teaching, learning and assessment. The word ‘Biomind’ is an integration of ‘biology’ and ‘mind’. The intent is to emphasise students’ ability to think like biologists.

**The rationale of the Biomind programme**

The Biomind programme is aimed at providing a framework for inquiry teaching, which emphasises the active search for knowledge. Biomind is suited to the rationale of the biology syllabus, which recognises the importance of learning both in the field and in the laboratory (Israeli Ministry of Education, 1991). In this programme, the students experience autonomous ‘full inquiry’ (Martin-Hansen, 2002), both in the field and in the laboratory. The research is related to a biological phenomenon that can be observed in the field and is associated with a whole organism. The emphasis of the programme is on the process of learning rather than the product, and thus it offers an informative approach to assessment, which is performed throughout the learning process. In Biomind, the student is supposed to function as an autonomous learner, and the teacher as a guide, who directs and focuses the learning.

**Goals of the programme**

The programme has two main goals:

1. **Developing students’ understanding of the inquiry process** through development of cognitive, meta-cognitive, psychomotoric and social skills:

   **Cognitive skills**

   Students experience full inquiry while receiving guidance and feedback: they carry out research through experiments and/or observations in order to answer several research questions. Students acquire and apply different inquiry skills, such as asking a question, raising a hypothesis, planning an experiment for examination of the hypothesis, and reaching grounded conclusions. Students acquire and apply skills of documentation, reporting and writing a research report.

   **Meta-cognitive skills**

   Students engage in reflective thinking throughout the learning stages, and they document this thinking. Students present their progress and achievements in a portfolio.

   **Psychomotor skills**

   Students acquire and apply laboratory skills such as: using a microscope, using different instruments such as a spectrophotometer, incubator, bath, scales, etc. Students acquire and apply computer skills.

   **Social skills**

   Students experience teamwork and come to recognise its benefits and difficulties.

2. **Increasing the student’s involvement and interest in learning biology:**

   Responsibility for learning is transferred to the student. Students can express their personal preferences and tendencies in their choice of research subject and methods, in distribution of the work between the team members and in the use of various documentation methods.

**Planning and developing the programme – from concept to practice**

The programme was initiated by an ex-teacher who has 30 years of experience in teaching and who has served as the assistant for the Supervisor of Biology. 30 high school teachers joined her to build the programme during its first two cycles (1999 – 2000), during which they received support from the Supervision of Biology unit. The teachers of the first cycle formulated the requirements the programme would place on students, and wrote draft instructions to students, which were changed and improved by the teachers of the second cycle. Planning began three months before programme commencement, and continued during the programme. Inquiry activities were carried out in classes according to the instructions given to students, and were also brought to the teachers’ forum for assessment, correction and rethinking. In general, it could be said that at every turning point (such as checking primary portfolios or a mock examination) the teachers’ activity was characterised by rethinking of the whole programme and its different components.

**Description of the plan**

The Biomind programme uses teaching strategies for developing students’ inquiry skills, such as reading articles, experiencing ‘dry’ and ‘wet’ laboratories, experiencing field research activities and carrying out full research.

The following is a specification of the curriculum’s main components:

**Laboratory**

The activities in laboratory classes are aimed at imparting
inquiry skills, technical skills and methods of reporting. Experience in the laboratory provides practice in the formulation of questions and hypotheses, practice in different measuring procedures, performing tasks according to written instructions, dealing with quantitative data with the help of a computer, and experiencing autonomous work. All these have great importance in preparing for autonomous research, which is carried out in the later stages of learning. The teachers choose the laboratory activities according to the biological content of the laboratory, the work techniques and the inquiry skills that are being learned.

Study excursions
The study excursions enable the student to get to know the nature of the country, its landscape, its plants and wildlife (Israeli Ministry of Education, 1991). The excursions enable the students to observe biological phenomena and to become familiar with different growth environments and research methods in the field, such as observations and measuring the coverage of plants. The excursions have an important role in raising the ideas and questions that will be the basis of the students' research.

Writing scientific reports
The Biomind programme places an emphasis on writing lab reports, excursion reports and research proposals as part of preparation for writing the summary of the research. Practising scientific writing in Biomind is done as follows:
1. The students get clear instructions for writing the reports and tools for assessing them, before they start writing. The students know exactly what is demanded of them from the instructions and assessment tools, which direct them in their report writing.
2. The teacher assesses the reports, writing notes to the students and directing them to the parts that need improvement. It is important to mention that the students can raise their grade by correcting the different reports. Going deeply into points of weakness contributes to meaningful learning. This way the students learn that the one who takes responsibility and makes an effort is rewarded.

The students' autonomous research
The climax of the Biomind programme is the planning and execution of an autonomous research study by the students, a research activity done with the teacher's guidance. The research has to relate to the whole organism and to a biological phenomenon that can be observed in the field. The questions, hypotheses, observation sets and experiments are built in such a way that they allow a possible answer to the research questions within the available time limit (12 months) and equipment, without causing any irreversible damage to nature. The primary research plan is built around at least two research questions, one of which is examined in an experiment, and another through observation. Then, by doing and observing the results of the first part of the research, a third question is raised and a full research plan is consolidated. In the research, the students are required to use professional literature, to adhere to a research plan and reach results and conclusions and to document all the stages of the research in the logbook. Most of the time the students are requested to carry out preliminary experiments in order to become familiar with the measurement methods and to determine the experiment's conditions. They are required to summarise their work in a well-written product resembling a scientific article. This task demands good writing skills, the ability to present an overview of the research process and critical thinking.

The portfolio as an informative assessment tool
The Biomind programme emphasises not only the product but also the process of learning that the student goes through. This is why students are required to do reflective thinking and to correct and improve their work. Students' work is assessed according to clear criteria, which are known to them and which clarify for them what is required in every task. These clear criteria guide students' writing and strengthen their sense of dignity in assessing the work they have created. One suitable tool for this kind of informative assessment is the portfolio, in which students present their efforts, their progress and their achievements.

The portfolio in Biomind is the tangible product of learning, while the learning skills and their use in the scientific research form the organisng basis of the portfolio. As can be seen in Table 1, the portfolio includes several sections: laboratory, excursion and research. Towards the end of their studies, students choose the items for the portfolio out of all the learning material they have collected during two years, while adding reflective pages to the different sections and to the whole portfolio. The reflection (reflective answers to set questions) on the different stages of work is written by each student individually and forms the evidence of the process that student has gone through. Reflecting on appropriate questions requires critical thinking about both the process and the product, and raises the students' awareness about the learning process they have undergone.

<table>
<thead>
<tr>
<th>Table 1 The content of the Biomind portfolio.</th>
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<tbody>
<tr>
<td><strong>Portfolio section</strong></td>
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<tr>
<td>Laboratory section</td>
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<td>Excursion section</td>
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<td>Research section</td>
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Student assessment
Student assessment is done throughout the two-year learning process. It takes into account the research carried out by students, their achievements performing tasks in the laboratory and in the field, their ability to work according to a timetable and each individual's contribution to a team. Students who take responsibility for their learning can improve their grades. The teacher determines the main part of the final grade (70%), and an external examiner determines the rest based on an oral examination, which is actually a conversation between the examiner and the student. During the examination, the student presents his or her portfolio and defends the work. The examiner comes to understand the student's unique contribution to the team's work, the learning process the student went through and his or her understanding of the theoretical background and the biological basis of the research.

Considerations in writing the instructions and learning material
The learning material and assessment tools were developed for the five (main) subjects of Biomind, presented in Table 1: excursion, laboratory, research, reflection and skills. Learning materials include instruction pages for carrying out and summarising laboratories and excursions, instruction pages for writing a research plan and instruction pages for writing a summary article. In addition, assessment tools and reflective questions were developed for the different stages of the learning process. Detailed instructions were written for the teacher's assessment of the student. A number of questions and issues were considered by the teachers while they were writing the learning materials. Below are some of the considerations relating to the content of questions, to the teamwork and to giving instructions for writing the research plan, the research summary and the reflections.

The content of tasks
There were two main considerations in writing the questions to be answered by students. One was specific biological knowledge and its importance as a part of the required 'biology education'. For example, the questions on characterising a habitat and assigning organisms to a habitat, with which the students become familiar during the excursion, aim to deepen their understanding of ecological concepts through a concrete familiarity with the nature of the country's flora and fauna. In this category the requirement to explain the biological basis of a certain research hypothesis was included.

An additional central consideration in the formulation of the tasks was the need for students to experience and exercise the inquiry skills they would require during their autonomous research. One requirement was that prior to each laboratory session, a theoretical background should be written as preparation for writing the introduction to the inquiry activity. In addition, students would be required to write a discussion in the summary of all laboratories, to formulate research questions, and to build a theoretical research design, based on these questions.

Teamwork
The different reports include sections that some students can answer together and others that each student has to answer individually. Here, the advantages and disadvantages of teamwork were taken into consideration. For example, it was decided that several students would be allowed to submit the summary of findings that they collected on the excursion, since data collection is done by groups. But in order to develop the students' scientific thinking each student is required to submit individually a new ecological research question. According to this same pedagogical idea, students are allowed to write a cooperative summary of the research, but the discussion of the results and the conclusions is written individually.

Research summary
While the instructions for a written research summary are based on accepted 'norms' of scientific research construction, a certain flexibility is permitted. The students are instructed to organise the research in one of two ways: They may organise their writing according to research questions, with materials and methods, results and discussion for each question and a general discussion at the end. The alternative is organisation of results according to the usual sections of a scientific article.

Reflection
The reflection questions that the students are required to answer relate to the activities they carry out during the different learning stages, to criticism of their own work and to analysis of the final product. For example, 'What were the difficulties you were confronted with when planning the research? How did you overcome the difficulties and/or reach solutions? ...describe concisely what the experience of Biomind has contributed to you. You may relate to the understanding of biology research, to planning the research, to writing a research paper...'.

The questions were written in order to enable the teacher to better understand students' ways of coping with difficulties during the research, and to increase students' self-assessment and critical thinking.

Implementation of the curriculum
Teacher training
During the first two cycles of Biomind, a nationwide, ongoing learning programme for teachers was held. The teachers were offered workshops on inquiry learning, ways of activating students in the laboratory and in the field, and portfolio construction. One emphasis was on the analysis of student output that the teachers brought in from their classes. Since the beginning of the third cycle, these teachers have been guiding the Biomind continued learning programmes on a regional level. In these regional workshops, teachers are first exposed to the spirit of Biomind by examining the programme and experiencing some of its components. Later on, the teachers inspire each other and form support groups and networked discussion groups.

The intended population and numbers of programme participants
The Biomind programme is aimed at students specialising in biology, in their last two years of high school. Table 2 presents data on the number of students, teachers and schools...
participating in the Biomind programme since its inception. The table shows an increase in number of participants, which is expressed in the percentage of students examined via this programme out of the whole number of students examined at an extended biology level during these years. In the first and second years up to 350 students participated in this programme, making up 4% of all students taking the extended biology level. In the third year there were 532 students, representing 5.8% of all students taking the extended biology level. During its three years of operation the number of students involved in the programme has significantly increased. The predicted number of students in 2003 is 700.

Assessment of the programme by the students
Students were asked to scale their response to phrases related to the Biomind programme, on a Likert scale. The questionnaires were given to the students at the end of their high school studies (60 pupils from the first Biomind term and 55 from the second Biomind term). Table 3 summarises the assessment of the different components of the programme as indicated from student questionnaires. It was found that the students felt responsible for carrying out their research, and that they were satisfied with the level of the teachers' involvement with the research, and with the way they were assessed by the teacher and by the external examiner. Similarly, the students felt that experiencing the Biomind programme contributed to their acquisition of inquiry skills such as the ability to plan an experiment and to draw conclusions from it. The results show that students had difficulties in planning their time and keeping up with the timetable. Especially prominent is the fact that the students gave a relatively low rating to the extent of their personal initiative and expression in the programme, and also to the contribution of the teamwork to the research.

Table 3 Assessment of the Biomind programme by the students. (The table includes the examined category, the question, the average rating on the scale of 1 (not at all) to 5 (very much) and the standard deviation N=15)

<table>
<thead>
<tr>
<th>Category</th>
<th>Question</th>
<th>Average</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>An autonomous learner</td>
<td>Rate the extent of responsibility you felt in relation to carrying out the personal research</td>
<td>4.4</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Rate the place of your personal initiative and your expression in the research</td>
<td>3.9</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Rate the contribution of the research to your ability to plan a long-term task and to get organised with a timetable, which you make for yourself</td>
<td>3.7</td>
<td>1.00</td>
</tr>
<tr>
<td>Teacher</td>
<td>Rate your satisfaction with the level of the teacher's involvement.</td>
<td>4.5</td>
<td>0.97</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Rate the contribution of the team's work to your satisfaction from the research.</td>
<td>3.9</td>
<td>1.25</td>
</tr>
<tr>
<td>Assessment</td>
<td>Rate your satisfaction with the means of assessment (grading) in the Biomind project.</td>
<td>4.3</td>
<td>0.86</td>
</tr>
<tr>
<td>Inquiry</td>
<td>Rate the contribution of the personal research to your ability to plan an inquiry experiment while defining the dependent and independent variables.</td>
<td>4.2</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Rate the contribution of the personal research to your ability to pay attention during planning the experiment, to the repetitions, to the controls and to keeping constant factors</td>
<td>4.2</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>Rate the contribution of your personal research to your ability to formulate the research question and to raise an hypothesis as an answer to this question.</td>
<td>4.1</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>Rate the contribution of your personal research to your ability to discuss the results of the experiment and to draw conclusions.</td>
<td>4.1</td>
<td>0.85</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>Rate your general satisfaction with the Biomind project.</td>
<td>4.0</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The Biomind programme has the characteristics of authentic inquiry
Chin and Malhotra (2002) define the characteristics of the authentic inquiry process, and claim that carrying out inquiry tasks according to the curriculum does not enable students to experience cognitive processes that characterise authentic science. The characteristics of authentic science, according to Chin and Malhotra (2002) are shown in Table 4. Evidence from the Biomind programme was compared with these. Written reflections on the different sections of the Biomind programme, together with the content analysis of teacher questionnaires and content analysis of student reflections led to identification and characterisation of the components of authentic inquiry which exist in Biomind. There are evidence and examples from the Biomind programme that students do experience the cognitive processes of authentic science (see Table 4).
### Table 4: The Biomind inquiry programme in comparison to authentic inquiry.

<table>
<thead>
<tr>
<th>Cognitive process</th>
<th>Characteristics of authentic scientific reasoning</th>
<th>Examples of cognitive processes – examples from the instructions of Biomind programme (Instruction) (Mendelović and Nussinovitch, 2002) or from students’ inquiries done within the Biomind programme (Biomind activity)</th>
</tr>
</thead>
</table>
| 1. Generating own research question | Scientists generate their own research question   | **Biomind activity:** Students choose to follow the rate of photosynthesis by measuring O$_2$ emission and/or absorption of CO$_2$.  
**Biomind activity:** In order to examine the influence of air pollution on plants’ growth, a volatile chemical material, which simulates air pollution in the plant’s environment, was located. Then the photosynthesis process was examined as an indicator of a process that supplies energy to the plant’s growth. In parallel, the growth of branches in polluted areas was measured in comparison to a clean area.  
**Biomind activity:** In enzymatic experiments the students understood that a few controls should be used with no enzyme, with no substrate and with no indicator. |
| 2. Designing studies               |                                                  | **Biomind activity:** The Biomind students used measuring instruments of different kinds such as analytical scales, different sensors, spectrophotometer and so forth. |
| Selecting own variables            | Scientists select variables (there are many possible variables) | **Transforming observations**  
**Observations are often repeatedly transformed into other data formats.**  

**Finding flaws**  
Scientists question whether the results are correct (or artifacts of experiment)  

**Indirect inferences**  
Observations are related to research questions by complex chains of inference (they are not the variables of interest).  

**Generalisation**  
Scientists must judge whether to generalise to dissimilar situations.  

**Type of reasoning**  
Scientists employ multiple forms of argument.  

**Biomind activity:** The results of the Biomind experiments were presented by graphs, illustrations, tables, and pie charts. For example: measuring of respiration rate was presented in a line graph, the differences in heights of different plants were presented in bar charts and the distribution of a population to groups was presented in pie charts.  

**Instruction:** ‘… write critically about part of your findings’ You need to relate to the extent of reliability of the conclusion’ (Mendelović and Nussinovitch, 2002, p. 31).  

**Biomind activity:** in inquiries that examine the influence of sewage on organisms that are declared as protected in nature, the examinations are done by simulating sewage on cultured organisms of the same species.  

**Instruction:** ‘Examine all of your conclusions in terms of their suitability to the theoretical background as presented in the introduction’ (Mendelović and Nussinovitch, 2002, p. 31).  

**Biomind activity:** In discussion of results in the research summary of Biomind students several possible explanations were often given for a phenomenon. For example: the students related the different amounts of fermentation in soil to which oxygenated water was added, to the differences in the amount of microorganisms in the soil or alternatively, to the influence of chemical materials in the soil. |
| Planning procedures                | Scientists invent complex procedures to address questions of interest. |
| Controlling variables              | Scientists often employ multiple controls. |
| Planning measures                  | Scientists incorporate multiple measures of independent, intermediate and dependent variables. |
| Making observations                | Scientists employ elaborate techniques to guard against observer bias. |
| 3. Explaining results              |                                                  | **Level of theory**  
Scientists construct theories postulating mechanisms with unobservable variables.  

**Coordinating results from multiple studies**  
Scientists coordinate results from multiple studies.  

**Biomind activity:** Students observed improvement in the germination of seeds after rinsing them with a great amount of water. Their conclusion was that the water washed away substances in the seed inhibiting germination. This conclusion was made without isolation of these inhibitors from the seeds.  

**Instruction:** ‘The research questions might be developed gradually so that they lead to each other (‘developing inquiry’ or they may all be formulated at the beginning of the research. The questions should be related to each other and relate to any aspect of the researched phenomenon’ (Mendelović and Nussinovitch, 2002, p. 21).  

**Instruction:** The answers to the three Biomind research questions complete each other until the extended picture for the research subject is reached. The instructions for the summary of the research tell the student: ‘Present a full picture of your findings while relating to the subject you researched’ (Mendelović and Nussinovitch, 2002, p. 31). |
| 4. Developing theories             |                                                  | **Studying research reports**  
Scientists study other scientists’ research reports for several purposes.  

**Instruction:** ‘For understanding the theoretical background you should use articles, textbooks, encyclopedias, Internet sites as sources’ (Mendelović and Nussinovitch, 2002, p. 29). |

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Discussion

For some time, the community of science educators has understood that teaching facts, concepts and scientific theories is not enough, and that students need to be helped to develop scientific thinking, especially by experiencing inquiry activities. Roberts (2001) claims that procedural understanding is required for building up scientific knowledge in concert with substantive understanding. But, as Roberts claims, it is not enough to agree upon the importance of procedural understanding of inquiry. Explicit teaching of the means of inquiry is required (Roberts, 2001; Tamir, 1998). In Israel it was found that explicit teaching of inquiry skills to biology students, in addition to teaching the inquiry subject in inter-curricular teaching, improved students’ understanding and their ability to apply the concepts and principles of scientific research (Tamir et al., 1998). This explicit teaching of inquiry skills is a central component of the Biomind programme. There is explicit teaching of inquiry procedures at the beginning of the programme, both at the level of introducing the methods of work and ways of carrying out an inquiry, and at the level of the concept of evidence as its basis. Later, students apply the skills they have acquired in new situations: they are required to identify a biological phenomenon, to learn about it and to apply the inquiry skills they have acquired to investigate the phenomenon.

Understanding the concept of evidence requires an appreciation of the task as a whole, and thus a higher level of understanding than that required to master a skill. Investigations allow pupils to see the impact of the concept of evidence on the resulting data (Gott and Duggan, 1996). Looking at the portfolios, the results of the questionnaires and the analysis of the written reflections, it seems that learning through the Biomind programme did indeed improve students’ understanding of the concept of evidence. This is mainly because the students experienced a complete process of inquiry. The inquiry process included the four components of the circle of inquiry model: wondering, collecting data, studying data and making connections (Friedrichsen, 2001). Here too, as Friedrichsen (2001) shows, the students’ curiosity was fostered. However, quantitative research is required in order to establish the extent to which the scientific inquiry skills of the Biomind students were improved.

The programme’s uniqueness lies in the possibilities given to students throughout the process to test and make corrections. This may be one of the main reasons for the fact that students in the Biomind programme experience to a great extent all of the components of authentic inquiry. Two characteristics that were found at low levels in curricula examined by Chin and Malhotra (2002) exist prominently in the Biomind programme: students’ generation of their own research questions, and consideration of methodological flaws. Biomind students are required to formulate the research questions they intend to investigate and to get the teacher’s approval before they are permitted to begin the research. In this way all students in Biomind experience the writing of research questions, which can be examined scientifically. In addition, since the students are responsible for the research, all Biomind students have to face possible faults in the methodological designs they have planned, during the experiment, during the analysis of the research results, or during writing the discussion, and also in answering the reflective questions.

The students in the Biomind programme are required to think reflectively, which stimulates their awareness of their own thinking during the learning process. Nickerson et al. (1985) claim that integrating meta-cognitive elements in teaching increases the chances of transfer. Extensive research of Biomind students is required in order to see if such transfer does occur. In addition, in the Biomind programme students learn to relate the findings of their research to a theoretical background. This opens the way for students to create new and unique meanings for biological concepts and ideas. By using a ‘deep approach’, in which students explore ideas and contrast their own meanings of concepts with those found in the literature, students focus on the underlying meaning of material, see relationships between ideas and construct their own meanings for concepts (Ma, 1994). Thus, there is a possibility that through Biomind an understanding of this ‘deep approach’ to learning can occur. This research also illuminated affective and social aspects of the learning process, from the students’ perspective. It will be important to investigate these aspects further and to see their impact on students’ personal initiative.

In accordance with the contemporary approach that sees teachers as the main factor in development of curricula (Barnett and Hodson, 2001), the Biomind programme was developed by biology teachers. Developing curricula by teachers may contribute to their professional development. The Biomind programme demands that teachers and students work in conditions of uncertainty, and changes the relationship between teacher and student. In this sense, it will be interesting to follow up the professional development of Biomind teachers, especially with regard to guiding students through the learning process, and also in regard to extending their own knowledge in biology.

The Biomind programme is not an easy one to implement, as seen from the primary findings, and there is a need to examine whether it suits all biology teachers and students. It seems that the Biomind programme could improve the scientific thinking ability of the students who participate in it. It could broaden the concept of guidance for teachers who teach according to the Biomind programme, and provide a variety of learning materials for all biology teachers. The Biomind programme can provide inspiration for those who construct curricula emphasising inquiry.

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References


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**Appendix**

**Assessment of the programme by the students**

Written reflections on the different sections of the Biomind programme. The reflections were collected from those students who answered the questionnaire, as well as from portfolios. The reflections of 150 students were examined. The analysis of the students’ reflection pages shows that the students see the Biomind programme as a unique programme.

The uniqueness of the programme is expressed in the students' remarks:

"Usually, when we study biology at school, or any other field – most of the thinking about the task or the experiment is done by the teachers who first thought about them. The research work in Biomind is different. This is an opportunity to collect theoretical material from the professional literature and knowledge that has been acquired through the years in biology, to use the laboratory skills we acquired and to do something with them… to decide upon a certain direction and to carry out an experiment that we ourselves design. When we finished an experiment – to summarise its results and consequently to decide where we want to go next. This is a real experiment because we thought of the questions and there are no right or wrong answers."

This is one of the few opportunities given to the student to develop an idea by himself and to go on with it until results are obtained. This brings a lot of satisfaction to the student who begins his biological research and eventually finishes with answers to questions that he raised himself. I was pleased to create an original question that was not thought of before and to see how an idea becomes reality."

The uniqueness of the programme is expressed not only in the cognitive aspect but also in the affective aspect: ‘... I can’t even begin to describe the minute I saw our results of the first fructification. My partner and I were jumping and screaming out of excitement. It was one of the most satisfying moments of my life. When we saw our tiny squash, the fruit of our work, blowing to great size, we were as proud as mothers are with their kids."

The means of assessing the student and the focus on the learning process are also special qualities of the programme:

An opportunity for informative assessment was created in Biomind: an informative, correcting and directing assess-
ment, through which the test defended the thesis was not just a test of knowledge in biology. When the students compared a regular test to the assessment in Biomind, they emphasised the advantages of the alternative assessment.

In a test we get anxious, we don’t know where we are going and the grade is determined by a single experience that could be influenced by many factors (such as tiredness, anxiety), versus the Biomind that emphasises the process. In a test usually there is no possibility to correct and it does not build or serve the goal of learning from mistakes and of progressing. In Biomind the opposite is true, and indeed this way the learning was deeper and the difficulties were challenging.

Also they understood the contribution of the portfolio to the research work:

'... it is a tool which reflects in a most realistic way the achievements and progress of the student in biology, which gives the student a stage to present his or her work...'

The students recognised the similarity between their work and the scientist’s work:

'I experienced scientific thinking and all the processes that a researcher goes through during his research – such as repeating the experiment, changing the experiment, examining additional theoretical material.'

'Teamwork in which several people integrate their knowledge and their skills is important for the development of a certain kind of inquiry, as is done in the scientific world.'

The students internalised the inquiry skills that are required for planning and carrying out an inquiry:

'We decided to share the work between us. We determined that each will prepare garlic extract and check the germs’ growth. We previously determined the concentration and the final volume of the extract, which tools and germs we would use. It was only when we gathered the results that we understood that there were many additional differences between the groups. Keren pounded the garlic with the garlic pounder, me and Moran pounded the garlic with a grater. Finally we understood that constant conditions might not have been kept during the experiment.'

The teacher added to what the student said: 'It is impossible to assess from the final work how many stages they went through until they reached the final experiment. This process was the most difficult and maybe they learned the most from it.'

The students recognised that there are many advantages to teamwork during the inquiry process:

'There are many ideas and many perspectives in teamwork. There is a great feeling of commitment and it drives one to do things. It is especially nice to work with someone else – nicer and a more meaningful experience.'

In addition, the students were also satisfied, although to a lesser extent, with the possibility of personal expression in a team. Students testified that teamwork had a price:

'Each was pulling in his own direction'

'Not everyone can express himself in a group. Had I worked alone I would have achieved more.'

Students felt that teamwork hurt their full autonomy, meaning that sometimes they had to keep in line and concede, accepting other people’s ideas and opinions. In spite of that, most of the students saw an advantage in teamwork:

'I think that a person who works alone does not reach the same achievements and progress that he would if he worked with someone else. It is very important to learn how to manage and work with someone else, with different ideas, which sometimes are different than yours, and finally to reach a product which is the fruit of thinking together.'

Students experienced and understood the challenges and the benefits of writing the research paper:

The students gained experience in scientific writing and logbook writing. On the one hand they understood the significance and the contribution of scientific writing:

'I learned that there are rules and wording for writing up research and that you need to follow them strictly. Also writing scientific research according to rules helps different researchers to accumulate information that can contribute to all of humanity.'

As for the contribution of the directions for writing:

'The directions we received for writing the reports contributed greatly to writing them because otherwise, we would have written them as a story or a composition. It might be that without the directions we would have missed the central ideas or would not have known to connect them with the research.'

On the other hand, the students were aware of the difficulties of scientific writing:

'The researcher knows and understands what the whole research is about and what conclusions can be drawn from it, but it is not simple to write down this understanding in such a way that others can understand the significance of the research.'

'Writing the research paper was, in my opinion, the most difficult part. The researcher understands and knows the principles of his research, and what conclusions are drawn from it. But it is not so simple to put this comprehension into writing, so that those who are interested will understand the true nature of the research.'