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Dynamic Open Inquiry Performances of High-School Biology Students

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In examining open inquiry projects among high-school biology students, we found dynamic inquiry performances expressed in two criteria: 'changes occurring during inquiry' and 'procedural understanding'. Characterizing performances in a dynamic open inquiry project can shed light on both the procedural and epistemological scientific understanding of students. In addition, we found a connection between the number of students in a team and the number of performances, in both fields: The greater the number of participants in the inquiry project (up to three students per team), the greater the number of performances. Regarding the characterization of dynamic inquiry performed in an open inquiry project, and in addition to characterizing student performances, we found that there were advantages in doing inquiry projects as a team.

Keywords: Dynamic inquiry skills, Inquiry learning, Open inquiry, Performances.

INTRODUCTION

The Challenge of Open Inquiry Learning

Scientific breakthroughs often result from thinking along new lines, and an intellectual flexibilility on the part of the researchers making the discovery. As scientists, we often find the magic that surrounds a scientific discovery captivating. For example, contamination in Fleming's lab led to the profoundly important discovery of penicillin (Horvitz, 2002). The 1997 Nobel Prize in Medicine was awarded to Stanley B. Prusiner for his discovery of prions – a small infectious protein capable of causing fatal dementia-like diseases in humans and animals. Prusiner was able to think creatively outside the paradigm that infectious diseases were caused only by living organisms such as bacteria, viruses, fungi, and parasites (Prusiner, 1996).

In addition, the 2004 Nobel Laureates in Chemistry, Aaron Ciechanover, Avram Hershko, and Irwin Rose, contributed ground-breaking biochemical knowledge on cell regulation in the presence of a certain protein by marking unwanted proteins with a label consisting of the polypeptide ubiquitin. Their fascinating discovery is given that much attention and research was expended on understanding how the cell controls the synthesis of a certain protein; whereas the reverse process, the degradation of proteins, has long been considered less important (Ciechanover, 2003; Reinstein & Ciechanover, 2006). Kuhn would refer to these landmark discoveries as scientific revolutions (Kuhn, 1996). These discoveries were based on unexpected results that were not accepted initially in the scientific community. It took years of implementing proper experimental procedures to finally convince the scientific community of the importance of protein degradation control. These discoveries likely occurred because the researchers thought creatively, dynamically, and critically.

These examples demonstrate how scientific knowledge about the world is subject to the interpretations and reinterpretations of a body of evidence in a fluid environment of scientific ideas and theory. Schwab (1962) analysed the nature of science

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State of the literature

- Open inquiry was characterized as a dynamic process, whereby learning is a process of continuous and renewed thinking. The categories of dynamic open inquiry were grouped into four main criteria: changes occurring during inquiry; learning as a process; procedural understanding; and affective points of view.
- Quantifying the dynamic inquiry focused on the quantification of the criteria, without breaking the criteria down into components (categories).
- There is an advantage of cooperative learning in an inquiry learning environment.

Contribution of this paper to the literature

- In light of the advantage of cooperative learning in an inquiry learning environment, and the need to quantitatively examine dynamic inquiry performances, this study examined students' dynamic inquiry performances in individual, pair and team work.
- The study revealed the relative frequencies of the different dynamic inquiry categories that are expressed during open inquiry. (The current research focuses on 'changes occurring during inquiry' and 'procedural understanding').
- A positive correlation was found between the number of students in teams and the number of dynamic inquiry performances.

and compared 'stable inquiry', where scientific principles define problems, with 'fluid inquiry', where principles are treated as problems themselves. It was not Schwab's primary objective that students conduct scientific inquiries themselves, but rather that students understand the nature of scientific inquiry as a dynamic and ongoing activity, and that they would understand scientific concepts of evidence upon which the scientific inquiry was based.

Although inquiry-based activities encompass a broad spectrum, ranging from teacher-directed structured and guided inquiry to student-directed open inquiry (NRC, 2000), the open inquiry learning approach matches Schwab's philosophical-pedagogical ideas regarding the dynamic nature of science. While participating in an open inquiry learning process, students incorporate decision-making throughout each stage of the inquiry process. Open inquiry demands high-order thinking, and the key to such an inquiry is the teachers' ability to motivate their students to ask the questions that will guide them in their inquiry (Chin & Chia, 2004).

Based on a qualitative action research study, Zion et al. (2004b) characterized open inquiry as a dynamic inquiry learning process, whereby learning is a process of continuous and renewed thinking. This process involves flexibility, judgment, and contemplation, as part of the changes that occur in the course of inquiry. Moreover, in characterizing the dynamic inquiry process, Zion et al. (2004b) emphasized the perspectives of critical thinking and change, reflective thinking about the process, and affective aspects, such as curiosity, which are expressed in situations of change and uncertainty. Furthermore, Zion et al. (2004b) grouped the categories of dynamic inquiry into four main criteria: 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 result in changes, and understanding the need to solve technical problems); learning as a process (such as documentation, researching additional professional literature, and devoting time throughout the course of inquiry); procedural understanding (such as understanding the importance of controlling variables, applying a different method of measurement on dependent variables and working methods, control, repetitions, and statistics); and affective points of view (such as curiosity, frustration, surprise, perseverance, and coping with unexpected results). The action research led to revisions in the instructions for implementing the curriculum the research examined, in two of four criteria: 'changes occurring during inquiry' and 'procedural understanding'.

Quantifying Characteristics of Dynamic Inquiry in an Open Inquiry Learning Process

For more than 50 years, dynamic changes have occurred in educators' and teachers' conceptions of science, learning, and science learning environments (Grandy & Duschal, 2007). However, research into the development of inquiry-based skills remained focused on concepts of evidence and linear research planning, beginning with one question and ending with a conclusion (Tamir, Stavy & Ratner 1998; Roberts & Gott, 1999). A recent study compared the influence of open versus guided inquiry learning approaches on dynamic inquiry performances among high-school biology students. This was the first study to quantify dynamic inquiry performances in relation to dynamic inquiry criteria. A quantitative content analysis of the two groups, using a dynamic inquiry performance index, revealed that open inquiry students applied significantly higher levels of performance in the criteria 'changes during inquiry' and 'procedural understanding'. However, the results of the study indicated no significant differences in the criteria 'learning as a process' and 'affective points of view' (Sadeh, & Zion 2009). Quantifying the dynamic inquiry focused on the quantification of the criteria, without breaking the criteria down into components (caterories). These results led us to the idea of deconstructing the two criteria, in which differences were found, 'changes during inquiry' and 'procedural understanding' then quantifying the performances by the categories which composed these criteria. The purpose of this study is to quantify dynamic inquiry performances that are identified throughout open inquiry learning, and that represent the dynamic inquiry criteria and categories. This in-depth analysis of the open inquiry process can contribute to our knowledge and understanding of the learning processes of open inquiry.

The open inquiry learning project on which this study is based (see Method Chapter for details) encouraged students to work cooperatively in teams. Quantifying dynamic inquiry performances of students performing open inquiry in pairs and threes, compared with students learning individually, will help us better understand the contribution of working in teams in comprehending the essence of the open dynamic inquiry process. The rationale of this goal is that approaching specific criteria of dynamic inquiry enables us to hypothesize the following: team work on a complex assignment, such as open inquiry, can assist students in making decisions where 'changes occur during inquiry' and 'procedural understanding' is obtained. For example, a situation may call for change in the definition of the independent variable. A student working alone may become frustrated when s/he realizes the experiment was of no use and must now be repeated with some procedural adjustment. The decision would more easily be made by several students cooperating as a team, as they can distribute the responsibility, the tasks, and the burden of repeating an experiment with improved, more reliable conditions. A three-student team, for example, can come up with both a wider variety of perspectives to discuss and ideas to advance the inquiry.

Team work in an Open Inquiry Process

Upon glancing through the list of Nobel Prize laureates, we see that most achievements in the scientific categories are the product of cooperation by several researchers, each one playing his part and taking personal responsibility. In this spirit, researchers of inquiry learning have come to understand the importance of students working both as individuals and as a team. Cooperative learning, a teaching strategy, has its theoretical underpinnings in social constructivism; this strategy encourages students to engage in inquiry tasks in small teams (Slavin, 1995). Constructivist inquiry learning environments should provide students with opportunities to reflect upon their thoughts, and negotiate ideas with peers and teachers, thus enhancing students' cognitive and metacognitive outcomes (Grindstaff & Richmond, 2008; Wen, Tsai & Chuang, 2004). By sharing their thoughts with others, students become aware of the processes and the knowledge they need to apply in order to solve the problems (Abd-El-Khalick & Akerson, 2007; DeCorte, 2000; Kim & Song, 2006; Krajcik, Blumenfeld, Marx & Soloway, 2000; Sowell, Johnston & Southerland, 2007). Discussion and negotiation help students clarify and visualize their thinking process (Crawford, Marx & Krajcik, 1999). These tasks are of special value for scientific inquiry performance, since analyzing and exploring the logical paths during the inquiry process is essential for inquiry performers (Mittlefehldt & Grotzer, 2003). By cooperating in an inquiry process, students can develop scientific knowledge and can learn how to cooperate within the scientific community (Lunetta, Hofstein, & Clough, 2007). Luckie, Maleszewski, Loznak, and Krha, (2004) found that college biology students even raised ideas, their teachers had not thought of, while working with other students whom they had never met before. Furthermore, cooperative student work and discussion of the process enhances motivation and critical thinking (Smith, 2000). Working in teams also enables the acquisition and application of social and emotional skills (Sowell et al., 2007).

The results of a meta-analysis indicate that, on average, students learning with computers in small teams attempted more tasks, used more learning strategies and had more positive attitudes toward small team learning, but needed more task completion time compared to students learning individually with computers. No significant difference was found in students' attitudes toward instruction, whether they learned in small teams or individually (Lou, 2004). However, Lou, Abrami, and d'Apollonia (2001) found that although larger groups resulted in better team performance than pairs, each student on average learned more when working with computers in pairs. In light of the advantage of cooperative learning in an inquiry learning environment, (Zakaria & Iksan, 2007), the idea that student performances should be examined in individual, pair and team work, and the need to quantitatively examine dynamic inquiry performances, we have raised two research questions:

- *What are the relative frequencies of the different dynamic open inquiry categories that are expressed during an open inquiry?*
- *How does team work contribute to dynamic inquiry performances in open inquiry learning?*

METHOD

The Open Inquiry Programme

A team of thirty teachers developed the open inquiry Biomind curriculum. The Biomind curriculum, was designed in 1999 for Israeli high-school students studying toward matriculation in biology, and continues to be used as an alternative to the practical part of laboratory and ecology work, which accounts for 40% of the total matriculation grade (Zion et al., 2004a). In the Biomind curriculum, the student is expected to function autonomously, whereas the teacher functions as a facilitator, who directs and focuses the learning throughout the entire process. The Biomind curriculum emphasizes both student's learning outcomes and the learning process that the student experiences. Different stages of the Biomind project offer opportunities for correction and improvement. The Biomind students keep logbooks while they are engaged in their scientific inquiry. Moreover, Biomind students completed a regulation of cognition questionnaire in order to gain more experience in developing reflective thinking skills. The core of the curriculum is a self-directed and authentic open inquiry project (Zion et al., 2004a). The open inquiry project relates to a biological phenomenon that can be observed in the field, and can be investigated by controlled lab and field observations. The students submit an inquiry proposal that includes three inquiry questions, at least one of which is examined in an experiment, and another through field observation. The formulation of these questions at the initial stages of the inquiry requires students to think of the logic that links the three questions (Zion & Sadeh, 2007).

The students conduct the inquiry, summarize it, and submit the summary as part of a portfolio. The portfolio includes reports of inquiry experiments and excursion reports that demonstrate the acquisition of inquiry skills in the laboratory and in the field. The students keep logbooks to document every stage of the inquiry process: planning, execution and data gathering, and data processing and writing discussions. They also used the logbooks to note difficulties encountered throughout the process, changes they made during the inquiry process, and other details relating to their manuscript of the inquiry project.

The Biomind program guidelines recommend that students work in teams of two or three. Students are responsible for the inquiry work and are expected to conduct the different stages together, but due to logistic difficulties - the many observations and measurements required, some students distribute the workload in a way acceptable to team members and their teacher. Nevertheless, students who find it difficult to work in teams as a result of social, logistic or cognitive reasons can choose to work individually.

Reflective answers to regulation of cognition questions about the different stages of work are written by each student individually and constitute evidence of the process that the student has undertaken. Reflecting on appropriate questions requires critical thinking about both the process and the product, and raises the students' metacognitive awareness about their learning process.

Participants

The sample population consisted of 154 biology students from eight comprehensive Israeli high schools who had similar socio-cultural backgrounds and academic achievements. The students came from middle-class neighborhoods in five cities in the central area of the country, and none of them received financial support. Eight teachers were selected from a larger pool of 25 volunteers, in order to match characteristics and similar backgrounds among teachers and students. All of the teachers shared many characteristics: more than ten years teaching experience; prepared students for matriculation exams more than five times; were informed of innovations in the field of biology; participated in continued professional development programs; and were highly regarded among biology teachers and their professional colleagues. The teachers also shared similar educational backgrounds; each having earned a university biology degree and a teaching diploma (Table 1). All teachers participated in a two-year program which prepared them to teach open inquiry and facilitate its implementation.

Students studied biology as a major in the 11th and 12th grades, and data were collected throughout this two-year period. The same teachers accompanied the students over these two years, both in class and as facilitators to their inquiry projects. In the current research, 73 open inquiry projects by Biomind students were examined in-depth. Twenty of the projects were performed by three students, 41 by two students, and 12 by students working individually.

Table 1 shows team of individuals, pairs and threes in each class, with the following exceptions: in one class, no one worked individually, and in another class there was no team of three. The importance of cooperation was emphasized and students were encouraged to find partners. Students chose their own teams; however in some cases, teachers tried to match together students who had not been selected. The students were previously exposed to different lab activities, conducted exploratory assignments and even guided inquiry, which did not require writing a comprehensive report. In doing lab assignments, they were exposed to the basic elements of inquiry – defining variables, the importance of control, repetition, maintaining constant factors, gathering data, processing data and drawing conclusions. The inquiry project on which this research is based was actually their first encounter with open inquiry performed from start to finish, from finding a phenomenon and subject of inquiry, through writing a research proposal and conducting the research to writing a summary report.

Table 1. Segmentation of research population by teachers, total number of students, and number of projects

School no.	Teacher's years of experience	Teacher's highest degree in education	Students in class	In-class inquiry projects	Projects segmented by number of students on project team		
					1 student	2 students	3 students
1	23	M.Sc. student	17	7	1	2	4
2	28	Ph.D.	25	13	2	10	1
3	25	Ph.D.	20	11	4	5	2
4	16	Ph.D. student	25	10	1	3	6
5	17	B.Sc.	22	12	2	10	
6	20	M.Sc.	12	6	1	4	1
7	14	B.Sc.	18	7		3	4
8	14	B.Sc.	15	7	1	4	2
Total no. of projects				73	12	41	20
Total no. of students			154		12	82	60

Table 2. Type of performances in students' open inquiry projects

Dynamic inquiry criterion	Performance category
Procedural understanding	1. Asking an inquiry question 2. Developing a hypothesis 3. Field observations 4. Controlling variables in field studies 5. Relative scale changes for the independent variable 6. Applying a different method of measurement for dependent variables 7. Control of variables 8. Determining the control/s 9. Size of sample 10. Repetition 11. Using statistics
Changes occurring during inquiry	1. Changes in the course of inquiry as a consequence of a literature search 2. Changes as a consequence of field conditions or field observations 3. Changes as a consequence of changes in the habitat 4. Changes as a consequence of organisms disappearing or not being found 5. Changes as a consequence of the experiment results 6. Additional ideas emerged and the original inquiry questions were modified 7. Understanding the need to solve technical problems and to suggest practical and creative ideas 8. Changes in an inquiry question by necessity 9. Conducting preliminary experiments to construct an experiment system 10. An answer to an inquiry question changes the direction of thinking 11. Financial reasons

The teachers accompanied the students in the field in search of suitable biological phenomena for inquire. Having defined a subject and inquiry question, the students were asked to submit an inquiry proposal. The students met after school hours to construct the proposal they submitted to their teacher. Once their proposal was approved, students began their practical work. The teachers dedicated a few hours of formal biology lessons to facilitating the students in class. Most of the teachers' assistance was provided in after-school meetings and by e-mail. As needed, teachers accompanied their students on field work. Meeting frequency depended on students' progress and their need for assistance. All teachers provided each team with feedback and encouragement, and discussed students' work at least four times throughout the process.

Data Collection

The current study is part of a greater research effort into students conducting open inquiry. The research thoroughly examined students' learning products as indicators of the inquiry learning process. Data sources included students' logbooks, inquiry summary reports, regulation of cognition questionnaires, and interviews. These data sources helped track the students' learning process and their handling of inquiry. The requirements for writing a report, keeping a logbook and completing a regulation of cognition questionnaire are an integral part of the Biomind curriculum. The interviews were conducted as a special addition to the current research.

Students' logbooks: The students used the logbooks to document every stage of the inquiry process. They also used the logbooks to record difficulties encountered throughout the process, changes they made during the inquiry process, and other details relating to how they conducted the inquiry project.

Inquiry summary reports: Students documented their project in a scientific summary report referring to inquiry questions and their biological basis, hypotheses, and findings. In these reports, students indicated changes made during the course of inquiry as a result of limitations or difficulties

Students' regulation of cognition questionnaires that were recorded in their Biomind portfolios: The regulation of cognition questions that the students answered was related to the activities they performed during the different learning stages, to criticism of their own work, and to the analysis of the final product. For example, 'What difficulties did you encounter 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 report?

Interviews: The students were interviewed in a semi-structured setting. Interview topics were derived either from an analysis of students' regulation of cognition questionnaires, or questions that arose during the interview. Topics included: Did the inquiry comply with the proposal you wrote at the beginning of the project? What if any changes were made? Why? Did you obtain a surprising result that did not match your hypothesis? How did you react? Those last two questions were important to ensure that students can identify anomalous results and know how to explain them (Rob, 2007). It was also important to obtain feedback from the students because there are differences in students' ability to express the evidential value of process activities in speech and in writing (Warwick, Stephenson, & Webster, 2003).

Data Analysis

In order to study the relative frequencies of the different dynamic open inquiry categories that are expressed during the students' open inquiry processes, we examined students' performances during inquiry. The term performance in this article refers to different activities conducted by the students performing the inquiry, activities that varied from their initial inquiry plan. We examined the performances, matching different categories of dynamic inquiry. The performances concerned two criteria of dynamic inquiry: 'procedural understanding' and 'changes occurring during inquiry' (Zion et al., 2004b). The categories, detailed in Table 2, match these criteria, as described by Zion et al. (2004b). Results of the current inquiry indicated the need to expand the list of categories by using the concepts of the evidence list (Roberts & Gott, 1999). In the criterion 'changes occurring during inquiry', an 11th category of 'financial reasons' was added.

The findings presented here include data collected from the students' summary report, logbooks, interviews, and regulation of cognition questionnaires – all were used to indicate performances. The comparative unit which quantified performances was an inquiry project conducted by a team of 1-3 students.

To increase the credibility of research, we considered only performances that appeared in at least two different information sources. Two experienced teachers who taught open inquiry and were familiar with the curriculum, but did not participate as research teachers, separately classified student performances according to the different categories of dynamic inquiry criteria. These two teachers agreed in 89% of the cases. In cases of disagreement, they discussed the case until an agreement was reached about grading the students. In three cases where there was no agreement, a third teacher, was asked for her opinion. The researchers later quantified the frequency of performances in each category and summed up all performances for each category. Appendix 1 lists examples of performances for each category and criteria.

In order to examine whether the difference in performances in different criteria ('procedural understanding' and 'changes occur during inquiry') was statistically significant, we applied the non-parametric Wilcoxon analysis. In order to examine whether the number of performances for each criteria depended on the team size (one, two, or three students), we performed parametric Kruskal–Wallis analyses. We also calculated Spearman's correlation for examining the link between the number of students in the team and the

Table 3. Number of performances concerning 'procedural understanding' and their frequencies in an open inquiry project

Categories	Number of performances	Frequency of performances (%)
Control of variables	20	32.26
Applying a different method of measurement for dependent variables	10	16.13
Relative scale changes for the independent variable	9	14.52
Repetition	5	8.06
Asking an inquiry question	3	4.84
Field observations	3	4.84
Determining control/s	3	4.84
Size of sample	3	4.84
Using statistics	3	4.84
Controlling variables in field studies	2	3.23
Developing a hypothesis	1	1.61
Total	**62**	

Table 4. Number of performances concerning 'changes occurring during inquiry' and their frequencies in an open inquiry project

Category	Number of performances	Frequency of performances (%)
Changes as a consequence of experiment results	24	18.18
Need to solve technical problems	24	18.18
Changes an inquiry question by necessity	17	12.88
Changes as a consequence of changes in the habitat	15	12.88
Changes as a consequence of organisms disappearing or not being found	15	11.36
Changes in the course of inquiry as a consequence of the literature search	11	8.33
Changes as a consequence of field conditions or field observations	9	6.82
Financial reasons	6	4.55
Additional ideas emerged and the original inquiry questions were modified	4	3.03
Conducting preliminary experiments to construct an experiment system	4	3.03
An answer to an inquiry question changes the direction of thinking	3	2.27
Total	**132**	

type of performances. We performed a Chi-square analysis in order to examine the correlation between the number of students and the type of performances.

RESULTS

Relative Frequencies of the Different Dynamic Open Inquiry Categories Expressed in the Open Inquiry

In order to examine the characteristics of a dynamic open inquiry, we examined 73 inquiry projects. We found 194 performances expressed in the students' projects – 62 concerning 'procedural understanding' and 132 concerning 'changes occurring during inquiry'. Tables 3 and 4 and Figures 1 and 2 present the categories found in each criterion. The figures also present the frequency of performances in each category.

Figure 1 shows that the frequency of performances concerning 'procedural understanding' was highest in the category 'control of variables', representing 32% of all performances. This is followed by 'Applying a different method of measurement on a dependent variable' and 'Relative scale changes for the independent variable', each representing approximately 16% of the performances. In other categories, the number of performances remained low, no higher than 10% of the total performances.

Student (98) provided a well-phrased explanation of the importance of maintaining 'control of variables':

"only after the experiment was underway, we noticed the surface areas of the instruments were different, so that the difference between experiment groups might not be a result of temperature, which we measured, but rather of surface area. We realized the experiment should be conducted with all conditions being the same except for temperature."

Figure 2 shows that the frequency of performances concerning 'changes occurring during inquiry' was higher in the categories of 'Changes as a consequence of experiment results' 'additional ideas emerged and the original inquiry questions were modified' and

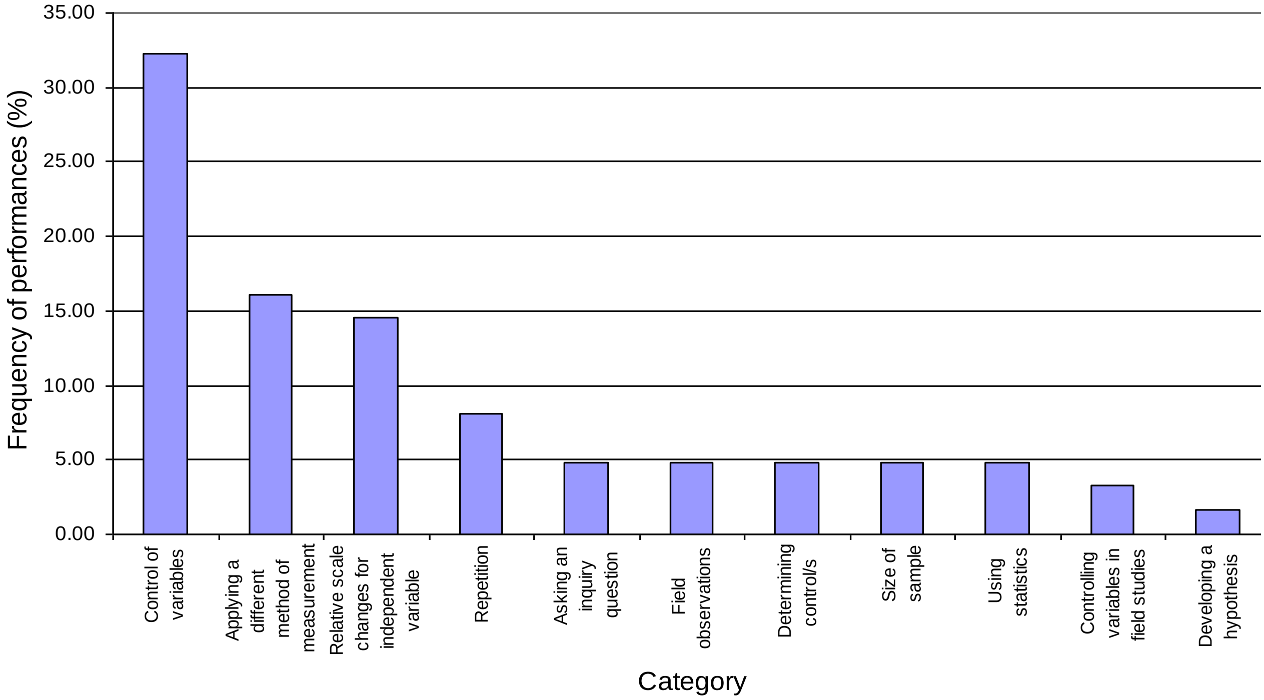

Figure 1. Frequencies of performances concerning 'procedural understanding'

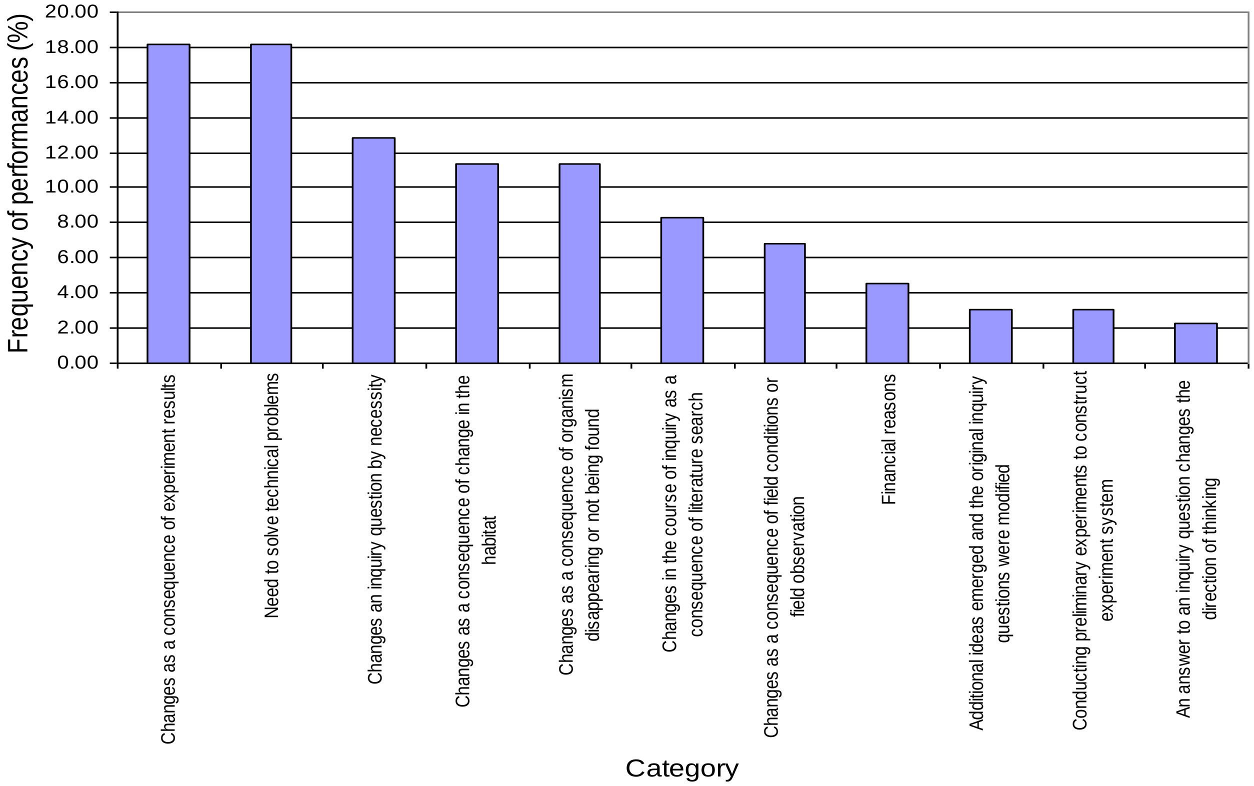

Figure 2. Frequencies of performances concerning 'changes occurring during inquiry'

'Understanding the need to solve technical problems and to suggest practical and creative ideas' – constituting 18% of the total performances. A lower frequency was found in the category of 'changes an inquiry question by necessity' – 13% of the total performances. 'Changes as a consequence of organisms disappearing or not being found' and 'changes as a consequence of changes in the habitat' were found to represent 11% of the total performances. Each other category was found to constitute less than 10% of the performances. These findings show that the number of performances concerning 'changes occurring during inquiry' was greater than performances concerning 'procedural understanding'. We applied Wilcoxon Test in order to determine whether the difference was statistically significant. This analysis was conducted because the SD was higher than the average number of performances M=0.85, SD=1.5 for performances concerning 'procedural understanding' and M = 1.81, SD=1.33 for performances concerning 'changes occurring during an inquiry'. Wilcoxon matched-pairs signed-rank tests revealed a statistically significant difference between performances: the number of performances concerning 'changes occurring during inquiry' was greater than the number of performances concerning 'procedural understanding' (df = 72, Z = 4.87, $p < 0.001$).

The Contribution of Working in Teams to Dynamic Inquiry Performances During the Course of Open Inquiry Learning

Students conducted their inquiry projects either individually or in teams of up to three members. Table 5 shows the average number of performances and SD for teams with a different number of students. This table shows that the greater the number of students in a team, the greater is the number of performances.

In order to examine the difference between the numbers of performances for each criteria of dynamic inquiry, depending on the team size, we performed Kruskal-Wallis parametric analyses. Averages, SD, and grading averages for each criterion by team size, as well as Kruskal-Wallis analyses for comparing them, are presented in Tables 6 and 7, respectively. The tables

Table 5. Number of average performances and SD in teams of varying size over the course of the open inquiry project

		Total number of performances			
Number of students in a team	Number of teams	Average number of performances	SD	Minimum for a team	Maximum for a team
1	12	1.67	1.97	0	6
2	41	2.49	1.58	1	6
3	20	3.60	1.50	1	8
Total	**73**	**2.66**	**1.73**	**0**	**8**

Table 6. Averages and SD of performances of each criterion, by the number of students in a team, in an open inquiry project

		Performances concerning 'procedural understanding'		Performances concerning 'changes occurring during inquiry'	
Number of students in a team	Number of teams	Average number of performances	SD	Average number of performances	SD
1	12	0.42	0.51	1.25	1.66
2	41	0.73	0.74	1.76	1.28
3	20	1.35	1.56	2.25	1.12
Total	**73**	**0.85**	**1.04**	**1.81**	**1.33**

Table 7. Kruskal-Wallis analyses for comparing the number of performances according to the different criteria, by the number of students in a team, in an open inquiry project

	Number of students in a team			
K-W	1 n =12	2 n =41	3 n =20	K-W
Criterion	Average grade	Average grade	Average grade	Chi^2
Procedural understanding	28.00	35.83	44.80	5.81*
Changes occurring during inquiry	25.38	36.26	45.50	7.41*

$p < 0.05$

show statistically significant differences by the number of students in each team according to both criteria: The greater the number of students, the higher the number of performances. In the 'procedural understanding' criterion, Kruskal-Wallis $H = 5.81$, $df = 2$, $p < 0.05$. In the 'changes occurring during inquiry' criterion, Kruskal-Wallis $H = 7.41$, $df = 2$, $p < 0.05$.

We note that the number of students in teams was correlated with the types of performance. A positive correlation was found between the number of students in teams and the number of performances concerning 'procedural understanding' (Spearman's rho= 0.28, $n = 73$, $P < 0.05$) and the number of students in teams and performances concerning 'changes occurring during inquiry' (Spearman's rho= 0.32, $n = 73$, $P < 0.01$). We performed chi-square analysis in order to examine the connection between the number of students in teams and different categories of performance, and we found no statistically significant. Also, we found no statistically significant differences regarding the number of performances by different participating classes. That means that the number of performances in each class was similar and not affected by the teacher or the school. Instead, the number of performances was affected by the number of inquiry team participants.

A summary of data presented in the Results section show that students' teamwork improved their inquiry achievements. In a large team (3 students) a variety of suggestions and avenues were expressed. For example, student 92 said: 'There are more working hands and more daring activities'. Student 98 said that mutual inspiration began from the early stages of inquiry, such as asking the inquiry question: 'We had many arguments, not just about when and where to meet. I mean about the inquiry questions. Each opted for a different question. Having raised several questions, we were able to choose which was best'. Student 100 praised the contribution of his team members: 'I was going in one direction but the girls had different suggestions for inquiry questions, which were also good, so we decided to combine them'. At more advanced stages of the inquiry projects, student 100 added: 'I do not want to brag, but I'm considered a good student. I'm always being told that I do all the work. From the knowledge and thinking perspective, there is something to it. But I also enjoy cooperating and the other sharing ideas with team members. For instance, the other experiment can be credited to Miri's (one of his team members) suggestion. If she had not raised this suggestion, we would have conducted an entirely carried difficult and complicated experiment; one which I had previously suggested'.

Student 44 also saw the advantage of team learning in improving the inquiry project: 'I enjoyed the teamwork and believe that our achievements were better than they could have been had I worked alone, because each of us saw different things and suggested improvements for the experiment. For instance, one member suggested repetition and I suggested control'. Students who insisted on working individually eventually saw the advantages of teamwork in improving the experiment's plan. Student 59 said: 'I would prefer working with one or more partners. Looking at other teams, I noticed they were able to improve their experience because they had considered each other's advice, whereas I had no one to consult'. Students 66 added: 'I would work with another person. I think it's more interesting and inspiring'.

Students mentioned that working in small teams helped those who experienced difficulty in expressing themselves easily. For instance, student 34 said: 'I learned a lot about teamwork. If you're willing, you can share and contribute. I'm usually silent in class whereas here, we are only three members, so I could participate; and even though I'm not a very good student, I had some suggestions that my colleagues accepted. It is nice when people listen to you and even nicer when they accept your opinion. I'm happy that I did not work individually because I could also rely on my friends' suggestions'. Student 80 also commented: 'I learned about teamwork – something that was new to me. I had not worked in a team before this project, and I saw how everyone contributed something. Although we were not at the same educational level, everyone contributed to the success of the project'.

In spite of the contribution of working in learning groups to the quality of inquiry, some students claimed that organizing in teams of three for a long-term project was problematic. Student 37 mentioned that she would pick another team member because 'he made all the choices, and whatever he said we had to do, and he would always show up late at the meetings we had scheduled. I do not feel that I influenced the work we were doing because he did not listen to me'. Student 110 mentioned that: 'The work should be performed in pairs and not in threes. Organizing in threes was difficult; the third party always had trouble showing up at the meetings and she was not contributing any important ideas'. Student 140 decisively said: 'I would switch my partner—he did not contribute anything, he was simply a disturbance'.

We can conclude that conducting inquiry in teams of three contributes to the dynamic of the inquiry process, but also requires the participants to be able to learn to work effectively as a team.

CONCLUSIONS AND DISCUSSION

Dynamics of the Open Inquiry Process as Reflected in Performance

Clearly, scientific inquiry and Nature of Science (NOS) are the foundations of current conceptions of what it means to be scientifically literate. Schwab's main interest was in preparing students to understand the nature of science, and not to learn the skills necessary to conduct scientific work themselves. The criteria of dynamic inquiry correspond to the NOS definitions (Zion et al., 2004b). 'Changes occurring during inquiry' correspond to the NOS definition, 'scientific knowledge is tentative' (Khishfe & Abd-El-Khalick, 2002, p. 556). 'Procedural understanding' meets another NOS definition that 'scientific knowledge is empirical' (Khishfe & Abd-El-Khalick, 2002, p. 556). Promoting students' understanding of these complex and abstract ideas and processes requires significantly different types of teaching, learning, and assessment from typical methods observed in our classrooms.

This research attempted to characterize dynamic inquiry expressed in projects performed by students engaged in open inquiry. The research examined the number of performances, and their frequencies were examined by two criteria of the dynamic inquiry process and their categories. Two thirds of the total performances in the inquiry projects concerned 'changes occurring during inquiry', and most performances were 'changes as a consequence of experiment' results' and the 'need to solve technical problems'. This finding indicates that students were indeed challenged in open inquiry in which experiment procedures and results were not predetermined. The results show that one third of the performances were linked to 'procedural understanding', and this was due to primarily maintain constant factors during experimentation.

When the inquiry work contains more than one inquiry question, and when these questions are interrelated, it is not surprising to see changes made in light of experiment results. The effort for creating a logical framework for the inquiry process, maintains the overall logical framework of the inquiry project (Zion & Sadeh, 2007). In school labs, technical problems often arise, as labs are usually not equipped to facilitate experiment systems that vary from curriculum requirements (Staer, Goodrum & Hackling, 1998; Finn, Maxwell & Calver, 2002). Students, therefore, had to think of creative solutions for seemingly trivial difficulties, as detailed in Appendix 1 (Example 7, Project 67). A students' forum may function as a platform in which students present their difficulties and seek the advice of teachers and peers (Zion, 2008).

We found that students made many changes to the proposal, they originally submitted. This finding may give impression that students found open inquiry a difficult, almost impossible challenge. We believe such dynamic inquiry performances actually indicate critical, logical thinking throughout the process. Evaluation methods should be appropriately revised to reflect such thought processes. An evaluation based solely on quantifying the end product, without any reference to the thought process experienced, could prove frustrating for the student who invested such great effort in the process of open inquiry.

The Importance of Teamwork in Performing Dynamic Open Inquiry

The current research found a statistically significant connection between the number of students in a team and frequency of performances over the course of the project. The difference between the number of performances and the number of student team members can be attributed to communication between project participants. Team members tend to consult one another and discuss the process and the results (Kim & Song, 2006), inside and outside the classroom (Krajcik et al., 2000). Students learning in teams, in a positive atmosphere, will ask one another 'what do you mean?', 'how do you know'? These questions advance learning and contribute to spotting faults in planning and performing the inquiry assignment (NRC, 2000). From these discussions, new insights may arise that help improve the experiment's plan. These consultations encourage students to think reflectively and thus contribute to inquiry learning (Gibson & Rea-Ramirez, 2002). The dialogue among team members helped both to clarify their thoughts and ideas (Hmelo-Silver ,Nagarajan & Day, 2002), and develop the discussion (Benckert & Pettersson, 2008). In addition, this dialogue enabled many new ideas to be raised, and many suggestions for changes in performance, among teams of three students, compared with students working individually, who had no one to consult. Holliday (2006) suggested that if we want students to perform inquiry and experience science in action, we must allow them to discuss among themselves, to be involved in the inquiry processes, and reflect on their activities. In this way, students will be able to comprehend the nature of science (Lederman, 2006).

There is a psychological justification for having students actively involved in hands-on inquiries and self-determination theory (Deci, 1975; Deci & Ryan, 1985). According to this theory, when students select questions that are interesting to them, when they are active in designing the investigation, and when they interact with their classmates in performing the work and in reporting and discussing the results, they develop a greater sense of control and autonomy, and the activity becomes more enjoyable and satisfactory.

Teachers of students who participated in the research were concerned that performing inquiry in teams could result in some students making all the effort while some of their partners do not contribute. This is a special concern in teams of three where one student could end up being a 'parasite', relying on the work of his colleagues. However, the findings of the current research dispel these concerns. The results show a link between the number of students in a team and the number of performances by students over the course of inquiry, performances of which a great portion has to do with improving the inquiry plan and its credibility. A couple of students working as a team show more performances on average than a single student, and three students working as a team show more performances than two students. Therefore, a third student contributes to the team and the inquiry project. It is reasonable to assume that the contribution of the students in advancing the assignment is not identical. Some come up with more suggestions whereas others approve or veto items. Division of roles among team members is legitimate and is in agreement with our understanding that students differ from one another, a fact that should be taken into consideration in learning administration (Hogan, 1999). This finding can help teachers encourage students to work in teams of three instead of readily approving students' requests to work individually on their inquiry project in an attempt to avoid teamwork. Three students decrease the burden on teachers who help students on many issues. From a pedagogical viewpoint, this creates a student discourse, and more intensive metacognitive thinking, which occurs in a team setting, compared to individual work. However, communication skills among team members are critical and should be developed among students. When team members are not attentive to one another and cannot organize and meet, the advantages of teamwork cannot be attained.

Lazarowitz and Hertz-Lazarowitz (2003) found that students who exhibit low academic achievements and work in small teams expressed greater satisfaction in their cooperative work than students who exhibit high academic achievements. Is this also the case among students performing an open inquiry project? Is open inquiry learning conducted by teams able to help students of varying cognitive levels more successfully cope with the complex tasks at hand? This question remains open to future research.

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REFERENCES

Abd-El-Khalick, F. & Akerson, V.L. (2007). On the role and use of 'theory' in science education research: A response to Johnston, Southerland, and Sowell. *Science Education*, *91*(1), 187-194.

Benckert, S & Pettersson, S. (2008). Learning Physics in Small-Group Discussions–Three Examples. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(2), 121-134.

Chin, C. & Chia, L. (2004). Problem-based learning: Using students' questions to drive knowledge construction. *Science Education*, *88*(5), 707-727.

Ciechanover, A. (2003). The ubiquitin proteolytic system and pathogenesis of human diseases: a novel platform for mechanism-based drug targeting. *Biochem Soc Trans*, *31*, 474-481.

Crawford, B., Marx, R. & Krajcik, J. (1999). Developing collaboration in a middle school project-based science classroom. *Science Education*, *83*(6), 701-723.

Deci, E.L. (1975). *Intrinsic motivation.* New York, Plenum Press

Deci, E.L. & Ryan, R.M. (1985). *Intrinsic motivation and self-determination in human behaviour*. New York, Plenum press.

DeCorte, E. (2000). Marrying theory building and the improvement of school practise: a permanent challenge for instructional psychology. *Learning and Instruction*, *10*, 249-266.

Finn, H., Maxwell, M. & Calver, M. (2002). Why does experimentation matter in teaching ecology? *Journal of Biological Education, 36*(4), 158-162.

Gibson, H.L. & Rea-Ramirez, M.A. (2002). *Keeping the inquiry in curriculum designed to help students' conceptual understanding of cellular respiration*. (Eric Document Reproduction No. ED465634).

Grandy, R. & Duschl, R.A. (2007). Reconsidering the character and role of inquiry in school science: analysis of a conference. *Science & Education, 16*(2), 141-166.

Grindstaff, K. & Richmond, G. (2008). Learners' perceptions of the role of peers in a research experience: implications for the apprenticeship process, scientific inquiry, and collaborative work. *Journal of Research in Science Teaching, 45*(2), 251-271.

Hmelo-Silver, C., Nagarajan, A. & Day, R. (2002). 'It's harder than we thought it would be': a comparative case study of expert - novice experimentation strategies. *Science Education*, *86*(2), 219-243.

Hogan, K. (1999). Relating students' personal frameworks for science learning to their cognition in collaborative contexts. *Science Education*, *83*(1), 1-32.

Holliday, W.G. (2006). A balanced approach to science inquiry teaching. In N.G. Lederman & L.B. Flick (Eds.), *Scientific inquiry and nature of science: implications for teaching, learning, and teacher education* (pp. 201–217). Dordrecht (The Netherlands), Kluwer Academic Publishers.

Horvitz, L.A. (2002). *Eureka! Scientific breakthroughs that changed the world*. New York, John Wiley & Sons, Inc.

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*, 551-578.

Kim, H. & Song, J. (2006). The features of peer argumentation in middle school students' scientific inquiry. *Research in Science Education*, *36*(3), 211-233.

Krajcik, J.S., Blumenfeld, P.C., Marx, R.W. & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E.H. van Zee (Eds.), *Inquiry into inquiry science learning and teaching* (pp. 283-315). Washington, DC, American Association for the Advancement of Science Press.

Kuhn, T.S. (1996). *The Structure of Scientific Revolutions*. The University of Chicago Press, Chicago.

Lazarowitz, R. & Hertz-Lazarowitz, R. (2003). Cooperative learning in science curriculum. In: B.J. Fraser & K.G. Tobin (Eds.), *International handbook of science education* (pp. 449-471). Netherlands: Kluwer Academic Publishers.

Lederman, N.G. (2006). Syntax of nature of science whitin inquiry and science instruction. In N.G. Lederman & L.B. Flick (Eds.), *Scientific inquiry and nature of science: implications for teaching, learning, and teacher education* (pp. 301-317). Dordrecht (The Netherlands), Kluwer Academic Publishers.

Lin, X. & Lehman, J.D. (1999). Supporting learning of variable control in a computer - based biology environment: effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36*(7), 1-22.

Lou, Y. (2004). Understanding process and affective factors in small group versus individual learning with technology. *Journal of Educational Computing Research, 31*(4), 337-369.

Lou, Y., Abrami, P.C. & d'Apollonia, S. (2001). Small group and individual learning with technology: a meta-analysis. *Review of Educational Research, 71,* 449-521.

Luckie, D.B., Maleszewski, J.J., Loznak, S.D. & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of 'Teams and Streams'. *Advances in Physiology Education, 28*, 199-209.

Lunetta, V.N., Hofstein, A. & Clough, M.P. (2007). Learning and teaching in the school science laboratory: an analysis of research, theory, and practice. In S. K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 393-442). Mahwah, NJ, Lawrence Erlbaum Associates, Publishers.

Mittlefehldt, S. & Grotzer, T.A. (2003, March). *Using metacognition to facilitate the transfer of causal models in learning density and pressure*. Paper presented at the National Association of Research in Science Teaching (NARST) Conference, Philadelphia, PA.

National Research Council (NRC). (2000). *Inquiry and the national science education standards*. Washington, D.C, National Academy Press.

Prusiner, S.B. (1996). Prion biology and diseases - laughing cannibals, mad cows, and scientific heresy. *Medicinal Research Reviews, 16* (5), 487-505.

Reinstein, E. & Ciechanover, A. (2006). Narrative Review: protein degradation and human diseases: the ubiquitin connection. *Review – Physiology in medicine, 145*(9), 676-684.

Rob, T. (2007). Evaluating science investigations at ages 14-16: dealing with anomalous results. *International Journal of Science Education*, *29*(2), 127-150.

Roberts, R. & Gott, R. (1999). Procedural understanding: its place in the biology curriculum. *School Science Reviews*, *81*(294), 19-25.

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.

Schwab, J.J. (1962). The teaching of science as inquiry. In J.J. Schwab & P.E Brandweine (Eds.), *The teaching of science*. Cambridge, Mass, Harvard University Press.

Slavin, R.E (1995). *Cooperative Learning: Theory, Research and Practice*. Boston: Allyn and Bacon.

Smith, K.A. (2000). *Inquiry-Based Collaborative Learning*. Retrieved August 10, 2010 from http://www.nciia.org/proceed_01/Smith%20handouts.pdf

Sowell, S., Johnston, A. & Southerland, S. (2007). Calling for a focus on where learning happens: A Response to Abd-El-Khalick and Akerson. *Science Education*, *91*(1), 195-199.

Staer, H., Goodrum, D. & Hackling, M. (1998). High school laboratory work in western Australia: openness to inquiry. *Research in Science Education 28*(2), 219-228.

Tamir, P., Stavy, R. & Ratner, N. (1998). Teaching science by inquiry: assessment and learning. *Journal of Biological Education*, *33*(1), 27-32.

Warwick, P., Stephenson, P. & Webster, J. (2003). Developing pupils' written expression of procedural understanding through the use of writing frames in science: findings from a case study approach. *International Journal of Science Education, 25*(2), 173-192.

Wen, L.M. C., Tsai, C.-C., Lin, H.-M. & Chuang, S.-C. (2004). Cognitive-metacognitive and content-technical aspects of constructivist internet-based learning environments: a LISREL analysis, *Computers and Education 43*, 237-248.

Zakaria, E. & Iksan, Z. (2007). Promoting cooperative learning in science and mathematics education: A Malaysian perspective. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(1), 35-39.

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

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., Orian, T., Nussinovitch, R., Agrest, B. & Mendelovici, R. (2004a). Biomind - A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education*, *38*(2), 59-67.

Zion, M., Slezak M., Shapira D., Link E., Bashan N., Brumer M., Orian T., Nussinovitch, R., Court D., Agrest B., Mendelovici R. & Valanides, N. (2004b). Dynamic, open inquiry in biology learning. *Science Education*, *88*, 728-753.

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Appendix 1: Examples of performances in the open inquiry project according to criteria and categories

Performances concerning 'procedural understanding' in stages linked to inquiry credibility

1. Asking an inquiry question (Project 2)

'The first inquiry question was 'how does light intensity affect the production of chlorophyll in the coleus leaf?' We decided that the question was too simplistic and the answer too obvious, so we began again with something more serious, studying not only the chlorophyll but also other pigments in the Coleus'.

2. Developing a hypothesis (Project 23)

'Our inquiry concerned resting eggs of different zooplankton species in a winter puddle. At first, we thought all species would begin to develop simultaneously when the rain came, but after discussing among ourselves and with our facilitator, we altered the hypothesis, and expected each species to develop at different times according to its own adaptations, such as shell width'.

3. Field observation (Project 67)

'We wanted to observe Salvia in the field, but there was a fire. The plants were harmed, and we had to change time and place for observations'.

4. Control of variables in the field (Project 9)

'We decided not to include the light intensity experiment in our inquiry, since light was not the only active factor. There were also varying conditions of temperature and humidity, other plants growing close by (Mint), and we learned that these too have an effect that we cannot rule out'.

5. Relative scale changes for the independent variable (Project 36)

'In the original experiment, the solution concentrations were 0.0M to 0.2M. We discovered that sprouting occurred in all concentrations, even in low salinity. We decided to change the concentrations, the independent variable, and make it similar to conditions on earth - 0.675M. So we prepared solutions ranging from 0.0M to 0.4M to determine the optimal concentration '.

6. Applying a different method of measurement for the dependent variable (Project 63)

'We wanted to measure the breathing rate of snails. At first, we tried to connect a pipette with a colorful liquid and KOH, which absorbs CO_2, but the liquid would not move, or hardly moved, so it was difficult to take a measurement. We decided to try another method, adding phenolphthalein to see how long it takes the colour to disappear. Applying this method, we were able to see changes, and see differences between the groups'.

7. Control of variables (Project 57)

'We examined photosynthesis of lichens that 'smoked' different amounts of cigarettes, that is, were exposed to different amounts of smoke. We added light to quicken the process, but the light bulbs affected temperature so that not all containers were equally exposed to light and heat. It was difficult to tell what had more effect, so we added a water container between the lamp and the lichens to cancel out the temperature variations as well as additional bulbs to make the light exposure even'.

8. Determining the control/s (Project 41)

'I measured the connection between the presence of elodea and *Gambusia affinis* activity, I measured the photosynthesis rate with different amounts of CO_2, but I had no control to tell me that the change can be attributed to the elodea. I repeated the experiment, adding a system without the elodea. This was an external control, and it is important'.

9. Size of sample (Project 60).

'We conducted the first experiment with only four seeds. In one container – nothing sprouted, even though it was the one we simply watered. So we understood that when we use so few seeds, what we see can be attributed to the seeds and not our intervention. We increased the number of seeds to twenty and repeated the experiment'.

10. Repetition (Project 13)

'In the first experiment, we thought three repetitions would suffice, but we got a relatively high SD: the first repetition varied considerably from the other two, so we decided to do another round'.

11. Using statistics (Project 68)

'Instead of changes in length and total weight, we noted changes over the week, making a 100% change attributed to one day. We understood this was impossible, so we calculated the total change. This time, we could see differences clearly and logically'.

Performances concerning 'changes occurring during inquiry'

1. Changes in the course of inquiry as a consequence of a literature search (Project 44)

'In the fourth experiment, we wanted to make a plant extract by boiling, as we had done with the eucalyptus, but we read somewhere about our plants' composition and decided boiling would be harmful. So we decided to make a physical extract by grinding'.

2 Changes as a consequence of field conditions or field observations (Project 27)

'We examined changes in the colour of the flowers. We thought that the process takes days, even weeks, so we scheduled accordingly. After the first observation, we realized it takes only a few hours. We rescheduled, so as not to miss the changes we were studying'.

3. Changes as a consequence of changes in the habitat (Project 61)

'I began my project studying the lettuce and its reaction to the position of the sun. After a few observations, the habitat was destroyed. A fire burned all of the lettuce so I had make changes'.

4. Changes as a consequence of organisms disappearing or not being found (Project 1)

'We wanted to focus our project on the silkworm. We'd already collected literature and planned questions. Then we found out that their season was very short, in fact, it was actually over, and we would not be able to study the larvae unless we waited until next year. This would have been too late, so we had to make changes'.

5. Changes as a consequence of the experiments results (Project 8)

'We examined different factors affecting the decomposition of fallen leaves. We examined the effect of light and sealed the boxes on our first repetition. This resulted in moldy leaves that had not decomposed, and this did not match our hypothesis. We decided that sealing the boxes had some effect, so we left an air opening. This small change was crucial. On our second repetition, we obtained results with which we could continue our project'.

6. Additional ideas emerged and the original inquiry questions were modified (Project 66)

'We examined ants' food preferences. While we were doing so, we wondered why they prefer a particular food and not something else. We had an organized plan of three questions concerning food preference: the first was an observation, the second an experiment, and then some effort to determine the preferred food. We were covered, as far as our project was concerned. But we wanted to examine at least one factor that we'd noticed when we were preparing the seeds. We tried smelling them and were curious to know whether it affects the ants, so we switched smells among foods... we did this beyond what was required, because it was interesting and we didn't feel like stopping our inquiry simply because we were done with our questions'.

7. Understanding the need to solve technical problems and to suggest practical and creative ideas (Project 67)

'We wanted to use a tape measure, but it was too short – measuring one part after another after another... it was awkward. So we used a rope, making a knot every half a meter and stretched it. This was more comfortable and more precise'.

8. Changing an inquiry question by necessity (Project 15)

'We were planning to examine how different types of aphids, winged and wingless, affect the rate of development of cereal roots. But we did not want to deal with the problem of mold that we encountered in the two previous experiments, so we decided instead to examine the effect of galls on the photosynthesis rate of leaflets'.

9. Conducting preliminary experiments to construct an experimental system (Project 65)

'Before we began the experiment of examining which colour attracts bees, we wanted to make sure that our sugar was attractive to them. We put the sugar water in a petri dish on Bristol paper to see if bees would come. Later, we put these petri dishes on each Bristol paper for the rest of our experiments'.

10. An answer to an inquiry question changes the direction of thinking

(Project 39)

'Our initial subject was the lichens, but after the first experiment and the discussion, we realized we weren't focusing on the lichen but rather on the tree. So we took a new course of inquiry'.

11. Financial reasons (Project 68).

'We planned to do several repetitions, but when we got to the gardening nursery, the plants turned out to be a lot more expensive then we'd thought. We had to give up doing repetitions. This is not the best result, but our teacher approved, as long as we explained the importance of repetition, because it was simply too expensive'.

