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# Which Type of Inquiry Project Do High School Biology Students Prefer: Open or Guided?

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**Abstract** In teaching inquiry to high school students, educators differ on which method of teaching inquiry is more effective: Guided or open inquiry? This paper examines the influence of these two different inquiry learning approaches on the attitudes of Israeli high school biology students toward their inquiry project. The results showed significant differences between the two groups: Open inquiry students were more satisfied and felt they gained benefits from implementing the project to a greater extent than guided inquiry students. On the other hand, regarding documentation throughout the project, guided inquiry students believed that they conducted more documentation, as compared to their open inquiry peers. No significant differences were found regarding 'the investment of time', but significant differences were found in the time invested and difficulties which arose concerning the different stages of the inquiry process: Open inquiry students believed they spent more time in the first stages of the project, while guided inquiry students believed they spent more time in writing the final paper. In addition, other differences were found: Open inquiry students felt more involved in their project, and felt a greater sense of cooperation with others, in comparison to guided inquiry students. These findings may help teachers who hesitate to teach open inquiry to implement this method of inquiry; or at least provide their students with the opportunity to be more involved in inquiry projects, and ultimately provide their students with more autonomy, high-order thinking, and a deeper understanding in performing science.

**Keywords** Attitudes · Guided inquiry · Inquiry learning · Open inquiry

Related subject areas: Science Education, Inquiry

The results of this research are part of the Ph.D. thesis of the first author.

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## Introduction

### Guided Versus Open Inquiry Learning Approach

Inquiry represents the processes that scientists routinely employ in their research, and provides a method for students to learn science content and skills. Inquiry is one of many instructional strategies that teachers implement in science education. Above all, inquiry in the classroom is student-centered, providing students with opportunities to formulate and conduct their own scientific investigations (Singer et al. 2000). A major effort in science education reform has been the implementation of inquiry strategies into K-12 classrooms and laboratories (National Research Council (NRC) 2000; Rocard et al. 2007). Rop (2003) emphasized that,

> a good test for the modern curriculum is whether it enables students to see how knowledge grows out of thoughtful questions. … The real test is in the development of a spirit of thoughtful curiosity and the disciplined habits of inquiry to support it (p. 32).

According to the NRC (2000), and Martin-Hansen (2002), inquiry-based activities encompass a broad spectrum, ranging from teacher-directed structured to guided inquiry to student-directed open inquiry. In **structured inquiry,** students investigate a teacher-formulated question through a prescribed procedure. The students receive complete instructions at each stage, leading to a predetermined discovery. This sort of inquiry has been compared to working with a recipe toward a desired outcome. In the next level of complexity, **guided inquiry**, the students investigate teacher-formulated questions and procedures, and later determine the processes and the conclusions. In guided inquiry, teachers provide the questions. The teachers are most likely to have a good idea of what results to expect. However, the students actually lead the guided inquiry process, and often reach unforeseen, but self-formulated conclusions. A third type of inquiry, known as **coupled inquiry,** is an intermediate stage between guided and open inquiry. Here, the teacher allows the student to select an inquiry question from a databank of predetermined questions. But still, in coupled inquiry, the students are not involved in formulating the inquiry question.

In **open inquiry**, the most complex level of inquiry, the teacher defines the knowledge framework in which inquiry is conducted, but the students formulate 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 the key to such an inquiry is the teachers' ability to motivate their students to ask those questions that will guide them in their inquiry (Zion et al. 2007). The student's participation in formulating the inquiry question is the key component in open inquiry. Nevertheless, the teacher assists students in making decisions throughout the different stages.

In recent years, accumulated 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 (e.g. Berg et al. 2003; Kaberman and Dori 2009; Lord and Orkwiszewski 2006; Yen and Huang 2001). For example, university students identified guided inquiry experiences as more engaging and effective than structured experiences in promoting learning (Friel et al. 2005). Berg et al. (2003) compared students' outcomes of an open inquiry with an expository version (structured) of laboratory activity. Berg et al. (2003) found that open inquiry shows the most positive outcomes regarding learning outcome, preparation time, time spent in the laboratory, and students' perceptions of the experiment. Germann et al. (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 autonomous open inquiry. The highest level of inquiry is achieved when students have the greatest amount of autonomy, engaging in activities that come closest to performing real science. Furthermore, Germann et al. (1996) and Furtak (2006) claimed that guided inquiry can be used to help students make the transition from structured to open inquiry.

Many science educators agree that both guided and open inquiry can be effective in developing inquiry skills and critical thinking. However, the type of inquiry that is more relevant to the teaching and learning facilities available in high schools remains controversial among educators (Zion and Sadeh 2007; Yerrick 2000). Some teachers prefer using guided inquiry, whereas others prefer using open inquiry (Zion et al. 2007).

Those educators who prefer open inquiry claim that this method achieves a higher level of inquiry, in which the students become more familiar with the nature of scientific knowledge and develop greater inquiry skills (Berg et al. 2003; Yen and Huang 2001). Krystyniak and Heikkinen (2007) found that students employed inquiry 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 who demonstrate both greater and lesser cognitive abilities (e.g., Germann et al. 1996; Yerrick 2000).

In contrast, researchers agreed that guided inquiry-based teaching helps students learn science content, master scientific skills, and understand the nature of scientific knowledge (e.g., Tabak et al. 1995; Quintana et al. 2005). The guided inquiry proponents view student instruction as a desired goal; more specifically, guided inquiry prevents a 'waste of time, 'reduces students' frustration due to achieving undesirable results or experiencing failure, and reduces students' fear of the unknown (Trautmann et al. 2004)—all of which may occur in open inquiry (Gallagher and Tobin 1987; Yen and Huang 2001; Zion et al. 2007). Sandoval and Morrison (2003) claim that many students find difficulty in conducting open inquiry. In addition, Moscovici (2003) doubts the ability of high school students to participate in open inquiry and benefit from it. We assume that students who lack both knowledge of biology and mastery of inquiry skills will find open inquiry difficult (Zion and Sadeh 2007).

## Attitudes toward Inquiry Learning

Both psychological and educational research suggests that students' scientific inquiry skills are not static; they depend on a variety of both cognitive and affective factors. These factors include interest and motivation in science, epistemological understanding of the scientific process and its value (Smith et al. 2000), familiarity with the domain of investigation and the context of the activity (Germann et al. 1996; Kuhn et al. 1995), environmental support of inquiry activities (Greeno 2001) and communication abilities (Germann et al. 1996). Researchers have claimed that in inquiry activities, students demonstrate autonomy in making choices, self-regulation, and opportunities in working on projects that interest them, features which may enhance students' motivation (Eilam 2002; Lepper et al. 1993; Polman 2000). Other research has shown that students' attitudes are motivated by their confidence in being able to attain achievements in science, the relevance of content students learn and, the pleasure of performing science and lab work (Lee and Burkam 1996; Shrigley et al. 1988; Simpson et al. 1994).

Research also demonstrates great enthusiasm among students regarding the integration of lab assignments with an inquiry approach (Garnett et al. 1995; Hofstein et al. 2001). According to Hsiao-Lin et al. (2005), student attitudes about their inquiry learning experience may indicate whether the student is ready for the challenge of inquiry learning in general, and in particular, if they are able to venture beyond guided inquiry and attempt the more demanding challenge of open inquiry. Based on the fact that attitude is defined as "a predisposition to respond positively or negatively to things, people, places, events, or ideas" (Simpson et al. 1994, p. 212), Simpson et al. (1994) wrote: "The key to success in education often depends on how a student feels toward home, self, and school" (p. 211). These ideas led us to ask the following questions: Can open inquiry satisfy the students' curiosity? Or is its uncertainty too much for students to cope with? Can students' attitudes about the type of inquiry they experience help determine which type of inquiry is more relevant to high school students?

The current research attempts to compare the attitudes of high school biology students performing open inquiry with students performing guided inquiry. The comparison is based on the following research questions:

1. What are students' attitudes about their inquiry project, according to the following parameters: 'the benefit of the project for the student', 'the investment of time', and 'the task of documentation'?
2. What are students' attitudes about the effort they invested in each stage of the inquiry process, and what factors led to changes in the process?

We assumed that students, who experienced open inquiry and were probably more involved in the learning process, would develop more positive attitudes toward their inquiry project, in comparison to students who experienced guided inquiry. We also assumed open inquiry students would be more autonomous, and more likely to cooperate with peers.

## Method

### The High School Biology Inquiry Project

In Israel, high school biology students who take the final examination must study some theoretical subjects (60%), perform lab assignments (20%), and conduct a practical inquiry project (20%). The Israeli Biology Syllabus for high school students, who major in biology, offers two different teaching approaches for the project which the teacher chooses: either guided or open inquiry (Israeli Ministry of Education 2006). The projects begin by identifying phenomena in the field and continue either on site, or in the lab. Students are required to document each step in both types of inquiry projects, working in teams of up to three students. In the Israeli high school open inquiry project, the student is expected to function autonomously from the stage of finding the phenomenon to raising inquiry questions, whereas the teacher functions as a facilitator, directing and focusing the learning throughout the entire process. In contrast, in the Israeli high school guided inquiry project, students are guided by teachers or by external facilitators, such as private instructors and field school guides. These guides or teachers present the students with the phenomenon they will research, and then dictate the inquiry questions and explain how to gather information. The students begin to work autonomously only after the information gathering stage. Despite the difference in roles of teacher and student, there is a strong resemblance between the open and guided inquiry projects: all stages of the inquiry process are handled by both student and teacher, with different degrees of involvement. Research topics can be identical, and deliverables, that is, the written assignments, can also be similar. When both groups of students have completed writing their assignments, the students undergo oral examinations.

Despite these similarities, the following example illustrates the differences between open and guided inquiry in a project involving the connection between air and soil temperature and the behavior of ants. In an open inquiry project, students observed the ants, and observed differences between the ants' behavior in the morning and during the afternoon. Based on the students' observations, they chose this topic and formulated the inquiry question. In guided inquiry, the teacher showed the students the ants, and provided the inquiry method and question. In another project, students examined the allelopathic effect of *Dittrichia viscose* bushes on other plants nearby. The method of inquiry is quite similar in both guided and open inquiry. The key differences between these types of inquiry depend on who observed the phenomena and who designed the inquiry question, the student or the teacher.

Thus, the most significant point of divergence between guided and open inquiry occurs at the critical stage of asking questions. At this stage, inquiry students must take responsibility for project management, and they must make their own decisions. Particularly, open inquiry students significantly assume more responsibility, and practice decision making skills at the asking questions and inquiry planning stages than guided inquiry students. Nevertheless, both open and guided students are assumed to function similarly from the work performing stage.

## Participants

In this study, 295 high school biology students from 12 high schools performed inquiry projects: 162 students performed open inquiry and, 133 students performed guided inquiry. The students had similar socio-cultural backgrounds and academic achievements. All students studied biology as a major for 2 years (11th and 12th grades). These biology majors fully completed their inquiry project and took the matriculation tests in biology. In order to verify the initial similarity between research groups, we decided to compare students using a test that examines their knowledge of inquiry skills. The test included analysis of an unfamiliar research description. The students were required to identify research variables in the description (such as control; maintain control of variables; and repetition) and describe their importance, and identify the research questions, results, and conclusions. The average achievement pretest grades among the guided and open students at the beginning of 11th grade were 74.77±9.75 and 76.22±8.33, respectively.

The research groups were based on the teaching model the teacher implemented in class. In order to recruit a large number of students appropriate for each research group, we contacted 80 teachers. Of this number, 60 teachers participated in the open inquiry based professional development program, known as Biomind (Zion et al. 2004). The remaining 20 teachers frequently participated in the guided inquiry based professional development program known as Biotop (Israeli Ministry of Education 2006).

Criteria for teacher participation in the research were experience in teaching 11th grade students, teaching for at least 5 years, including preparation for matriculation exams, and teaching a class of more than 15 students. Furthermore, all the participating teachers were well informed professionally, tended to introduce innovations in class, created original worksheets for their students, and implemented a variety of teaching methods in class. Each teacher was interviewed to discuss their teaching method, the number of professional development programs they attend, the degree of their intervention in the students' inquiry projects, and a description of the class composition. The teachers received a description of their responsibilities in the classroom: teaching the class for 2 years, incorporating questionnaires into the ongoing learning process, and interviewing students. Teachers who taught open inquiry had previously taught guided inquiry up to three or 5 years before the onset of this study and they were very familiar with the guided inquiry method.

Of the potential teacher participants, 18 teachers who were willing to participate in the research were found appropriate. The interviews were designed to help ensure that teachers adhered to the inquiry teaching method they implemented in the first year. Two semi-structured interviews with these 18 teachers were conducted at the beginning of the research, in 11th grade, and again, at the beginning of the second year, in 12th grade. The researchers asked the teachers: who formulates the project's inquiry questions (student, teacher… if cooperatively—to what degree is each participant involved?) Who chooses the subject matter? How involved is the teacher in the stage of defining goals? How involved are they at the stage of experiment preparation and in the stage of execution? In addition, to the interview conducted at the initial stage of the research, before the students began inquiry work, another interview was conducted at the project's mid-point, to make sure teachers hadn't altered their approach. Furthermore, observations were carried out during lab and inquiry classes, where we also monitored teacher instruction.

Finally, the research considered results collected from 13 teachers who maintained comprehensive inquiry methods throughout the research: eight teachers who taught open inquiry and five teachers who taught guided inquiry. Five teachers and their classes were dropped from the research after they transitioned into structured inquiry as a result of technical problems with the inquiry process and lack of time. Teachers of open and guided inquiry had an average 19.6±5.3 and 17.8±3.4 years of experience, respectively. Among open inquiry teachers—two held a PhD, two held MSc, and four held BSc degrees. Of the guided inquiry teachers—one held a PhD, one held MSc, and three held BSc degrees.

## Data Collection

Data collection was based on an attitudes-to-the-inquiry-project questionnaire which was administered to the students upon completion of 12th grade—the completion of the project. Questions in this questionnaire referred to common concepts in inquiry teaching that were familiar to the students of both research groups. The questionnaire (Appendix) included three sections: statements, multiple choice, and open ended questions. The sections are detailed below:

- Structured Questionnaire (SQ): This section included 11 statements referring to different aspects of the inquiry project: 'the benefit of performing inquiry for the student', 'the investment of time', and 'the task of documentation'. The students were asked to note their agreement concerning these statements on a Likert Scale (Taylor et al. 1995) of five degrees, from 'strongly disagree' to 'strongly agree'.
- Semi-Structured Questionnaire (SMSQ): This section (questions 12–14) contained multiple choice questions, requiring the student to select the appropriate answers. Although students were asked to circle only one response for each question, they sometimes chose more than one response, and this finding was taken into account when analyzing the responses. The first question (#12) concerned the students' investment of time in each stage of the project. The second question (#13) concerned the students' attitudes about the most difficult stage of the inquiry process, and the factors that led to changes in the inquiry process. These questions had four possible answers: 1. preparing the project (choosing a subject/formulating inquiry questions/planning the work); 2. performing the work; 3. processing the data; and 4. writing the discussion.

The third question (#14) concerned factors leading to changes in the inquiry process, and contained six possible responses, attributing the change to: me/my peers/the teacher/the lab assistant/the habitat/other.

- Open Questionnaire (OQ): This section (Question 15) enabled the students to freely express themselves in writing, replying to the following three topics: How did you benefit from the inquiry project? How would you improve the inquiry process if you could repeat the project? Write your own opinions about the inquiry project.

## Data Analysis

To investigate whether attitudes differ as a function of the type of inquiry, we conducted MANOVA and Chi Square ($Chi^{2}$) tests, and we compared the two research groups. To investigate whether SQ components can be divided into groups, we conducted a Principal Component Analysis on items 1–11. The analysis revealed three factors which accounted for 59.61% of the difference. The first factor **'the benefit of the project for the student'** contained six components (item numbers: 1–3, 9–11). The second factor **'the investment of time'** contained three components (item numbers: 6–8), and all showed a high degree of communality. Common to these components was the students' assessment of the investment of time in the inquiry project. The third factor **'the task of documentation'** contained two components (item numbers: 4–5), and both showed a high degree of communality. Common to these components was the implementation of documentation during the inquiry project—carrying it out and realizing its importance.

We used a Cronbach $\alpha$ analysis to verify the internal consistency of the factors. The first factor, benefit of inquiry for the student, showed good consistency: $\alpha = 0.81$, and so did the third factor, documentation, with an $\alpha = 0.80$. A reasonable consistency of $\alpha = 0.71$ was found in the second factor, 'the investment of time'. $Chi^2$ tests were conducted to check for significant differences between the two groups of students and student responses for each SMSQ question were coded.

The open question section enabled students to write freely, and responses were categorized by content analysis. The categories were similar to those used by Zion (2008), and they were based on aspects and subjects referenced by students and teachers in on-line discussion groups of biology inquiry projects. These groups were hosted on the national website for biology teachers. Regarding the benefit of the inquiry process to learning, the responses were categorized as:

- *Cognitive aspects:* data processing; conclusion and writing; understanding the essence of inquiry, including the ability to construct an inquiry question; experimentation—planning and systematizing; understanding a biological phenomenon; familiarity with methods; knowledge about the inquiry work; coping with unexpected results, and coping with the analysis of an unfamiliar research description, and conducting lab assignments independent of the inquiry project.
- *Affective aspects:* motivation and persistence in research; team work; feeling autonomous; satisfaction/enjoyment/interest/creativity. Every word in students' answers was categorized as either a cognitive or affective aspect, and counted appropriately.

To increase the credibility of the research, two experienced teachers who were familiar with the curriculum separately classified student responses. These two teachers agreed in 90% of the cases. In cases of disagreement, they discussed the case until an agreement was reached about grading the students. In the isolated remaining cases where there was no agreement, a third teacher, was asked for her opinion. The researchers later quantified the frequency of responses in each category.

## Results

### What Are Students' Attitudes toward Their Inquiry Projects?

Based on the SQ questionnaire, students were asked to relate to different statements about 'the benefit of the project for the student', 'the investment of time', 'the task of documentation'. Table 1 presents means and SD of students' attitudes regarding the SQ questionnaire, after they finished their projects, according to both open and guided inquiry. A unidirectional MANOVA analysis of students' attitudes regarding the project showed significant differences between the two groups: $Eta^2 = 0.24$, $F(4,290) = 22.67$, $p<0.001$. Table 1 presents means and SD, and the results for difference analyses performed for each statement separately. Students in both groups expressed positive attitudes (above the average of scale) toward their inquiry project. Significant differences were found in their attitudes towards the benefits which resulted from the project and towards documentation.

The means shown in Table 1 indicate that open inquiry students were more satisfied and believed that they gained benefits from implementing the project, to a greater extent than guided inquiry students. On the other hand, regarding documentation throughout the project, guided inquiry students believed that they conducted more documentation, as compared to open inquiry students. No significant differences were found regarding 'the investment of time'.

Students were asked to indicate the stage in which they invested the most time. Table 2 details the number of students who mentioned each inquiry stage, in each research group. Some students marked more than one answer. $Chi^2$ analyses were applied to examine differences between the groups. On the issue of the investment of time, significant differences were found in all stages, except data processing. Open inquiry students spent more time on preparation and practice, while guided inquiry students spent more time on writing the discussion. Research groups differed significantly in defining the most difficult stage of the inquiry process. Open inquiry students believed that the performance and discussion stages were the most difficult parts of the project. Guided inquiry students found data processing and writing the discussion the most difficult stages of the inquiry process.

Table 3 presents the distribution of answers given by students who were asked to identify factors leading to change in the inquiry process: me/my peers/the teacher/the lab assistant/the habitat/other. Thirteen students—all from the guided inquiry group—said no changes were necessary in their projects. Thirteen others—all from the open inquiry group—replied that the lab assistant assisted in introducing the change. A $Chi^2$ analysis for examining the differences between research groups shows significant differences in the question of initiative for change over the course of the project. No significant differences were found in relation to the teacher as initiator of changes. Open inquiry students attributed most of the initiative to their project teams: themselves, a peer, or the lab assistant, as compared to guided inquiry students. The guided

**Table 1** Means and SD of open/guided inquiry students' attitudes towards their inquiry project (Based on the SQ)

| Student attitude | Inquiry type | | | | | |
|---|---|---|---|---|---|---|
| | Open | | Guided | | | |
| | M | SD | M | SD | F(1,293) | $Eta^2$ |
| Benefit | 3.54 | 0.06 | 2.98 | 0.07 | 36.48*** | 0.11 |
| Investment of time | 4.19 | 0.06 | 4.13 | 0.06 | 0.66 | 0.00 |
| Documentation | 3.84 | 0.07 | 4.31 | 0.08 | 19.08*** | 0.06 |

***$p<.001$

Scores ranged from 1 (nothing) to 5 (a lot)

**Table 2** Chi tests of open/guided inquiry students' attitudes regarding the investment of time, and difficulties experienced during the different stages of the inquiry process (Based on the SMSQ)

| Inquiry project stage | Inquiry type | | | | | |
|---|---|---|---|---|---|---|
| | Open | | Guided | | | |
| | N | % | N | % | Chi | |
| "The longest stage was…" | | | | | | |
| Preparation | 22 | 13.6 | 5 | 3.8 | 8.47 | ** |
| Actual performance | 83 | 51.6 | 15 | 11.3 | 53.16 | *** |
| Data processing | 41 | 25.5 | 37 | 27.8 | 0.21 | |
| Discussion | 45 | 28 | 86 | 64.7 | 39.73 | *** |
| "T "The most difficult stage.." | | | | | | |
| Preparation | 26 | 16 | 9 | 6.8 | 6.02 | ** |
| Actual performance | 35 | 21.9 | 5 | 3.8 | 20.02 | *** |
| Data processing | 32 | 20 | 45 | 34.1 | 7.4 | ** |
| Discussion | 71 | 44.4 | 77 | 58.3 | 5.64 | * |

*$p<0.05$ **$p<0.01$ ***$p<0.001$

N = Number of students% = Percentage of students who chose each answer

inquiry students attributed change primarily to external factors (habitat, result) or mentioned no change occurred. Among open inquiry students, 61 mentioned two or more factors initiating change (37.65% of the group), compared to 16 guided inquiry students (12% of the group).

### *Aspects of the Inquiry Process Beneficial to the Students*

Of the 295 students who participated in the research, 263 mentioned that aspects of the inquiry process were beneficial to them. Of this figure, 153 were open inquiry students (94% of the group) and 110 were guided inquiry students (83% of the group). Student

**Table 3** Factors leading to changes in the inquiry process. Frequency of student responses and Chi$^2$ analysis between groups

| Reason for change during inquiry | Teaching method | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Open | | Guided | | | |
| | N | % | N | % | Chi$^2$ | |
| Me | 96 | 61.5 | 21 | 17.6 | 53.20 | *** |
| Peer | 79 | 50.6 | 21 | 17.6 | 31.76 | *** |
| Teacher | 52 | 33.3 | 48 | 40.3 | 1.43 | |
| Lab assistant | 13 | 8.3 | 0 | 0.0 | 10.41 | *** |
| Habitat/result | 0 | 0.0 | 46 | 38.7 | 72.00 | *** |
| No change needed | 0 | 0.0 | 13 | 10.9 | 17.78 | *** |

*$p<0.05$ **$p<0.01$ ***$p<0.001$

responses regarding 'the benefit of the project for the student's learning' were categorized as either cognitive or affective.

*Cognitive benefits* referred to: formulating inquiry questions, processing data, reaching conclusions, planning and conducting an experiment, demonstrating familiarity with methods, understanding a biological phenomenon, understanding the essence of inquiry, coping with unexpected results, and conducting structured inquiry lab assignments unrelated to the main inquiry project, and understanding published research reports. Here are a few exemplary quotes by students referring to cognitive aspects (with analysis categories in parenthesis): "The inquiry project helped me understand how to plan and conduct an experiment (planning and conducting an experiment), and how to make sure results are reliable (understanding the essence of inquiry)" (student's No. 92). "The project opened my eyes to the world of the scientist (understanding the essence of inquiry), and personally helped me to write a research paper (understanding published research reports) and draw conclusions (reaching conclusions). I would plan ahead better and increase the number of repetitions in the field (planning and conducting an experiment)" (student's No. 100).

A*ffective benefits* referred to aspects of motivation, wanting to conduct research, curiosity, team work, satisfaction, pleasure, interest, creativity, feelings of independence and even 'activities that you usually don't learn in school', such as an outdoor picnic. Six students (one from the open inquiry and five from the guided inquiry group) referred to negative aspects, such as 'headache' and 'overload'. Due to the few negative comments, the results analysis disregarded these comments. Below, we quote a couple of examples for the method of analysis: Student No. 105 wrote: "I enjoyed the challenge of solving the problem—this was more interesting than expected" (an expression of pleasure and interest). Student No. 44 wrote: "This is the first time I was given the opportunity to conduct biology research. It deepened my knowledge of biology and I enjoyed the team work" (an expression of pleasure and satisfaction). In order to check for differences between students who participated in both open and guided inquiry groups in s*tudents' perception of'the benefit of the project for the student learning'*. $Chi^2$ analyses showed a significant difference regarding cognitive benefits ($Chi^2 = 27.53$, $p<0.001$), but not affective benefits ($Chi^2 = 0.49$, $p>0.05$). The average number of responses provided by open inquiry students was M = 1.58, SD = 0.87, and the average provided by guided inquiry students was M = 1.07, SD = 0.73. A *t*-test showed a significant difference of $t = 4.88$, $p<0.001$. Open inquiry students noted more positive references about 'the benefits of the project for the learning' as compared to the number of references noted by guided inquiry students. Figure 1 displays participants' responses regarding cognitive benefits, by inquiry method. In addition, Fig. 1 shows that in both groups, the majority of students found the inquiry cognitively beneficial. However, while 90.2% of open inquiry students found their participation in an inquiry project was significantly beneficial, only 65.2% of guided inquiry students shared this opinion.

Table 4 (cognitive benefits) and Table 5 (affective benefits) detail the different beneficial aspects mentioned by students, the number of students per category, and their percentage of the entire research group. These tables also incorporate $Chi^2$ test results comparing the groups. A $Chi^2$ analysis of the differences between the groups shows that these differences refer to understanding the essence of inquiry, planning and conducting an experiment, and demonstrating familiarity with methods. The percentages displayed in the table show that open inquiry students mentioned a greater benefit in these fields than their guided inquiry peers. A $Chi^2$ analysis to examine differences between the groups did not reveal any significant difference in affective aspects of the benefits of conducting an inquiry project.

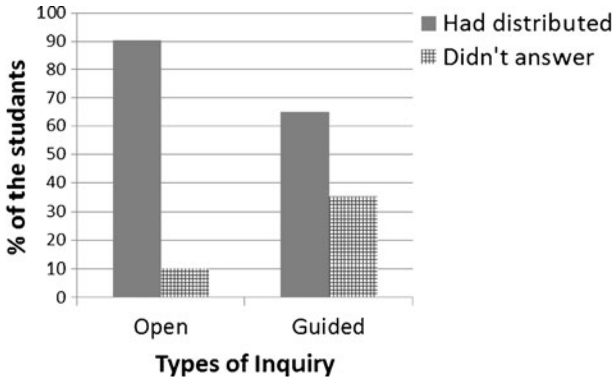


**Fig. 1** Distribution of participants by cognitive benefit, according to the method of inquiry implemented. 'Didn't answer' means that the students didn't mention a benefit

## Conclusions

Following the analyses of student responses to the questionnaire of attitudes toward their inquiry project, we found that open inquiry students believed they had benefitted from having conducted an inquiry project. This finding was expressed in the first section of the questionnaire, where students rated their agreement to given statements (Table 1); and in the third section (Tables 4 and 5), where they wrote freely about what they gained from the inquiry. The difference in benefits was seen in cognitive contexts, whereas in the affective context the benefits appeared similar.

Regarding the time spent—significant differences were found in all stages, except for data processing. By comparison, guided inquiry students invested most of their time graphically processing the data and writing the inquiry report discussion. Guided inquiry students believed that a great deal of attention was given to documentation both in the importance assigned to documentation and in the actual effort required to implement the task. During the project, open inquiry students invested more time in practical work and in the preparatory stages (choosing a subject, formulating questions, and planning the project).

**Table 4** Different aspects of cognitive benefits for open and guided inquiry students, and $Chi^2$ analysis between research groups

| Cognitive contribution | Teaching method | | | | | |
|---|---|---|---|---|---|---|
| | Open inquiry | | Guided inquiry | | | |
| | N | % | N | % | $Chi^2$ | |
| Essence of inquiry including formulating of the inquiry question | 69 | 42.59 | 13 | 9.77 | 38.34 | *** |
| Knowledge relevant to inquiry work | 60 | 37.04 | 46 | 34.59 | 0.12 | |
| Processing data, conclusion, and writing | 33 | 20.37 | 22 | 16.54 | 1.18 | |
| Understanding a biological phenomenon | 20 | 12.34 | 15 | 11.28 | 0.06 | |
| Planning and conducting an experiment | 19 | 11.73 | 4 | 3.01 | 7.55 | ** |
| Demonstrating familiarity with methods | 10 | 6.17 | 1 | 0.75 | 5.88 | * |
| Conducting structured inquiry lab assignments, and analysis of an unfamiliar research description. | 7 | 4.32 | 7 | 5.26 | 0.16 | |
| Coping with unexpected results | 4 | 2.47 | 0 | 0.00 | 3.28 | |

*$p<0.05$ **$p<0.01$ ***$p<0.001$

**Table 5** Different aspects of affective benefits for open and guided inquiry students, and $Chi^2$ analysis between research groups

| Aspects of affective benefits | Teaching method | | | | |
|---|---|---|---|---|---|
| | Open inquiry | | Guided inquiry | | |
| | N | % | N | % | $Chi^2$ |
| Satisfaction/pleasure/interest/creativity | 15 | 1.44 | 18 | 13.53 | 9.26 |
| Cooperation and teamwork | 9 | 0.04 | 8 | 6.02 | 5.56 |
| Motivation for learning | 7 | 1.90 | 2 | 1.50 | 4.32 |
| Feeling autonomous | 2 | 0.16 | 1 | 0.75 | 1.23 |

Significant differences between research groups were found in defining the most difficult stage of the inquiry project. Students working in an open inquiry environment felt that the practice and discussion writing were the most difficult stages of the project. In contrast, students working in a guided inquiry environment found graphic data processing and discussion writing to be the most difficult stages. Student responses about coping with change in the course of the project indicate that open inquiry students take more initiative, and to a greater extent cooperate with their project partners (students, teacher, lab assistant) than guided inquiry students. The guided inquiry students attributed most changes over the course of inquiry to an abstract reality such as 'the habitat' and not for themselves.

## Discussion

Ornstein (2006) discusses the importance of students' attitudes about inquiry learning in relation to preparing a student to become an active participant in society.

> How well students perform in academic science courses, over the long run, is not as important as their understanding of broad science concepts and their attitudes toward science. As adults, these factors will influence their reaction to issues that affect them and society as well as whether they support or oppose proposed political decisions. It is therefore imperative that educational systems recognize the important role played by student attitudes and seek actions that will achieve a positive view (p. 285).

The current research attempts to examine the difference between students' attitudes to inquiry learning in the two higher levels of inquiry: Guided and open. In the current research, students of both groups believed that they invested a lot of time in the project.

Significant differences between the research groups were found in student reports about documentation over the course of inquiry, and the benefits gained from the project. Guided inquiry students believed that they were more heavily involved in documentation, even though open inquiry guidelines also require documentation. Perhaps open inquiry students did not perceive documentation as the bulk of the work, but rather the planning and execution of experiments. Guided inquiry students found documentation the prominent activity as they were minimally involved in the initial planning stages and during the decision making process in selecting project methods.

The students' attitudes toward time invested in different stages of the project were significantly different between the research groups. Open inquiry students mentioned that they exerted more effort in the initial stages of subject choice, inquiry question formulation, project planning, and work performance. Unlike open inquiry students, guided inquiry students mentioned that they invested more time on writing the discussion. These findings correlate to characteristics of both inquiry levels, and are seemingly trivial and unsurprising. However, it is interesting to compare student attitudes about the time they spent on each stage of inquiry, and the difficulties they experienced throughout their projects. On one hand, the results of this comparison correlate with findings regarding the difficulties experienced by students in each stage. Guided inquiry students mentioned writing the discussion and data processing as the most difficult tasks. We can explain these results by considering the guided inquiry teacher's leading role in the initial project stages and execution. Guided inquiry teachers enable students to take the lead in the project only later, during the data processing and discussion writing stages. On the other hand, open inquiry students were more autonomous from the onset of the project, having experienced the processes of choosing a subject, formulating questions, and making decisions about how to investigate the questions. When open inquiry students reached the stages of data processing, they had already invested more time and accumulated more experience in being autonomous learners, than guided inquiry students. Surprisingly, although more than half the guided inquiry students reported difficulty with the discussion stage, the open inquiry students also found writing the discussion to be the most difficult task. Over two fifths of open inquiry students mentioned this stage in comparison to one fifth who mentioned other earlier stages in the inquiry process. This finding concurs with existing knowledge that writing demands advanced thinking skills, a difficult task for students (Ogens 1991; Zohar 2004).

In addition to 'time invested' in different stages and'documentation', a significant difference was found in the benefits gained by students conducting the project. Open inquiry students mentioned a greater benefit gained from the inquiry they performed as compared to guided inquiry students. These findings match other research that has measured open inquiry's benefits for students (Berg et al. 2003; Chin and Chia 2006; Germann et al. 1996; Ornstein 2006; Ritchie and Rigano 1996; Yen and Huang 2001). Students who were more active in the inquiry project felt they gained more from having performed inquiry (Taraban et al. 2007). When students chose subjects they liked, and collected and analyzed their own data, they expressed more motivation and interest (Germann et al. 1996).

Notice the consistency between the first section (statements) and the third section (open reference) in regards to cognitive contribution. Open inquiry students rated statements regarding cognitive contribution higher than guided inquiry students. Open inquiry students also rated verbal contribution significantly higher: understanding the essence of inquiry, being able to plan and conduct an experiment, and familiarity with research methods. Only open inquiry students referred to the contribution of the inquiry process in regards to coping with unexpected results. This is not surprising: guided inquiry students experienced a safer inquiry process where results could often be foretold by the teacher. A guided inquiry teacher directs his students toward safer questions and territory familiar to him. Open inquiry students and teachers face unexpected results that are not always easy to explain. Perhaps, this is the reason why open inquiry students found discussion writing difficult, to some degree. However, open inquiry students positively referred to unexpected results as a contribution. As dynamic and unexpected results are important aspects in the essence of science (Khishfe and Abd-El-Khalick 2002), these findings should be seriously considered when discussing the type of inquiry appropriate for high school students.

Quantifying the open question "how did you benefit from the project?" we noticed that between groups, answers varied in degree concerning cognitive aspects but not regarding affective aspects. Students found inquiry projects and out-of-classroom activities fun, clearly preferring them over other activities (Cerini et al. 2003). Cerini et al. (2003) have shown that the percentage of students who described inquiry activity as fun was greater than the percentage of students who described these activities as effective for learning. This finding may explain the similarity in affective aspects between these two research groups. In addition, research has shown that interest in science increases with outdoor activities and experimentation (Dimopoulos and Smyrnaiou 2005). This phenomenon was also seen in the current research—students expressed satisfaction with activities involving field excursions and with experimental activity—regardless of the subject of inquiry.

In the 1990s, researchers believed that curricula emphasizing inquiry did not achieve an increase in student scientific literacy. One possible reason for this finding is that the inquiry approach emphasized academic and cognitive aspects, neglecting affective and social aspects (Lazarowitz 2000). Venturing out of the classroom has the potential to enable social interaction and expression of affective aspects (Orion and Hofstein 1994). The current research found that guided inquiry students in general, and open inquiry students in particular, were both pleased with their inquiry projects.

The attitudes questionnaire demonstrated that open inquiry students cooperated more intensely than their guided inquiry peers. In open inquiry, the initiative for change over the course of the project derived from a collaboration of the peers involved, and could not be attributed to a single factor, as was commonly the case among guided inquiry teams. This finding concurs with previous findings that open inquiry contributes to understanding the importance of cooperation (Yen and Huang 2001). And yet this cooperation did not compromise students' feelings of authonomy. Open inquiry students reported greater autonomy and showed more initiative than guided inquiry students. Autonomy and initiative are indeed skills expected to be expressed in open inquiry (Chin and Chia 2006; Chinn and Malhotra 2001; Germann et al. 1996; Herron 1971; Zion and Sadeh 2007).

## Implications

In open inquiry, there's a greater chance of choosing an interesting subject, and a higher probability of encountering unexpected results. High school students cannot choose which method of inquiry to apply because high school students depend on the teacher's choice. Trautmann et al. (2004) found that in some cases teachers who were willing to implement open inquiry, found it impossible for the following reasons. The most commonly perceived barriers include district or state mandated curricula, insufficient time to perform the inquiry project, lack of students' inquiry skills, concern about the potential for not accomplishing specified learning goals, and fear of the unknown. Trautmann et al. (2004) reported that through partnerships with university colleagues, teachers are able to address these concerns and become increasingly comfortable with inquiry-based teaching and learning. Benefits reported by teachers and students include: increased motivation and interest in science, a greater degree of higher order thinking leading to deeper understanding, and development of abilities to work autonomously in designing and conducting valid scientific experiments and interpreting the results.

Students enjoy leaving the classroom and performing inquiry outdoors (Dimopoulos and Smyrnaiou 2005). As we have shown here, the inquiry type was less important for affective aspects, but had a clear influence on the students' feelings about cognitive aspects of the inquiry process. According to this research, open inquiry students seemed to become more autonomous, cooperative and believed that they gained more cognitive skills than guided inquiry students. The Sadeh and Zion (2009) found that the procedural understanding of the students who experienced open inquiry was higher than their guided inquiry. Teachers who teach guided inquiry should pay attention to these findings. Perhaps they need to give their students more autonomy in order to make their students more satisfied. Towndrow and Ling (2008) found that the number and quality of students' questions increased over time. Accordingly, we suggest that teachers encourage their students to write a reflective journal before beginning their inquiry project. Perhaps this journal will help the students to formulate their inquiry question, and perhaps the journal will help the guided inquiry teacher to provide their students with more autonomy in formulating their inquiry question.

We also propose to examine students' attitudes toward inquiry before beginning the project. Berg et al. (2003) found that students who approached lab activity with less positive attitudes about experimentation at the beginning of the learning process, required more teacher assistance than students who expressed more positive attitudes. The current research focused on the attitudes of students conducting inquiry projects; we suggest drawing a comparison between these findings and students' attitudes towards performing structured inquiry lab work. A correlation between findings would emphasize the importance of considering student attitudes, and in so doing, could improve students' motivation, achievements (Koballa and Glynn 2007), and inquiry skills.

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## Appendix

Attitudes questionnaire examining student's view of the inquiry project

Name/ID __________________

Read the following and indicate your level of agreement for each statement.

| | | Strongly disagree | | | | Strongly agree |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | The inquiry work helped me in my assignments. | | | | | |
| 2 | I felt I was doing a scientist's work. | | | | | |
| 3 | I was busy thinking during the inquiry project and not just doing technical work. | | | | | |
| 4 | I noted every detail in my logbook. | | | | | |
| 5 | My logbook references were of great help for the inquiry process. | | | | | |
| 6 | I invested a lot of time on the practical work. | | | | | |
| 7 | I invested a lot of time organizing data/results in tables and graphs. | | | | | |
| 8 | I invested a lot of time writing the discussion. | | | | | |
| 9 | I enjoyed conducting the inquiry project. | | | | | |
| 10 | I found the project interesting and challenging. | | | | | |
| 11 | My inquiry work helped me cope with unfamiliar research description. | | | | | |

Circle the most appropriate answer:

12. Looking back, I think I spent the most of my time:
    **Preparing** (choosing a subject/constructing research questions/planning the work)/ **performing the work/processing the data/writing the discussion**.
13. The most difficult stage was:
    **Preparing** (choosing a subject/constructing research questions/planning the work)/ **performing the work/processing the data/writing the discussion**.
14. When we needed to make changes in our project, this change was usually initiated by:
    **me/my peer/the teacher/the lab assistant/other** ______________.
15. Notes and remarks.

    A. How did you benefit from the inquiry project?
    B. What would you improve in the inquiry process if you could repeat the project?
    C. Write your own opinions about the inquiry project.

Thank you for your cooperation.

## References

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

Cerini, B., Murray, R., Reiss, M. (2003). *Student review of the science curriculum.* London: Planet Science, The Institute of Education, University of London and The Science Museum

Chin, C., & Chia, L. (2006). Problem-based learning: Using ill-structured problems in biology project work. *Science Education, 90*, 44–67.

Chinn, C. A., & Malhotra, B. A. (2001). Epistemologically authentic scientific reasoning. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from every day, classroom, to professional settings* (pp. 351–392). Mahwah: Erlbaum.

Dimopoulos, K., & Smyrnaiou, Z. (2005). Factors related to students' interest in science learning. In D. Koliopoulos & A. Vavouraki (Eds.), *Science education at cross roads: Meeting the challenges of the 21st century* (pp. 135–142). Greece: Athens.

Eilam, B. (2002). Strata of comprehending ecology: Looking through the prism of feeding relations. *Science Education, 86*, 645–671.

Friel, R. F., Albaugh, C. E., & Marawi, I. (2005). Students prefer a guided-inquiry format for general chemistry laboratory. *Chemical Educator, 10*, 176–178.

Furtak, E. M. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education, 90*, 453–467.

Gallagher, J. J., & Tobin, K. G. (1987). Teacher management and student engagement in high school science. *Science Education, 71*, 535–555.

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Refocussing the chemistry lab: A case for laboratory-based investigations. *Australian Science Teachers Journal, 41*, 26–32.

Germann, P. J., Aram, A., & Burke, G. (1996). Identifying patterns and relationships among the responses of seventh-grade students to the science process skill of designing experiments. *Journal of Research in Science Teaching, 33*, 79–99.

Greeno, J. G. (2001). *Students with competence, authority, and accountability: Affording intellective identities in classrooms*. New York: College Board.

Herron, M. D. (1971). The nature of scientific enquiry. *School Review, 79*, 171–212.

Hofstein, A., Levy Nahum, T., & Shore, R. (2001). Assessment of the learning environment of inquiry-type laboratories in high school chemistry. *Learning Environments Research, 4*, 193–207.

Hsiao-Lin, T., Chi-Chin, C., Chi-Chung, T., & Su-Fey, C. (2005). Investigating the effectiveness of inquiry instruction on the motivation of different learning styles students. *International Journal of Science and Mathematics Education, 3*, 541–566.

Israeli Ministry of Education. (2006). *Teaching biology in the lab and the field.* Jerusalem (Hebrew)

Kaberman, Z., & Dori, Y. J. (2009). Question posing, inquiry, and modeling skills of high school chemistry students in the case-based computerized laboratory environment. *International Journal of Science and Mathematics Education, 7*, 597–625.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578.

Koballa, T. R., & Glynn, S. M. (2007). Attitudinal and motivational constructs in science learning. In S. K. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 75–102). Mahwah: Lawrence Erlbaum Associates Inc, US.

Krystyniak, R. A., & Heikkinen, W. (2007). Analysis of verbal interactions during an extended, open inquiry general chemistry laboratory investigation. *Journal of Research in Science Teaching, 44*, 1160–1186.

Kuhn, D., Garcia-Mila, M., Zohar, A., Andersen, C. (1995). Strategies of knowledge acquisition. *Monographs of the society for research in child development, 60* (4, Serial No. 245)

Lazarowitz, R. (2000). Research in science, content knowledge structure, and secondary school curricula. *Israel Journal of Plant Sciences, 48*, 229–238.

Lee, V. E., & Burkam, D. T. (1996). Gender differences in middle grade science achievement: Subject, domain, ability level, and course emphasis. *Science Education, 80*, 613–650.

Lepper, M. R., Woolverton, M., Mumme, D. L., & Gurtner, J.-L. (1993). Motivational techniques of expert human tutors: Lessons for the design of computer-based tutors. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 75–105). Hillsdale: Erlbaum.

Lord, T., & Orkwiszewski, T. (2006). Moving from didactic to inquiry-based instruction in a science laboratory. *The American Biology Teacher, 68*, 342–345.

Martin-Hansen, L. (2002). Defining inquiry. *The Science Teacher, 69*, 34–37.

Moscovici, H. (2003). Using the dictator, the expert, and the political activist prototypes with secondary science preservice teachers: Shifting practices towards inquiry science teaching and learning. Paper Prepared for the 2003 Annual Meeting of the National Association for Research in Science Teaching (NARST), Philadelphia, PA

National Research Council (NRC). (2000). *Inquiry and the national science education standards*. Washington: National Academy.

Ogens, E. M. (1991). A review of science education: Past failures, future hopes. *The American Biology Teacher, 53*, 199–203.

Orion, N., & Hofstein, A. (1994). Factors that influence learning during a scientific field trip in a natural environment. *Journal of Research in Science Teaching, 31*, 1097–1119.

Ornstein, A. (2006). The frequency of hands-on experimentation and student attitudes toward science: A statistically significant relation. *Journal of Science Education and Technology, 15*, 285–297.

Polman, J. L. (2000). *Designing project-based science*. New York: Teachers College.

Quintana, C., Zhang, M., & Krajcik, J. (2005). A framework for supporting metacognitive aspects of online inquiry through software-based scaffolding. *Educational Psychologist, 40*, 235–244.

Ritchie, S. M., & Rigano, D. L. (1996). Laboratory apprenticeship through a student research project. *Journal of Research in Science Teaching, 33*, 799–815.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., Hemmo, V. (2007). Science education now. A renewed pedagogy for the future of Europe—European Commission. Available online: http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

Rop, C. J. (2003). Spontaneous inquiry questions in high school chemistry classrooms: Perceptions of a group of motivated learners. *International Journal of Science Education, 25*, 13–33.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching, 46*(10), 1137–1160.

Sandoval, W. A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching, 40*, 369–392.

Shrigley, R. I., Koballa, T. R. J., & Simpson, R. D. (1988). Defining attitude for science educators. *Journal of Research in Science Teaching, 25*, 659–678.

Simpson, R. D., Koballa, T. R., Oliver, J. S., & Crawley, F. E. (1994). Research on the affective dimension of science learning. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 221–234). New York: National Science Teacher Association.

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

Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction, 18*, 349–422.

Tabak, I., Sandoval, W. A., Smith, B. K., Agganis, A., Baumgartner, E., & Reiser, B. J. (1995). Supporting collaborative guided inquiry in a learning environment for biology. In J. L. Schnase & E. L. Cunnius (Eds.), *Proceedings of the computer support for collaborative learning'95 conference* (pp. 362–366). Bloomington: Erlbaum.

Taraban, R., Box, C., Myers, R., Pollard, R., & Bowen, C. W. (2007). Effects of active—learning experiences on achievement, attitudes, and behaviors in high school biology. *Journal of Research in Science Teaching, 44*, 960–979.

Taylor, B., Curtice, J., Heath, A. (1995). Balancing scales: Experiments in question form and direction. *Working Paper Series, 37*. The Centre for Research into Elections and Social Trends (CREST). Retrieved April 7, 2010, from http://www.crest.ox.ac.uk/p37.htm

Towndrow, P. A., & Ling, T. A. (2008). Promoting inquiry through science reflective journal writing. *Eurasia Journal of Mathematics, Science & Technology Education, 4*, 279–283.

Trautmann, N., MaKinster, J., Avery, L. (2004). What makes inquiry so hard? (And why is it worth it?). Paper presented at the Annual Meeting of the NARST, Vancouver, Canada

Yen, C., & Huang, S. (2001). Authentic learning about tree frogs by preservice biology teachers in open-inquiry research settings. *Proceedings of the National Science Council, Republic of China, ROC(D), 11* (1), 1–10.

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

Zion, M. (2008). On-line forums as a 'rescue net' in an open inquiry process. *International Journal of Science & Math Education, 6*, 351–375.

Zion, M., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biological Education, 41*(4), 162–168.

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

Zion, M., Cohen, S., & Amir, R. (2007). The spectrum of dynamic inquiry teaching practices. *Research in Science Education, 37*(4), 423–447.

Zohar, A. (2004). *Higher order thinking in science classrooms: Students' learning and teachers' professional development*. Dordrecht: Kluwer.