The Development of Dynamic Inquiry Performances within an Open Inquiry Setting: A Comparison to Guided Inquiry Setting

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Abstract: Dynamic inquiry learning emphasizes aspects of change, intellectual flexibility, and critical thinking. Dynamic inquiry learning is characterized by the following criteria: learning as a process, changes during the inquiry, procedural understanding, and affective points of view. This study compared the influence of open versus guided inquiry learning approaches on dynamic inquiry performances among high-school biology students. We hypothesized that open inquiry students who engage in the inquiry process from its initial stage, participating in the decision making process of asking inquiry questions and planning *all aspects* of the inquiry, will outperform students who experienced guided inquiry, in terms of developing dynamic inquiry performances. Students were divided into two groups: guided and open inquiry learning approaches. Both groups were followed throughout their 2-year inquiry learning process. The data sources included interviews, students' inquiry summary papers, logbooks, and reflections. A quantitative content analysis of the two groups, using a dynamic inquiry performances index, revealed that open inquiry students used significantly higher levels of performances in the criteria ''changes during inquiry'' and ''procedural understanding.'' However, the study's results indicated no significant differences in the criteria ''learning as a process'' and ''affective points of view.'' The implementation of dynamic inquiry performances during inquiry learning may shed light on the procedural and epistemological scientific understanding of students conducting inquiries. © 2009 Wiley Periodicals, Inc. J Res Sci Teach 46: 1137–1160, 2009

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Introduction

The Challenge of Guided and Open Inquiry Learning

Engaging K-12 students in inquiry-based learning is the cornerstone of ongoing science education reforms (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2000). Schwab (1962) led the way for these reforms by describing inquiry as a way of teaching classroom science. Inquiry-based teaching helps students learn science content, master how to do science, and understand the Nature Of Science (NOS) (e.g., Dori, 2006; Krajcik, Czerniak, & Berger, 1998; Olson & Loucks-Horsley, 2000).

Over the years, a scale of openness to inquiry has been devised by Schwab (1962). The scale consisted of three levels of inquiry learning based on the degree of student involvement in the inquiry process, the degree of teacher intervention in instructing the student, and the student's scientific background regarding the inquiry subject and any relevant working methods. The lowest level is defined by strict instructions given to the student. At the intermediate level, the students are given an inquiry question but must decide on their own what methods to apply in searching for a solution. At the highest level, all stages of inquiry remain ''open''—the student must ask an inquiry question, choose methods, and find a solution. Herron (1971) added

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another level, based on these three levels: the student receives the inquiry question and its solution, so that learning is expository, with all contents in their final form. This is, in effect, a confirmation stage. This division of inquiry levels served as a basis for defining the types of inquiry recognized today by The National Research Council (NRC, 2000).

According to the NRC (2000), inquiry-based activities encompass a broad spectrum, ranging from teacher-directed structured and guided inquiry to student-directed open inquiry (NRC, 2000). During structured inquiry, the students investigate a teacher-presented question through a prescribed procedure. The student receives complete instructions at each stage, leading to a predetermined discovery. This sort of inquiry has been compared to working by a recipe toward a desired outcome. In the next level of complexity, guided inquiry, the students investigate teacher-presented questions and procedures and later determine both processes and solutions. Although in guided inquiry the questions are supplied by the teacher, who most likely has a good idea what results to expect, the students actually lead the inquiry process, enabling them to come up with unforeseen but self-conceived conclusions. Coupled inquiry is an intermediate stage between guided and open inquiry. Here, the teacher allows the student to choose an inquiry question from a databank of predetermined questions.

In open inquiry, the teacher defines the knowledge framework where inquiry is conducted but leaves the students to select a wide variety of inquiry questions. During open inquiry, students investigate topic-related questions that are student-formulated through student designed/selected procedures. The students make their own decisions throughout each stage of the open inquiry process. This method reflects the type of research and experimental work performed by scientists. Open inquiry demands high-order thinking, and an important component in implementing such an inquiry is the teachers' ability to motivate their students to ask those questions that will guide them in their inquiry (Chin & Chia, 2004). The student's participation in asking the inquiry question is the key in open inquiry. The teacher aids the students in all stages and assists them in making choices throughout the different stages.

In recent years, accumulating evidence has indicated that structured inquiry, by systematically guiding the student to solve one predetermined question, is insufficient in developing critical and scientific thinking, and appropriate dispositions and attitudes (Berg, Bergendahl, Lundberg, & Tibell, 2003; Kaberman & Dori, 2008; Yen & Huang, 2001). For example, Berg et al. (2003) compared students' outcomes of an open inquiry activity and structured laboratory activity. The main findings were that the open inquiry activity shows more positive outcomes regarding learning outcome, preparation time, time spent in the laboratory, and students' perception of the experiment. Over the past decade, accumulating evidence has supported the effectiveness of open inquiry learning in developing skills for inquiry and autonomous learning (Roth, 1994; Yen & Huang, 2001).

Germann, Haskins, and Auls (1996) claimed that the goal in inquiry learning 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 to. The highest level of inquiry is achieved when students have the greatest amount of independence, engaging in activities that come closest to doing real science. Furthermore, Germann et al. (1996) claimed that guided inquiry can be used to help students make the transition from a structured inquiry level to an open inquiry level. Interestingly, as students move from structured inquiry to guided inquiry, they transform their data much more into complex and abstract forms, such as graphs and concepts maps (Lunsford, Melear, Roth, Perkins, & Hickok, 2007).

Inquiry's main purpose is to guide students to construct their own knowledge. Since inquiry-based teaching motivates students when they are confronted with an authentic problem, and they must take risks to solve the problem (Krajcik, Czerniak, & Berger, 2002; Minstrell & van Zee, 2000; Palmer, 2009), developing curricula that emphasize guided or open inquiry learning is considered an important challenge. For this reason, the entire process of identifying a relevant problem, posing questions, and designing an approach to reach a conclusion is considered an essential skill (Crawford, Krajcik, & Marx, 1999). Specifically, in order to deepen students' understanding of the nature of science, science educators are continually searching for innovative ways to encourage students to conceptualize the dynamic and ever-changing nature of the scientific process, via a complex, ill-structured inquiry learning process such as guided and open inquiry (Carter, 2008; Chin & Chia, 2006; Khishfe & Abd-El-Khalick, 2002; Zion et al., 2004a,b).

Dynamic Inquiry Perspectives Embedded Within the Context of an Inquiry Process

Zion et al. (2004b) conducted a long-term, 3-year action research study that documented and identified the basic constituent elements of the open inquiry learning process, based on logically related inquiry questions. Zion et al. (2004b) characterized open inquiry as a dynamic inquiry learning process, where learning is a process of continuous and renewed thinking that involves flexibility, judgment, and contemplation, as part of the changes that occur in the course of inquiry. Moreover, characterizing the dynamic inquiry process emphasized the perspectives of critical thinking and change, reflective thinking about the process, and affective aspects, such as curiosity, which are expressed in situations involving change and uncertainty. Zion et al. (2004b) grouped the elements of dynamic inquiry into four main criteria (each criterion includes several defined categories), see Appendix: changes occurring during inquiry (such as changes in the course of conducting an inquiry as a consequence of field conditions or a literature search, new ideas that emerged and induced changes, and understanding the need to solve technical problems); learning as a process (such as documentation, researching additional professional literature, and devoting adequate time throughout the course of the inquiry); procedural understanding (such as understanding the importance of controlling variables, learning how to approach each question from different research perspectives and working methods, controlling, repeating, and maintaining statistics); and the affective points of view (such as curiosity, frustration, surprise, perseverance, and coping with unexpected results).

Research Rational

The trigger for characterizing the elements of dynamic inquiry was an action research that was conducted in parallel to the implementation of an open inquiry project. We can, however, assume that elements of dynamic inquiry could also be identified in guided inquiry learning, since students who conducted guided inquiry were also exposed to all stages of the inquiry process: the inquiry results are not predetermined, and the student, who cannot know these results in advance, functions autonomously throughout the stages of data collection and analysis.

Many science educators agree that both guided and open inquiry can be efficient in developing inquiry skills and critical thinking. However, which type of inquiry is more relevant to the teaching and learning facilities available in high schools remains controversial among educators (Yerrick, 2000; Zion, 2007). Some teachers prefer using guided inquiry whereas others prefer open inquiry (Zion, Cohen, & Amir, 2007). Those who prefer open inquiry claim that this method achieves a higher inquiry level, and the student becomes more familiar with the nature of science and develops inquiry skills and sharper mental processes (Berg et al., 2003; Yen & Huang, 2001). Krystyniak and Heikkinen (2007) found that students employed science process skills and engaged in higher-order thinking during an open inquiry project. Several researchers have indicated that logical thinking and assimilation of the principles of the open inquiry process can be developed among students of both greater and lesser abilities (e.g., Germann et al., 1996; Yerrick, 2000). Furtak (2006) claimed that if students were to learn in an open-ended setting, in which the answer was not known in advance, then the application of the methods and thinking processes of scientists might make more sense to them. Furthermore, Furtak (2006) found that teachers had difficulties in maintaining an atmosphere that encourages student-directed inquiry while facilitating guided inquiry. Whether inquiry is described as an expository versus inductive method, product versus process oriented, instructional versus facilitating method, or guided versus open inquiry, those science educators who claim that the open inquiry experience may deepen student's understanding of the nature of science have called for further investigation of open inquiry learning practices (Berg et al., 2003; Chin & Chia, 2006; Crawford, 2000; Roth, 1999; Yerrick, 2000).

In contrast, researchers agreed that guided inquiry-based teaching helps students learn science content, master how to do science, and understand the nature of science (e.g., Tabak et al., 1995; Quintana, Zhang, & Krajcik, 2005). The guided inquiry proponents view student instruction as a desired goal; more specifically, it prevents a "waste of time," reduces student frustration due to achieving undesirable results or experiencing failure, and fear of the unknown (Trautmann, MaKinster, & Avery, 2004)—all of which may occur in open inquiry (Gallagher & Tobin, 1987; Yen & Huang, 2001; Zion et al., 2007).

Much research has covered the development of inquiry-based skills, showing that students doing guided inquiry develop a high level of inquiry skills (Flick & Lederman, 2006; Roberts & Gott, 1999; Tamir, Nussinovitz, & Friedler, 1982). We therefore do not expect to find a significant difference in the inquiry skills levels developed by guided and open inquiry students.

To date, no empirical research has characterized dynamic inquiry performances of inquiry work using guided and open inquiry in high school. Hence, this study's purpose was to compare these instructional methods and their influence on the development of dynamic inquiry performances. Based on the qualitative characterization of the dynamic inquiry processes of the students who engaged in open inquiry, we hypothesize that these students will outperform students who experienced guided inquiry, in terms of developing dynamic inquiry performances.

The working assumptions for this hypothesis will be detailed below. As open inquiry students experience the stages of defining a phenomenon, asking a question, hypothesizing and planning an experiment. Their inquiry will likely be more dynamic, based on changes, proofs, and wavering which come up during the inquiry process. We assume that the greater the level of uncertainty in the inquiry process, the greater the level of performances in the following criteria: ''changes occurring during inquiry'' and ''affective points of view.'' The open inquiry students under this investigation were instructed to arrange an inquiry plan that was based on three interconnected questions. Four models for establishing a logical association between inquiry questions were found to serve as an infrastructure that emphasizes the open inquiry process (Zion & Sadeh, 2007). For this reason, we assumed that open inquiry students will outperform their counterparts in the criterion ''learning as a process.'' Furthermore, we assumed that as dynamism and uncertainty are higher in open inquiry, the open inquiry students will pay greater attention to credibility of inquiry and of procedure, both in the planning and the practice stages. For this reason we assumed that open inquiry students will outperform their peers in the criterion ''procedural understanding.''

We posed the following research question: What is the effect of different inquiry learning approaches (open/guided) on students' dynamic inquiry performances? We hypothesize that students who experience open inquiry, and are probably more involved in the learning process, develop better dynamic inquiry performances in terms of the four dynamic inquiry criterions, in comparison to students who experience guided inquiry. Supporting the notion that students who perform open inquiry develop a higher level of dynamic inquiry performances will, in turn, encourage educators to support the teaching of open inquiry in schools, despite many difficulties and challenges. On the other hand, proof that students develop dynamic inquiry performances similarly while performing both open and guided inquiry would support educators' inclination to focus on the teaching of the simpler method and improve it. Just as characterizing the dynamic inquiry process emphasized perspectives of critical thinking and change (Zion et al., 2004b), examining students' dynamic inquiry performances may add new dimensions to the pedagogical understanding of learning and teaching inquiry. Such an examination may help in developing students' critical thinking, which is the fundamental objective of inquiry learning.

Method

The research presented in this article was part of a larger research project studying the effects of applying different inquiry methods (open as opposed to guided inquiry) by high-school students engaged in inquiry. This project encompassed a wide variety of aspects such as matriculation achievements, development of inquiry skills, types of knowledge developed, and student attitudes. The results reported here were derived from a longitudinal study in which 50 high-school students were observed throughout their biology studies in preparation for matriculation exams, and studies during 11th and 12th grade. This provided multiple contexts for assessing the level of students' dynamic inquiry performances through interviews, students' written scientific summaries of their inquiry projects, students' logbooks, and written reflections.

The Biology Study Framework

An Israeli public high student majoring in biology must pass a final exam in order to pass the course. The exam is divided as follows: a theoretical section making up 60% of the total biology grade; and a practical section comprising lab work (20% of the total grade); and an inquiry project (the remaining 20%). There are two alternatives in the practical section with varying degrees of student autonomy. The teachers choose one of two learning strategies—guided inquiry or open inquiry—by which all of their students are required to study.

The guided inquiry project was based on ecological phenomena in the field. ‘‘The student conducting the project studies an ecological issue, by performing guided work themselves’’ (Israeli Ministry of Education, 2006, p. 14). In addition to monitored observations in the field, students conducted lab experiments. Throughout the work, students studied several organisms in their natural habitat. These students also answered several inquiry questions regarding these organisms, based on field data. The questions and procedures for collecting the data were presented by the teachers, and the students collected and analyzed the data, discussed the results, and drew conclusions. In light of the results collected, the student, aided by the teacher, could alter and revise the inquiry plan. The teacher was also closely involved in processing the results.

An example of a guided inquiry project is as follows: a teacher chose an Eucalyptus tree in the school vicinity. Next to the tree was an ant nest. The teacher instructed the students to visit the spot several times over a 6-month period, collecting data such as air temperature, soil temperature, soil moisture, wind direction and velocity under the tree, next to the ant nest, and at varying distances from the tree. In addition, the teacher also asked the students to observe the biotic factors at the site and to calculate the percentage of vegetation coverage under the tree, next to the nest, and at varying distances from the tree; identify a diversity of species in the chosen sites; and vegetation height. The teacher told the students that these data will help answer the inquiry questions concerning the connection between the Eucalyptus and the percentage of vegetation coverage beneath and away from it, the connection between the location of the nest and plants (diversity and coverage), and the effect of abiotic factors (for instance, air temperature and soil temperature) on the activity of the ants.

Of central importance to the open inquiry project, students are encouraged to select an inquiry topic and construct their own inquiry questions. The inquiry process evolved first from the students’ observation of a field phenomenon, and then advanced through three inquiry questions, the answers to which were not previously known by the student, and often not by the teacher (Zion et al., 2004a,b; Zion & Sadeh, 2007).

An example of an open inquiry project is as follows: a teacher took her students on an excursion in the school vicinity. The teacher and students looked for different biological phenomena on which an inquiry project can be based. During their excursion, the students noticed ants carrying seeds in a long line leading to their nest. The students chose this subject and asked the first inquiry question about the connection between the plants surrounding the nest and the ants’ food preference. The students also raised two additional inquiry questions concerning food preference. Both questions included field experiments for examining food preference: (1) Exposing ants to different foods at identical distances from the nest; (2) examining the effort ants put into bringing the food back to the nest. The students consulted the teacher about how to conduct the experiments, what tables should be used to best present the data and what foods should be used based on the literature they had read, but they actually exhibited a great deal of independence in planning and execution. Later on, the teacher continued to participate in student discussions, but usually offered guidance instead of overtly influencing the students.

Both projects share a similar framework: 11th grade, the teacher exposed students to biological phenomena in the field. During this time, he also taught inquiry skills during lab hours; this included identifying variables, collecting data and drawing graphs, and drawing conclusions based on simple laboratory experiments (e.g., the effect of temperature on enzymatic activity, the effect of light on photosynthesis). Halfway into 11th grade, the students must begin their actual inquiry work. Guided and open inquiry projects usually lasted for 6–8 months (Israeli Ministry of Education, 2006). During the first trimester of 12th grade, when the students have finished collecting data, they write a report according to specific instructions: theoretical background, methods, results including data analysis in appropriate graphs, a discussion, conclusions, and bibliographic list. Upon submission of the reports, students are given an oral exam by an external examiner (Israeli Ministry of Education, 2006). The stages of inquiry, from planning (open inquiry), through data collection and writing the report (both types of inquiry), were carried out in the student’s spare time, not during school hours. The teachers maintained contact with their students throughout the process. Teachers and students met according to the students’ schedules. Each group (of up to three students) worked at its own pace, and the meetings with the teacher were timed accordingly (Zion & Slezak, 2005).

Participants

Students. The sample consisted of 50 biology students, half (25 students: 18 females and 7 males) engaged in open inquiry and half (25 students: 19 females and 6 males) engaged in guided inquiry. The students were chosen from four general high schools and had similar socio-cultural backgrounds and academic achievements. The students come from middle-class neighborhoods and none of them receives financial support. Students studied biology as a major for 2 years (11th and 12th grade), and data were collected throughout this period. We compared the students from both groups with regard to their ability to take on a theoretical structured inquiry biology assignment, based on a list of inquiry skills, following the work of Tamir et al. (1982). We found no significant differences in inquiry skills between the two groups, in a structured inquiry assignment: the average grades among the guided and open students at the beginning of 11th grade were 79.8 ± 10.4 and 81.5 ± 9.28 respectively.

In the structured inquiry assignment, the students were presented with both a research design and results, and were asked to indicate the inquiry process components in the text, analyze the results, and link them to students' knowledge in biology. In a similar structured inquiry assignment, at the end of 12th grade, the average grade was 82.9 ± 11.2 and 81.8 ± 9.7 among open inquiry and guided inquiry students, respectively. No significant difference was found between the groups. The research groups were assembled according to the teaching model implemented in class. The details are presented in the Teachers' Section.

Teachers. Four teachers were selected from a larger pool of 18 volunteers, in order to provide the two types of inquiry teaching approaches. Two teachers taught the open inquiry approach and two taught the guided inquiry approach. All of the teachers had many characteristics in common: they had more than 10 years experience, they had prepared students for matriculation exams more than five times, they liked to be informed of innovations in the field of biology, they participated in continued professional development programs, and they are highly regarded among biology teachers and their professional colleagues. The teachers also shared similar educational backgrounds. Two of the teachers, who aided the guided inquiry, hold second and third degrees, as do the two teachers who aided the open inquiry, as seen in Table 1. Another biology teacher, who has taught for 20 years, holds a second degree in biology, was appointed by the Ministry of Education to instruct teachers and carried out the interviews in the current research.

We divided the students into two research groups according to the type of inquiry taught by the teachers: open or guided inquiry. Before the research project began, we interviewed the teachers about their method of inquiry teaching and about their involvement in facilitating their students' projects. In addition to the preliminary interview, discussions were held with the teachers every 3 months, in order to verify that they adhered to the methods they declared at the beginning of the research. Furthermore, the researcher went to classes and participated in teachers' meetings with students on assignment, in order to note any change in the teacher's method of facilitation. The four facilitating teachers did not alter their methods throughout the 2 years of research.

Data Collection

Data sources included interviews, students' inquiry papers, a logbook, and reflections.

Interviews

The purpose of the interviews was to obtain information that would help identify and characterize dynamic inquiry performances developed by the students throughout their inquiry work. All student

Table 1
Teachers' characteristics

Number of Teacher	Type of Inquiry	Gender	Years of Service	Academic Degree	Participates in Teacher Training
1	Open	Female	28	PhD	+
2	Open	Female	16	MSc	+
3	Guided	Female	18	PhD	+
4	Guided	Female	17	MSc	+

participants were interviewed. The data were gathered in several interviews with each student, at the beginning and at the end of their inquiry project. The students were questioned in a semi-structured setting. By questioning the students, they were encouraged to explain in detail the learning process they engaged in during the inquiry project. Questions were asked according to the four criteria and defined categories, which were characterized by Zion et al. (2004b) and are presented in Table 2. During the interview, students were asked to provide examples from their inquiry process for each question. The students were also presented with a scientific inquiry case study, and were asked to examine and comment on the case study according to the categories of dynamic inquiry. See Table 3 for examples.

Research has shown that the interviewer can influence the interviewee's ideas and responses (Patton, 1990). An interview is both a tool for gathering information and a process whereby the two participants create a reality that may, to some degree, affect the content (Woods, 1996). In addition, some interviewees are, naturally, hesitant to express themselves freely about grades, matriculation exams, and the inquiry project, since these topics are directly and indirectly associated with teacher's evaluation. For these reasons, and in order to develop a sense of trust (Shkedi, 2003), the interviewer participated in several practical lessons (lab and students' inquiry projects) before conducting the interviews. In addition, in order to create an intimate environment and an atmosphere of trust, some interviews were not tape-recorded in accordance with students' wishes (Shkedi, 2003). Likewise, written notes during and after the interviews were taken in accordance with students' wishes (Sabar, 1999).

Students' Logbooks, Inquiry Summary Papers, and Reflections

The students from both research groups used the logbooks to document every stage of the inquiry process: planning, execution, data gathering, data processing, and writing the discussion. They also used the logbooks to note difficulties encountered throughout the process, changes they made during the inquiry process, and other details relating to how they conducted the inquiry project. The students documented their project in a scientific summary paper in which they referred to inquiry questions and their biological basis, hypotheses, and findings. When they were finished writing the scientific summary, students of *both* groups were asked to complete a written reflection questionnaire. In cases where students did not complete this questionnaire, they were interviewed by the researcher who asked them the questions and wrote down their answers. We emphasize that students of both groups carried out the reflection activity after they had written the scientific summary. The reflection questions that the students answered were related to their activities during the different learning stages, to criticism of their own work, and to an analysis of the final product. For example, "What were the difficulties you encountered when planning the inquiry? How did you overcome the difficulties and/or reach solutions? Describe concisely how the experience of the inquiry project contributed to your understanding of biology research, to planning the inquiry, and to writing an inquiry summary paper." The researchers read the students' scientific summary papers and logbooks and

Table 2
Questions on which the interview was based

Criterion	Examples
Changes occurring during inquiry	Did the inquiry proceed as you had expected? Were there any changes? What changes occurred? Why did you have to change? Did you obtain a surprising result, one that did not match your expectation/hypothesis? What was it? If so—how did you handle this unexpected result?
Learning as a process	Describe the different stages of conducting an inquiry project At what stage did you use the Internet or the library? Why? Did you use a logbook? When? Why? How would you continue the project? Why?
Procedural understanding	Why were the inquiry questions constructed in such an order, one based on the other? How would skipping any of the stages influence your work?
Affective points of view	Did you enjoy participating in the project? Write down a special experience that occurred Describe any disappointments that you experienced during the process

Table 3
Examining an inquiry case study by dynamic inquiry characteristics

Criterion	Examples
Changes occurring during inquiry	I You placed 25 seeds on filter paper, in a plate, prepared a concentrated solution of dish-soap water, and added soap solution once every 2 or 3 days into the seed plate. You were careful to ensure that the filter paper was humid throughout the experiment. Three weeks later, no seeds had sprouted. Disappointed, you said
	(a) No results means the experiment is a failure
	(b) "No results" is also a result
	(c) The experiment should be repeated in exactly the same way
	(d) The experiment should be repeated with a different concentration of soap
	II Which of the four (a–d) reflects your attitude? Why?
Learning as a process	III How can you examine the connection between detergent A and the seeds' sprouting rate? Organize the actions in the correct order
	(a) Prepare detergent solutions of different concentrations
	(b) Calculate the sprouting rate
	(c) Conduct a literature search
	(d) Prepare a table to record the results
	(e) Formulate a hypothesis
	(f) Split the seeds into several groups
	(g) Reach a conclusion regarding the connection between variables
	(h) Count the number of sprouted seeds
	(i) Formulate an inquiry question
	(j) Water each group with a different solution
	(k) Draw a graph
	IV Which of the above actions would you repeat several times during the experiment? Why?
Procedural understanding	V What can be done in order to ensure there was no problem with the seeds? Explain
	VI What can be done to determine whether the effect was due to the soap?
Affective points of view	VII How do you feel about the appearance of the mold?
	(a) Was there an opportunity to cope with failure and surprise?
	(b) Was boring
	(c) Was interesting
	(d) Improved my understanding of how to conduct an experiment
	(e) Was flexible enough to take a new direction according to the findings
	(f) Was it irrelevant?

looked for the expression of dynamic inquiry performances. The information in these reports helped the researcher construct interview questions and encouraged students to explain the choices they had made and the activities they had performed in their project.

Data Analysis

The findings presented here include data collected from students' interviews, inquiry summary paper, logbooks, and reflections—all used to indicate the presence and levels of dynamic inquiry performances among students of each research group. The use of multiple data sources allowed for triangulation by enabling us to check for consistency between data sources (Patton, 1990). Triangulation was ensured through the analyses developed by both the researcher and two experienced teachers assisting her. This collaborative approach improved the validity of analysis and the interpretation of results, and reduced the influence of bias and subjectivity (Denzin & Lincoln, 1994; Patton, 1990).

A "personal report" was developed for each student detailing their references to dynamic inquiry categories, as expressed through the different research tools. The personal report data were classified into the four criteria of a dynamic inquiry. Within each criterion, the data were assigned to the different categories created by Zion et al. (2004b). The personal report data were then used to determine the student's level of inquiry performances, quantified by the Dynamic Inquiry Performances (DIP) Index. Table 4 details the DIP Index, including components of the four criteria, and three levels of dynamic inquiry performances, constructed to indicate the degree to which the student understands and applies the categories associated with

Table 4
Dynamic Inquiry Performances (DIP) Index

Level	(3) High	(2) Medium	(1) Low
Criteria			
Changes occurring during inquiry	Exhibits a deep understanding of the components of change—knows how to explain stages and reasons	Makes general references to the components of change—knows how to mention stages and reasons	Ignores or sees the changes as "facts," or refers the changes to the teacher
Learning as a process	Exhibits a deep understanding of the importance of documentation, detailed examples of change, and a connection between inquiry questions Explains the importance of stages and their contribution to the learning process	Makes general references to documentation, changes, and reasons for change	Ignores documentation, changes, and reasons for change, or gives the teacher all the credit
Procedural understanding	Exhibits a deep understanding of inquiry components Provides examples of different components Demonstrates correct critical thinking	Exhibits a general understanding of the inquiry components Demonstrates some critical thinking	Exhibits a poor understanding of the inquiry components Demonstrates no critical thinking
Affective points of view	Makes detailed references to affective aspects with many relevant examples	Makes some reference to the affective aspects with some relevant or general examples	Makes a superficial reference with almost no examples

those criteria. Level 1 indicates a low level of understanding and applying dynamic inquiry performances, Level 2 indicates a medium level, and level 3 indicates the highest level. Two judges, who were senior biology teachers, separately quantified the dynamic inquiry skill levels of the students.

The judges were specifically instructed to look for all levels of the index in each student. They were instructed to begin by looking for the highest level, and to move down the scale only when this level could not be found. The judges also reviewed the research tools in order to increase analysis credibility. The judges relied on some key expressions when analyzing the interviews, logbooks, and reflections, in determining the dynamic inquiry level of each student. In order to classify at the highest level (3), they looked for expressions such as "important" followed by an explanation of the importance, "statistics/statistical," "expected/unexpected," and "understand;" for the intermediate level (2): "important" without an explanation of the importance, expected (mostly unexpected); for the lowest level (1), passive expressions such as "I was told" ("the teacher told me"). Expressions critical to determining these levels are underlined in Table 5.

The judges agreed in 93% of the cases. Upon disagreement, the teachers would discuss the case until an agreement was reached about grading the student. In rare cases, the student's teacher was requested to give her opinion and help decide on an appropriate criterion. The students were eventually given a score of 1–3 for each of the four criteria, and student grades in the four criteria were then added to a summary score between 4 and 12. When evidence indicating the level of a certain criterion was not found, the data were reviewed again to increase validity. MANOVA tests were run for each criterion and the summary score and the two groups of students were compared.

Results

The results are presented in two sections. The first section presents the expression of dynamic inquiry performances in each research group, including examples of student references to dynamic inquiry criteria, categorized as low, medium, and high levels. The second section presents the relative values of the dynamic skill level for each criterion, including statistical tests to examine differences between the two research groups.

Table 5
Examples for different levels of dynamic inquiry skills of all criteria from both research groups

Criterion[a]	Inquiry type	Level	Examples
Changes occurring during inquiry	Open (90)[b]	High (3)	Changes during inquiry, reacts to field conditions—"We thought of measuring coverage under and around the Dittrichia viscose bushes, but we saw this was impossible because the vegetation was too thick to tell one shrub from another. We believed it was *important* to note plants growing at different distances from the sea, *so we changed the measure*" (L).[c] Ideas emerge during the process—"We noticed that leaves dried fast, and the soil without leaves dried faster. We *understood* that coverage and water remaining for seeds were significant factors, so we *had to add a treatment* of covering the soil as if leaves were there, though without the leaves themselves, so they would not have an effect... we cut cardboard and used it to make leaves that have no effect. We chose the color of the cardboard to be the same color of the leaves... if we make leaves, we want them to be as real as possible... why not?" (R) The need arises to solve technical problems and to suggest practical solutions—"We wanted to make an extract quickly, using several pots. We then noticed that the pots were different in size, and although we put in the same amounts of water and leaves, the water surface was different. This might affect evaporation and thus extract concentrations. *We thought of ignoring the difference, but decided against doing so... so we decided to cover the pots* in order to inhibit evaporation, and this worked well because we wanted the water to boil" (I)
	Open (96)	Medium (2)	Changes during inquiry, reacts to field conditions—"We wanted to investigate the color most attractive to bees. We decided on four colors, but there were not enough bees, so we *took out one color* and remained with three, which was *easier to work* with and produced more decisive results... the bees were uncooperative. Perhaps our sugar water was not good enough, so we prepared new solutions with more sugar" (I) The need arises to solve technical problems and to suggest practical solutions—"We put the solution in a glass but the bees could not easily reach it to drink. Noting the distance between the rim of the glass and the solution, *we decided* to pour it into a Petri dish, where the bees could *easily stand* on the edge and drink" (R)
	Guided (226)	Medium (2)	Changes during inquiry, reacts to field conditions—"We had *few changes* while doing our inquiry project. There were changes in weather, in nature, but not in the inquiry itself. We proceeded as we planned with our teacher. We measured as planned and observed as planned in order to answer the inquiry questions regarding the connection between temperature and pollinators and between flower type and pollinators" (I) The need arises to solve technical problems and to suggest practical solutions—"It was *difficult* to count all the insects, some of which we could not identify. It was also difficult to tell whether an insect flying by a flower was a new one or one that has visited the flower before and was counted twice... so later we *developed a system* of closely observing together and announcing every new insect, noting it, and then comparing notes" (P)
Learning as a process	Guided (226)	High (3)	Understands the importance of documentation—"It was *very important to write down everything*. We wrote down everything we saw, and later, when we had to answer questions about the plants and the insects, *we had the information*. We saw other groups that did not write down things properly, and later they were *missing information*, some of *which was impossible to recover*" (R)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
			Understands the importance of the connecting thread between inquiry questions throughout the inquiry process—"At first we thought of addressing two questions regarding changes in our selected habitat—changes in blossoming and changes in insects, and the connection of these with factors such as ground water and temperature. When we arrived at the site, we saw one area with many flowers and another with less, though they were very closeby, *and we decided we would also compare* the two, not only because it adds another question and makes our assignment look more serious, but also because *the difference might help explain the interactions we were examining*" (L)
			There's a need to continue searching for more literature throughout the entire process—"*If we'd waited until the end of our assignment to understand* the interaction between flowers and insects, *we might have missed things*, we might not have noticed all the insects and what they were doing. Having read that red flowers attract small beetles, we knew where to look for beetles. And when you look closer and in the right places, you see more details in the entire system" (I)
			Inquiry takes time—"The work took time. Both the practical part—going out to the field, measuring, counting—you can't do that in a moment and be finished; and the literature search, and later drawing all the charts—which I think took more time than other activities. Deciding what sort of chart, whether to draw a linear graph or doing it in columns. What should we put on the X axis? Just the time, or other factors? The discussion, later, did not take so much time, because we talked about things we observed as we were working and drawing the charts, and discussed why things were as they were and whether what we found fits our hypotheses" (I)
	Open (96)	Medium (2)	Understands the importance of documentation—"I didn't really use the log that much, although I wrote down everything. *It seemed important to do it, but I didn't use the log much*, perhaps because I have a good memory" (I)
			There's a need to continue searching for more literature throughout the entire process—"It's *important to read before you begin inquiry*, because it helps in deciding on things. For instance, it helped us decide which colors to use." (R)
			Inquiry takes time—"*Making a date* with the beekeeper was not easy, and we *needed to arrange* for one of our parents to drive us to the site. In the field, it *took time to place* the solutions and wait for the bees. It took time to prepare the inquiry proposal and write the scientific summary—everything took so much time" (I)
Procedural under-standing	Open (90)	High (3)	The importance of reliable observation reliability and understanding the limitations of isolating variables in the field—"When we arrived at the beach and saw all the plants around us, we were awed. We wanted to examine the connection between the effect of the Dittrichia on the surrounding plants and its distance from the sea. *But other factors might also be present*, not only the distance from the sea. For instance, the ground was changing, becoming less sandy as we moved away from the sea. That might also be *significant*. Garbage left by people or blown in by the wind, and animals roaming around; these might also have some effect... we therefore decided to begin with a lab experiment where we could control conditions, which was impossible in the field" (I)

(*Continued*)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
			Understands the importance of maintaining constant conditions—"On our first experiment we noticed the sprouting was poor in the plate that we watered, *even though we expected* the watered seeds to sprout better than others. We wondered why, and noticed that the cotton wool there was the driest. That was because the cotton wool, unlike the fibers, did not have any leaves on it. The leaves prevented a lot of evaporation. We then *understood that evaporation was also a factor* to be considered, and we made fake cardboard leaves. We made them as leaf-like as possible, and we even made them out of green cardboard, so that there would not be any effect we weren't aware of, such as light reflection. . . we noticed that the presence of leaves greatly affected the water in the cotton wool. . . we had another problem: when we transferred the Dittrichia from the roof of the building into the lab, every girl took home a dish and had to bring it to school the next day. *But each of us left the dish at a different temperature*: one put it in an air-conditioned room, another in a non-air-conditioned room, and a third simply left the dish outside her house. This may have affected the seeds" (I)
			Understands the importance of control—"At first we thought of doing only three treatments—on bushes at different distances from the sea. But then we thought the seeds in the lab might be old and wouldn't sprout, not because of the Dittrichia, so we prepared a control group of seeds that we watered without Dittrichia to see how they sprout without the presence of the Dittrichia, *to which we could compare and determine how much it really affects sprouting*. We also had to add the same amounts of water, *but that has to do with the constant conditions*" (L)
			Understands the importance of repetitions—"*I made several repetitions. It's important*. If I'd done the experiment only once, I couldn't be sure if this is how it was supposed to be, or maybe my results were merely coincidental. Having conducted the experiment three times and after having obtained similar results, it allowed me to draw conclusions without any excuses. . . *We also understood that multiplicity was important*. The first time we conducted the experiment with only four seeds. In one dish, no seeds sprouted. *We finally understood that maybe the results we obtained were due to the seeds and not our treatments, so we increased the number of seeds* to twenty per dish. It was annoying to repeat the experiment, but it was *impossible to proceed based on our first results with so few seeds*" (I)
Procedural under-standing	Open (90)	High (3)	Understands the importance of using statistics—"Our results were as we'd *expected*: almost all of the seeds, 18 of 20, sprouted in water. Close to the sea, 12.3 of 20 sprouted and further away from the sea, 10 of 20 sprouted. We were glad since we'd hypothesized that the allelopathy would be weaker near the sea. However, *a statistical calculation showed this difference* to be insignificant, and therefore we didn't find a basis for the conclusions we were seeking to draw. It *was important to carry out the statistical calculation*—otherwise we'd have drawn erroneous conclusions. We could have been wrong about there being no significant difference, but there's only a 5% chance of that. *We could have ignored statistics, but then we'd have no foundation for our conclusions*" (P)
	Guided (226)	High (3)	The importance of observation reliability—"There were many plants and insects in the field. *It was important to note them all, and not count any twice or ignore them*, because then what we'd written would not have been a true description of what happens in the habitat" (I)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
			Understands the limitations of variable isolation in the field—"While writing the discussion we had to refer to the fact that there were several relevant factors—water, temperature, and wind. So even if water is a very significant factor, maybe it was the wind that disturbed the insects' flight at the specific time we were there to examine" (I) Understands the importance of maintaining constant conditions—"*In order to give a fair comparison* between a more and a less blossoming field, we *tried visiting both at the same time so that conditions would be similar.* As I've said, other things may have an effect, not just more or less flowers—temperature, for instance. If there were differences in temperature, they were minute, and were due to different vegetation coverage, or instruments being slightly off scale" (I) Understands the importance of control—"Comparing two areas helped us in knowing whether there was any connection with the degree of blossoming. *You can't check that unless you have a comparison group*. This is comparative control, unlike school lab experiments, where we had external control, or pharmaceutical experiments with and without drugs" (I) Understands the importance of repetitions—"Actually, we didn't do repetitions. Every once in a while we went out for one excursion. Perhaps different days of the season were different from each other, but we could not tell that. *Now I know that in inquiry, you have to examine several times* under the same conditions. But it's just a Biotope (referring to the Israel Ministry of Education's requirements. Researcher's note) which is so much work anyway, and we put in a lot of effort" (I)
Procedural understanding	Open (97)	Medium (2)	Understands the limitations of variable isolation in the field—"We wanted to check the effect of pollution on lichens, so we examined lichens at varying distances from the road. But at some point, we were also getting closer to the sea, which has its own effect. *So it's impossible to tell which effect was at work and to distinguish between them*" (P) Understands the importance of control—"Control is also important; it is a component of experimentation just like repetition. We gain knowledge by comparison." (*The student was unable to explain her meaning*) (I) Understands the importance of repetitions—"It's important to do repetitions; it makes you more confident (*the student could not answer when asked 'confident about what?'*). We repeated the experiment three times and repeated the measurements in the iris reservation several times" (I)
	Guided (217)	Medium (2)	Understands the limitations of variable isolation in the field—"We compared an area under the Eucalyptus with an area not under the Eucalyptus. We knew there was allelopathy in the Eucalyptus and examined it, then there was a fire and *we couldn't tell which had a greater effect, the fire or the Eucalyptus*" (I) Understands the importance of control—"Control is important for comparison. For instance, we compared two areas that were very much alike in every aspect, except that one had an Eucalyptus, so we could see the effects of a Eucalyptus being there. If we hadn't had an area without an Eucalyptus, we wouldn't be able to determine the effect of an Eucalyptus. *Every good experiment must have such a comparison*" (I) Understands the importance of repetitions—"*It's important, we always talked about this in class.* It's important because it's a part of conducting a good experiment or research" (the student could not elaborate what she meant). (I)

(*Continued*)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
	Open (60)	Low (1)	"I was working on the Squill and had to examine catalase activity, but in every experiment I did there was no change. Bubbles, which should have appeared in every test tube hardly formed, and it's a good thing I did repetitions. . . you do repetitions to have control and so that things come out well" (*the student could not explain what is a control and what are repetitions*) (I)
	Guided (278)	Low (1)	"The Oak tree is very beautiful and we examined what it has on its different sides, north and south and east and west; these were repetitions and we did four of them. It's also important to have a control, to repeat what you're doing so you can monitor it. *The teacher told us to do this several times*." (The student was later asked again to confirm that he was not momentarily confused, and he repeated his statements. At the end of the interview, the terminology was explained to the student and his references to the inquiry were corrected) (I)
Affective aspects	Open (90)	High (3)	Curiosity arises especially when expectations are not met, and copes with unexpected results—"On our first question we obtained results that fit our hypothesis, though the difference was not significant. We tried to figure it out. *Why was it not working as expected*?... It was actually *more interesting* than if we'd gotten what we'd *expected*. We thought it was all clear and predetermined, no thinking needed, we had our biological basis. But now we *had to figure it out and it was more interesting*.We came up with several reasons that can be examined, but not by us. . . perhaps the students next year" (R)
Affective aspects	Open (90)	High (3)	Expects disappointments and surprises—"We were a little *disappointed* when the first experiment did not succeed. Actually, we didn't prepare it properly. As I said, we used only four seeds, and then had to repeat it—simply a waste of time. But later, the results seemed to meet the hypothesis. However, *the statistica*l test showed that they didn't. We were *afraid* our results would be inadmissible, but then we *understood*that even when they weren't, they are. . . that is, we could explain the results, so we calmed down. It was very nice to succeed with the second experiment. It was also a success in terms of the results matching the hypothesis, and we conducted it better, with fewer difficulties, *and felt we were making progress*.. . . I was also surprised that we got along well. My mother said three girls is a bad idea, that we'd get into fights, with two always ganging up on the third, but we got along well and cooperated and became better friends. *I enjoyed working* with friends and enjoyed the inquiry itself, doing stuff and *understanding* why *it's important* to have repetition and control and everything else the teacher said; we saw it really was *important.* I didn't make any ground-breaking discoveries, but I was working like a real researcher, and *it was fun* once we were done with the writing that took forever" (I)
			Mood swings, persistence and determination—"We *were very angry* that we had to redo the first experiment. . . *angry* at each other, at the teacher, I was *angry* at myself—how could we not think about it?! But after we got over the *anger*, we decided we want to do the assignment properly, and for that you have to do it again—so we did it, and it is a good thing we didn't give up. We also stopped being *angry* at our teacher, who told us we'd better show her what we plan to do, which we hadn't before, so it wasn't really her fault" (I)
			A student shows initiative—"The inquiry process demands a lot of *initiative*. I felt the teacher was a partner to the process, not someone in charge of it. I felt I was more in charge of the process than the teacher. . . It takes a lot of *responsibility* to initiate and carry out an inquiry: finding a phenomenon, formulating an inquiry proposal, conducting work on schedule, and writing a final report to sum everything up. It was good to have a partner in this process, with whom I could *share the* responsibility" (R)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
	Open (126)	High (3)	Disappointment and surprise mixed with curiosity—"We were experimenting to see if the gall affects the morphological structure of the leaflet, expecting to discover that the gall harms the symmetry of the leaflet, but the examination proved us wrong and we were disappointed. In the same observation, we discovered something *curious and unexpected*—the gall only makes it down to the leaf vascular bundles. We were later able to support this conclusion with results from the experiment examining whether the gall affects the photosynthesis rate in the leaflet" (R)
Affective aspects	Open (121)	High (3)	Disappointment and surprise mixed with curiosity—"I have examples of *surprise and disappointment* from my inquiry. We repeated our third experiment (with the grain sprouts) three times and mold developed in our Petri dishes on all occasions. We knew mold was an inhibiting factor and were disappointed when it showed up despite our efforts to avoid it. We used dispensable syringes and needles every watering, using Merpan (0.2% concentrated fungicide substance), watering with pre-boiled water. *I had an unpleasant surprise* looking for galls in the school yard. I was stung by a bumblebee and we had to postpone the experiment and take the day off... On the third experiment, the aphids died and we couldn't obtain any results. That was really un*expected*... it was a nuisance because I wanted to obtain results on which to base appropriate conclusions. Dealing with un*expected* results was not what we *expected*... the solution was that in time, I realized I must carry on and make the most of the given situation... I made the inquiry choices, and I decided in what direction to proceed, and *this is what is unique and exciting about the inquiry*. I learned how to develop the subject according to varying data. If, for example, an experiment went wrong, I learned that it doesn't necessarily mean the inquiry project and question are null, but rather that I should analyze the process to *understand* what went wrong and learn the appropriate lesson" (R)
	Open (115)	High (3)	Disappointment and surprise mixed with curiosity—"The results of the third inquiry question did not match our hypotheses, which *was a great disappointment*, but I quickly overcame it once I reached the conclusion that un*expected* results are also results, even good results, because they help us rule out incorrect hypotheses and *open up the possibility of thinking creatively of alternative hypotheses*" (R)
	Open (146)	High (3)	Disappointment and surprise mixed with curiosity—"I think I really learned to cope with un*expected* results during this inquiry. For instance, the results of the experiment for our first inquiry question did not support our hypothesis at all, and were partly unexplainable altogether. But we used these results, developed a discussion and conclusions, and I think *I'm quite pleased* with the final outcome... *curiosity arose*" (R)
	Guided (226)	High (3)	Curiosity arises especially when expectations are not met, copes with unexpected results—"The assignment contributed greatly to my attitude, looking at certain phenomena and not taking them for granted, and having an open mind about different explanations. We came across several instances where the results did not match our hypotheses; the results even *contradicted our assumptions*. This made us try to figure out what was 'wrong'-biology or our methods? Perhaps we hadn't counted all the insects, perhaps it was a coincidence. *It made us think and it was more interesting*" (P)

(*Continued*)

Table 5
(*Continued*)

Criterion[a]	Inquiry type	Level	Examples
Affective aspects	Guided (226)	High (3)	Expects disappointments and surprises—"When we came in May, there were lots of flowers and lots of pollinators; it was *very beautiful and we had fun*, but when we came in August, there were no flowers, it was very hot and not much fun at all... we also noticed that when coverage was greater, so were the blossoms and number of pollinators, but also was the quantity of other animals hiding in the plants, such as spiders. They were hiding to catch their prey but also to avoid predators. It was *nice to discover* an entire food web in such a small area" (I) Mood swings—"We had a good time, most of the time. Some students complained and did not do a very meticulous job, but we got along well and we chose something colorful and flowery that would be nice. True, we didn't always have time to go out to the field, and it was a bit of an effort, but on *the whole—it was fun*. We didn't just write what we wrote in the introduction, *we really meant it*!" (I) Below is an excerpt from the students' inquiry paper introduction: "Today, in the 21st century, surrounded by the Internet, TV and hi-tech, we tend to ignore the wonders of nature and the incredible events it encompasses. But here, in one small class, we were given a chance to step away from advanced technology, pull up our sleeves, sharpen our minds and dig into some research. What seemed an insurmountable task for teenagers became an enchanting experience, enriching the minds of our friends and ourselves. The guided assignment increased our awareness and expanded our horizons regarding the interaction between plants and animals. We chose the subject because we both feel closely connected to the topic of blossoming and pollinators—we find these interactions incredible. *We were curious* to study beyond our requirements and discovered how fascinating those things are that people today totally disregard. We would walk down the street and suddenly notice a bee—which would be the cause of *great excitement due to our new understanding of what was going on*. We are now proud to say: nature is man's best friend" (P)
	Guided (240)	High (3)	Disappointment and surprise mixed with curiosity—"If at the beginning we thought of observations as an assignment chore, we soon *discovered the interesting, fascinating side* of such work. We came across *many obstacles*, such as a controlled fire scheduled by authorities, which we'd been unaware of in advance. On the one hand, the fire disrupted three months of observation and inquiry, but on the other hand, it opened up a new field for inquiry, a chance to see nature recovering and the ants rebuilding their nests" (P)
	Open (108)	Medium (2)	Expects disappointments, surprises and copes with unexpected results—"At first I was incredibly disappointed that things did not match the hypothesis, regarding how much each plant photosynthesized, but then I realized not every unexpected result is a bad result, and *what we obtained is good enough to complete our assignment*" (*R*) Students and teachers show initiative—"We went abroad in the middle of our inquiry, which was a problem, because the tadpoles were not waiting for us. We felt *despair until our teacher suggested* that we alter the question, which helped us progress" (R)

[a]For more details see Appendix.

[b]The number refers to the student's code number in the research.

[c]Index: interviews (I), students' inquiry papers (P), logbook (L), and written reflections (R).

Expression of Dynamic Inquiry Performances in Each Research Group

Table 5 lists examples of different levels of dynamic inquiry performances of all criteria and related categories for each research group. Not all categories were found among both research groups. Examples of the ‘‘changes occurring during inquiry’’ criterion were found at high levels only among open inquiry students. Students exhibited a detailed reference to changes occurring throughout the project, and referred to reasons for and implications of changes: changes that occur during work because of field conditions, new ideas that arise and may be implemented during the process, and technical problems that emerge and require students to devise practical solutions. No high-level examples of this criterion were found among guided inquiry students. Medium-level examples were found among both groups. Students generally referred to changes and the reasons for changes. Most references refer to changes dictated by ‘‘the situation,’’ that is, field conditions. Low-level examples of this criterion were found mainly in the guided inquiry group. Changes referred to teacher’s instructions and field conditions.

Both groups exhibited high levels in the criterion ‘‘learning as a process.’’ Students demonstrated a profound understanding of components of the learning process, detailed references to learning processes and learning stages, and explained the importance of stages and their contribution to the learning process. Students also noted the importance of documentation, preliminary learning, the need to conduct literature searches throughout the entire process, and to invest sufficient time starting from the project’s early planning stages to the final stage of drawing conclusions. Medium-level examples of this criterion were found in both research groups. Students generally referred to learning process components and/or mentioned learning stages and their importance. All students interviewed generally referred to learning process components, or at least to some of the categories of ‘‘learning as a process’’ in some way that indicated medium- or high-level internalization. No low-level examples of this criterion were found in either group.

Both groups exhibited high levels in the criterion ‘‘procedural understanding.’’ Students who provided these examples exhibited a profound understanding of conducting an inquiry process, appropriately referring to components of the inquiry process, and supplying examples for most components of concepts of evidence (e.g., repeating, controlling variables, and sampling). Students also exhibited a critical approach to the components and limitations of conducting experiments, observing, and isolating factors. Medium-level answers by students of both groups indicated a general understanding of the inquiry process, a general reference to most components of the procedural understanding of the inquiry process criterion, and/or a semi-critical reference to the inquiry they conducted. Most students who exhibited a low level of procedural understanding were from the guided inquiry group. Their reference to the inquiry process was superficial, ignoring the components of inquiry or excusing their choices by stating that ‘‘the teacher told me.’’

Students of both groups exhibited a high level in the affective points of view criterion. They referred to affective aspects in detail, supplying examples and explanations to reasons for changes in mood, curiosity, and unexpected conditions. Medium-level references were also found in both groups, with students exhibiting more general references and supplying fewer examples. The ‘‘surprise and disappointment’’ and ‘‘coping with unexpected results’’ categories were more often mentioned by open inquiry students. Guided inquiry students also referred to curiosity, though not as often (Table 5). Low levels were not found among students of either group. All students exhibited at least a general reference to affective points of view, and provided examples of disappointment, surprise, and initiatives.

In summary, the dynamic inquiry skill levels are generally higher among open inquiry students. Moreover, the students’ references were ‘‘richer,’’ they seemed to use a larger vocabulary of words, with better descriptions and explanations, and often applied several examples when explaining their inquiry project. Open inquiry students were less dependent on the teacher. These students followed their critical thinking. Open inquiry students exhibited higher levels of dynamic inquiry performances. However, the picture varies when the four criteria are examined. Some criteria show no difference in students’ dynamic inquiry performances—for instance, in the ‘‘affective points of view’’ criterion. This impression is reinforced by gathered quantitative data, and is presented below and in Table 6.

Levels of Dynamic Inquiry Performances in Each Research Group

The research examined student performances according to four criteria: changes occurring during inquiry, learning as a process, procedural understanding, and the affective point of view, as well as a total

Table 6
Students' mean scores (M) and standard deviations (SD) on dynamic inquiry performances level by research group

	Learning Approach					
	Open Inquiry ($n = 25$)		Guided Inquiry ($n = 25$)			
Criteria	M	SD	M	SD	F(1,48)	η^2
Changes occurring during inquiry	2.6	0.58	1.84	0.55	22.56	0.32***
Learning as a process	2.4	0.5	2.2	0.41	2.4	0.05
Procedural understanding	2.56	0.58	1.92	0.64	13.65	0.22***
Affective points of view	2.76	0.44	2.72	0.46	0.1	0.00
Sum (total score = 12)	10.36	1.41	8.68	1.18	19.95	0.29***

Scores ranged from 1 to 3.
***$p < 0.001$.

summary score. Table 6 presents the means and SD of dynamic inquiry skill levels according to both the open and guided inquiry methods. Table 6 also presents the results for the differential analysis of each measure separately and of the total score. A unidirectional MANOVA analysis of dynamic inquiry measures revealed a significant difference between the two groups, $F(4,45) = 7.32$, $p < 0.001$, $\eta^2 = 0.39$. A significant difference in total score was also found, $\eta^2 = 0.29$ $F(4,48) = 19.95$. The open inquiry research group significantly outperformed the guided inquiry research group (p values <0.001). The results show significant differences in the level of the criteria "changes occurring during inquiry" and "procedural understanding" among students who had experienced the two different inquiry approaches (Table 6). Importantly, there were no significant differences involving the criteria "learning as a process" and "affective points of view" between the two groups.

Discussion

Guided Inquiry Versus Open Inquiry Learning Approaches

This research examined students experiencing open inquiry and guided inquiry in the course of 11th and 12th grade high-school biology studies. The students of both research groups received similar scores in conducting a theoretical structured inquiry assignment. This assignment was administered in the matriculation exam at the end of 12th grade. Specifically, students who had experienced open and guided inquiry were presented with a similar level of inquiry skill challenges, such as identifying a question, constructing a hypothesis, analyzing results, and drawing conclusions. If students of both groups performed equally in implementing a structured assignment, then perhaps a guided inquiry project is sufficient for developing inquiry performances, and there is no need to challenge high-school students with a complex open inquiry project. But is the structured inquiry assignment by which students were examined sufficient for developing inquiry performances? Accumulating research indicates that handling a structured inquiry assignment is not indicative of a student's understanding of the essence of the inquiry process or the nature of science (Crawford, 2007).

According to the National Science Education Standards (NSES), students in K-12 science classrooms are expected to develop abilities *to do* scientific inquiry, and gain understanding *about* scientific inquiry. Furthermore, teachers should aid students in acquiring a deep understanding of scientific concepts *through* the presentation of inquiry approaches (NRC, 1996). According to this view of teaching inquiry in science, educators expect students to have the following outcomes: to appreciate the diverse ways in which scientists conduct their work; to understand the power of observation; to gain the knowledge of and the ability to ask testable questions, make hypotheses; to use various forms of data to search for patterns, and to confirm or reject hypotheses; to construct and defend a model or argument; to consider alternate explanations; and to gain an understanding of the tentativeness of science, including the human aspects of science, such as subjectivity and societal influences (Crawford, 2007). All these outcomes are expressed in the criteria of dynamic inquiry. Analyzing students' inquiry processes by dynamic inquiry criteria may therefore contribute to comparing guided and open inquiry learning, by indicating the students' understanding of the essence of both the scientific inquiry process and the nature of science.

Results of this research indicate a difference between students' mastering of dynamic inquiry performances in open and guided inquiry. Open inquiry students exhibited a greater mastery of dynamic inquiry performances in general and of two criteria in particular: ‘‘changes occurring during inquiry'' and ‘‘procedural understanding.'' Better achievements by open inquiry students in the ‘‘changes occurring during inquiry'' criterion supports the fact that students experiencing open inquiry cope with dynamism during their inquiry project. Being autonomous learners, they realize how much the inquiry process does not proceed in a predetermined path, and results that emerge during the process are often unexpected, requiring making changes and solving different problems (Yen & Huang, 2001; Zion et al., 2004b).

A significant difference between open and guided inquiry students was also found at the level of procedural understanding. In this context, we must distinguish between basic executive performances, such as reading a thermometer and operating equipment, and an understanding of the essence of the inquiry process. Conducting a reliable inquiry process demands procedural understanding beyond the ability to use equipment. Understanding the inquiry process relates to the more complex thinking skills required to collect reliable data and draw conclusions, while addressing aspects of the concept of evidence (Roberts, 2001; Roberts & Gott, 2003). Results of the current research indicated that the open inquiry students possess deeper procedural understanding. These students often express procedural understanding when facing problems and difficulties in the inquiry process. In contrast, in a guided inquiry process, students follow teachers' instructions when planning and conducting inquiries. For example, teachers supply the students with inquiry questions and experimental procedures likely to succeed, and the student does not participate in the decision making process about the experimental procedure. According to Millar and Osbourne (1998), since open inquiry students need to understand the scientific approach to inquiry, they become aware of the difficulties in obtaining reliable and valid data. This may explain the fact that guided inquiry students developed poorer procedural understanding than open inquiry students, whereas open inquiry students had a better chance to develop procedural understanding because of the need to handle difficulties and problems that arise during the inquiry process.

Criteria of Dynamic Inquiry and NOS

‘‘Changes occurring during inquiry'' and ‘‘learning as a process'' correspond to the NOS definition that ‘‘scientific knowledge is tentative'' (Abd-El-Khalick, 2006; Khishfe & Abd-El-Khalick, 2002). ‘Procedural understanding' meets other NOS definitions: that, ‘‘science is the existence of the scientific method'' and ‘‘experiments are a goal-oriented form of scientific observation'' (Abd-El-Khalick, 2006; Khishfe & Abd-El-Khalick, 2002). Affective points of view add the emotional dimension needed when conducting a dynamic process that involves many changes and intellectual crossroads. By NOS definition, ‘‘scientific knowledge is partly the product of human imagination and creativity'' (Abd-El-Khalick, 2006; Khishfe & Abd-El-Khalick, 2002). Dynamic inquiry performances may influence students' understanding about scientific inquiry and understanding the nature of science. Moreover, since the two criteria, ‘‘changes occurring during inquiry'' and ‘‘procedural understanding,'' respectively, match the several criteria of the nature of science, and since these criteria were demonstrated at a higher level among open inquiry students, we suggest examining whether engaging in open inquiry improved students' understanding the nature of science.

We feel that further research is needed to examine the comprehension of the nature of science by open inquiry students compared with guided inquiry students. Schwab (1962) claimed that the highest inquiry level becomes more common as students develop independence, and perform activities in the same way that scientists work in their labs. As for the two criteria—‘‘changes occurring during inquiry'' and ‘‘procedural understanding''—we can conclude that by using open inquiry, students expressed their understanding of the similarity between the inquiry work in class and scientists' work. Roberts and Gott (1999) claimed that without procedural understanding, students cannot understand inquiry; therefore, teachers who teach guided inquiry should pay more attention to those criteria that can influence both open and guided students' achievements (Tamir, Stavy, & Ratner, 1998).

No significant differences were found between the research groups at the level of the dynamic inquiry criterion ''affective points of view.'' As for affective points of view in conducting an inquiry project, students of both research groups often elaborated on mood changes, reaction to progress or problems with their project, the expression of curiosity, and their relationship with their teacher. The lack of differences between the groups may be because in both research groups the inquiry process concerns field phenomena. Lazarowitz (2007) assumed that students' field work helped them develop responsibility and a sense of caring for the environment. The current research has shown that conducting an inquiry project that begins with identifying an intriguing field phenomenon elicits affective expression in students. This finding is in agreement with previous research that reports outdoor learning is popular with students (Mooney, 2006; Orion & Hofstein, 1994), raises curiosity (McGlashan, Gasser, Dow, Hartney, & Rogers, 2007), and engenders fun (Orion, Hofstein, Tamir, & Giddings, 1997). Although there was no overall significant difference between the groups, open inquiry students referred to ''surprise and disappointment,'' a category of the ''affective points of view'' criterion, more often than others (see Table 5 for examples). This category appeared among almost all of the students who conducted open inquiry, whereas only a few of the guided inquiry students referred to feeling surprised and disappointed throughout their project. Open inquiry students planned their project, and they were exposed to change and expressed anticipation (Yen & Huang, 2001; Zion & Slezak, 2005), whereas guided inquiry students were led by the teacher, thus they were less exposed to change, more passive than their open inquiry peers, and did not express feelings of anticipation. Without anticipation, there is often no disappointment and no surprise (Castelfranchi & Lorini, 2003).

Considering the hypothesis we raised in the Research Rational Section, we were surprised to find no significant difference in the criterion ''learning as a process'' when comparing the open and guided methods. Discovering no significant difference between the open and guided inquiry groups in the ''learning as a process'' criterion can be explained by the following reasons: Zion et al. (2004b) indicated in their research that students understand individual events in the course of an open inquiry process, without understanding the entire dynamic process. Furthermore, Zion et al. (2004b) have shown that students who performed open inquiry attributed great importance to planning the inquiry, investing time in it, while sparing little time or attention to documentation of (1) the procedures, (2) the data collection process, and (3) the actual inquiry progress. In addition, in our opinion, students in both research groups submitted poor and unfocused reflections at the end of the learning process. These results apparently have to do with the reflection performed only at the end, and not consistently or methodically throughout the process. We discovered that when students performed reflective activity several times throughout the inquiry process, the quality of this activity occasionally increases (Michalsky, Zion, & Mevarech, 2007). If the reflective activity was performed throughout the entire process, open inquiry students would have demonstrated better achievements than guided inquiry students in the criterion ''learning as a process.'' We base this assumption because open inquiry students are involved in the inquiry process in earlier stages, and aided by reflection, we believe that they would better internalize the process they are experience. Based on this analysis, we suggest that an improvement in the documentation of the inquiry process and the accompanying metacognitive thinking is necessary, in order to improve the performance of students who conduct an inquiry.

Recommended Future Research

Based on the findings and limitations of the current research, avenues for future research can be suggested. The research results were limited to a certain number of classes and students, and participants did not constitute a genuine cross-section sample of the entire Israeli high-school student population. Further research should be conducted with a larger sampling population. As we noted in the Discussion, both curricula studied here should be improved, requiring students to conduct reflective activity at different stages throughout the inquiry process. We can then re-examine differences between dynamic inquiry performances of the two research groups.

Teachers play a critical role in implementing inquiry-based learning (Bybee & Loucks-Horsley, 2001). Identifying the elements underlying the dynamic inquiry learning process and their benefits to students' learning processes could provide guidance and encouragement for teachers in implementing open inquiry learning and in helping their students experience it. Moreover, teachers' awareness of the elements of dynamic inquiry can also improve the teaching of guided inquiry.

The DIP index suggested in this article can be used to develop new evaluation methods of students' inquiry competencies based on dynamic inquiry performances. For instance, we can suggest that a quantification of a student's performance for asking an inquiry question should consider the logical connection of the question to the subject, to other questions in the project, and to the student's ability to improve the question, while setting up an experimental system and preliminary experiments.

Implementing elements of dynamic inquiry into inquiry teaching can be carried out in stages. Giving teachers the hands-on opportunity to experience an open inquiry project can serve as a first stage in their professional development. In this project the teachers will analyze the dynamic inquiry performances expressed in the work that they conducted. The teachers could also suggest how to improve dynamic inquiry performances both in open and guided inquiry processes. This experience by teachers, combined with results of the current research, can help teachers determine the type of inquiry they would like to teach according to different teaching environments.

Barak, Ben-Chaim, and Zoller (2007) wrote:

> "Our ever-changing and challenging world requires students, our future citizens, to go beyond the building of their knowledge capacity; they need to develop their higher-order thinking skills, such as critical system thinking, decision making, and problem solving" (p. 354).

In our opinion, emphasizing dynamic inquiry performances within the context of inquiry learning will contribute to the development of higher-order thinking skills. More research needs to be conducted in order to develop efficient learning strategies to achieve this goal.

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Appendix

The Criteria of Dynamic Inquiry (Based on Zion et al., 2004b)

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