THE CHARACTERISTICS OF OPEN-ENDED INQUIRY-TYPE CHEMISTRY EXPERIMENTS THAT ENABLE ARGUMENTATIVE DISCOURSE

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ABSTRACT

One of the key goals of science education is to provide students with the ability to construct arguments – reasoning and thinking critically in a scientific context. Over the years, many studies have been conducted on constructing arguments in science teaching, but only a few of them have dealt with studying argumentation in the science laboratory in general and in the chemistry laboratory in particular. Our research focuses on the process in which students construct arguments in the chemistry laboratory while conducting different types of inquiry experiments. The experiments that were assessed for their argumentation level differed in their level of complexity. It was found that the more complex experiments served as a better platform for developing arguments as well as regarding their relative numbers. Moreover, we identified a number of characteristics during the discourse that serve as a catalyst for raising arguments: asking questions and unexpected results obtained in the experiments.

KEY WORDS

Argumentation; Chemistry laboratory; High-order learning skills; Inquiry-type experiment; Complexity of inquiry-type experiments.

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THEORETICAL BACKGROUND

Learning science in a laboratory has a number of features that have contributed to establishing its centrality in the learning and teaching of science in general and chemistry in particular (Hodson, 1993; Hofstein & Kind, 2012; Hofstein & Lunetta, 2004; Lazarowitz & Tamir, 1994; Lunetta, 1998; Lunetta, Hofstein & Clough, 2007). Clearly, the science laboratory, if structured properly, has the potential to develop many important high-order learning skills (Hofstein, Navon, Kipnis & Mamlok-Naaman, 2005; Katchevich, Hofstein & Mamlok-Naaman, 2013; Kipnis & Hofstein, 2008; Tobin, 1990) such as asking questions, developing critical thinking, problem-solving, and developing metacognitive and argumentation skills (Hofstein & Kind, 2012). It provides a unique opportunity to collaborate, deliberate, and communicate with peers. In a nutshell, it provides an opportunity to learn science by doing hands-on as well as minds-on science.

Over the years, the educational effectiveness of science laboratories as a unique learning environment that enables meaningful student learning has been emphasized in many research studies (see, for example, Abrahams & Millar, 2008; Hodson, 1993; Lazarowitz & Tamir, 1994; Lunetta et al., 2007; McElhaney & Linn, 2011). Moreover, the laboratory provides support for high-order learning inquiry skills that include observing, planning an experiment, asking relevant questions, hypothesizing, and analysing the experimental results (Bybee, 2000; Hofstein, Shore & Kipnis, 2004).

In this paper we define science laboratory activities as learning experiences in which students interact with materials to observe and better understand the natural world. Note that assessing the educational effectiveness of the laboratory and its related learning skills requires distinguishing between the different modes of instruction, namely, the nature of the experiments in which the students are involved. Laboratory experiments can be classified into four types: confirmatory, inquiry (various types such as guided inquiry and open-ended type inquiry that can differ in their degree of complexity; see for example, Hofstein & Kind, 2012), discovery, teacher's demonstrations, and conducting an experiment around a specific problem.

In this paper we will focus solely on the issue related to the degree of complexity of inquiry-type experiments. Domin (1999) suggested criteria to define experiments according to the type of results obtained from the experiment: the inductive vs. deductive approach to the activity and, according to who wrote the procedure, either the teacher or the student who must perform the experiment. Other researchers (Fradd, Lee, Sutman & Saxton, 2001; Herron, 1971; Schwab, 1962) suggested characterizing experiments according to their degree of open-endedness. «Open» in this sense means that the experiment is performed entirely by the student and «closed» means that it is performed entirely by the teacher (e.g., a demonstration). A confirmatory experiment is considered «closed» when the students, after learning in the science classroom, perform an experiment that is planned by the teacher. Its approach is deductive and the results of the experiment are known to both the teacher and students in advance. In contrast, an inquiry experiment is considered «open» when the students plan how it will be carried out. Its approach is inductive and the results are not known in advance to the students and sometimes to the teacher. For a more comprehensive discussion regarding this issue see Hofstein, Kipnis and Abrahams (2013).

ARGUMENTATION IN THE CONTEXT OF TEACHING AND LEARNING SCIENCE

One of the goals of science education is to provide students with the ability to formulate arguments – reasoning and critiquing in a scientific context. Progress in science is partially based on arguments and their related rebuttal. Formulating arguments is a particular genre of discourse in which a central epistemological framework is formed as a result of scientific actions. Upon examining the type of activities, it was found that formulating arguments is central and significant in developing and conducting science activities. Consequently, it is reasonable to assume that imparting the meaning of scientific content and the essence of developing a scientific concept would be a way to formulate arguments (Erduran, Simon & Osborne, 2004; Hofstein & Kind, 2012; Hofstein, Kipnis & Kind, 2008). Scientific language is based on arguments; therefore, students should be provided with opportunities to «talk science» (Lemke, 1990). We believe that argumentation in a scientific context should be an integral part of this process. In a classical science lesson teachers ask questions, expect certain answers, and immediately evaluate the students' replies (Cazden, 2001). In contrast, working in small groups, in which the members are exposed to scientific tasks, provides them with an opportunity to become involved in a debate and to be supported or rejected by their arguments. During a group debate, sometimes with the teacher's intervention, the group has an opportunity to construct individual as well as group knowledge. Formulating knowledge in this manner is an example of constructivist socio-cultural knowledge, as described by Vygotsky (1978).

According to Jiménez-Aleixandre (2008), the characteristics of an optimal learning environment for constructing arguments that relate to students, teachers, curriculum, assessment, reflection, and communication are as follows: (1) the students must be active in the learning process; they must assess knowledge, establish their claims, and be critical of others; (2) the teachers have to adopt to student-centred learning, act as a role model regarding the way they verify their claims, support the development of understanding the nature of knowledge among students, and adopt learning strategies such as inquiry; (3) the curriculum should incorporate an authentic problem-solving approach, which will require the students to learn by inquiry; (4) students and teachers should be skilled in assessing claims, and assessing the students should go beyond written tests; (5) the students should be reflective about their knowledge and understand how it was acquired, and finally (6) the students should have an opportunity to conduct a dialogue in which cooperative learning will take place. Combining these six elements encourages the implementation of an argumentative, interactive learning environment.

From a cognitive perspective, formulating an argument is a conceptual process that can aid in developing an understanding of these concepts.

Furthermore, the skill of reasoning, which requires creating a link between claims and evidence, is developed (Osborne, 2010). In general, students often have difficulty in formulating arguments; they also have difficulty in selecting and connecting findings that can be used as evidence in supporting their claims (Sandoval & Millwood, 2005). Furthermore, students do not formulate high-level arguments on their own. It is therefore necessary to initiate activities that encourage and support formulating arguments, especially with controversial-type activities that have diverse types of solutions (Andriessen & Schwarz, 2009; Duschl & Osborne, 2002). Osborne, Erduran and Simon (2004), for example, offered a number of strategies to develop argumentation skills, e.g., exposing students to several explanations regarding a particular scientific subject and dealing with claims that the students may accept or reject. They based their assessments on appropriate professional criteria and expose students to two opposing theories that can explain a particular phenomenon. The students should: (1) explain what evidence supports each of the theories, (2) construct arguments using structured patterns that include guiding questions, and (3) predict the experiment's results, based on appropriate arguments, (4) observe the experiment and explain its results (Predict, Observe, and Explain), and (5) design an experiment, carry it out, and discuss the results. Chin and Osborne (2010) claim that questions (posed by students either to their peers or to themselves) are an excellent trigger for raising arguments.

Other researchers suggested using socio-scientific dilemmas because these dilemmas are ambiguous and enable students to practice the process of simultaneously posing claims and counter claims (Dawson & Venville, 2010; Jiménez-Aleixandre, Rodriguez & Duschl, 2000; Sadler, 2004; Zohar & Nemet, 2002). Building an argument has significant social importance for students, in addition to their learning scientific concepts and high-order learning skills. While students are engaged in activities in which they are provided with opportunities to develop argumentative skills, they learn how to conduct a meaningful conversation with peers. Needless to say, these skills are useful for overcoming life's challenges and are not used solely in the context of science learning (Jiménez-Aleixandre et al., 2000).

In recent years, several researchers have used Toulmin's model (Toulmin, 1958) in their studies. This model includes three basic components: a claim, evidence, and a warrant for formulating grounded and rational arguments (Bell & Linn, 2000; Driver, Newton & Osborne, 2000; Erduran et al., 2004;

Jiménez-Aleixandre et al., 2000; Kind, Wilson, Hofstein & Kind, 2010; Sandoval, 2003). The claim is an assertion whereby the one who suggests it believes it to be true, e.g., a conclusion, an answer to a question, or a problem. Evidence is scientific data that support the claim. Scientific data consist of information, such as observations and measurements. The claim should be based on evidences and the warrant justifies the link between the findings and the claim. A higher level of argumentation includes a theoretical basis or explanation at an elementary level, namely, it also includes backing. Similarly, a conditional (qualified) argument or counter claim is intended to refute a particular argument. A rebuttal makes a claim about why certain claims are incorrect and uses additional evidence and reasoning to justify it.

It is assumed that teaching science through the inquiry method is an effective teaching strategy for teaching and developing the ability to expand argumentation skills (Duschl & Osborne, 2002; Kind et al., 2010; Wilson, Taylor, Kowalski & Carlson, 2010). It is also assumed that an inquiry activity stimulates the students to better understand the research process that scientists undergo. Scientists seek answers to unclear phenomena; they try to explain them by collecting evidence and by constructing arguments. The construction of arguments is a sort of discourse that creates an epistemological framework within the scientific process. When considering the type of activities in which scientists engage, one realizes that building significant arguments is central to the development of science (Hofstein et al., 2008). Therefore, it was reasonable to assume that we would find evidence for argumentation in the laboratory.

Argumentation in the science laboratory

Several researchers (e.g., Gott & Duggan, 2007; Sampson & Gleim, 2009) who focused on the issue of argumentation suggested that the inquiry-type laboratory in science education can provide opportunities for students to develop argumentation skills (see also the detailed discussion in Hofstein & Kind, 2012). However, only a few research studies were conducted with the goal in mind of accepting or rejecting this assumption.

For example, Tien and Stacy (1996) found that students who participated in guided inquiry-type laboratories were better at evaluating evidence obtained from their research. Kelly, Druker and Chen (1998) analysed the discourse in a physics laboratory and found that claims accompanied by justifications are generally given in response to the claims of a colleague in light of the experiment's findings or of the instructions, which may require an explanation or reasoning on the part of the student.

Richmond and Striley (1996) claimed that the development of argumentation skills in the laboratory depends on the type of group. They presented a study, conducted among 10^{th} grade students, who performed a series of experiments dealing with the ability to cope with the disease cholera. The students worked in small groups; the researchers found that the argumentation skills that developed depended on the group leader's personality. In the groups that had an inclusive leader, all the group members contributed in developing the argumentation, whereas in the groups that had a persuasive leader, it was the leader who developed the argumentation.

Other researchers (Hohenshell & Hand, 2006; Keys, Hand, Prain & Collins, 1999) suggested a strategy of best practice in the laboratory whose outcome is a written report: Science Writing Heuristic (SWH). The lab reports, which are written in this way, should replace the traditional way in which students prepare laboratory reports (usually after performing the laboratory experiment). The students receive written guidelines that make connections among the components of the inquiry process: observations, posing questions, data collection, and evidence-based claims. The construction of knowledge and the building of relationships are done by inquiry questions, which help students establish their claims for the data that they gathered. This strategy enables the students to become more active, especially in classroom group discussions. Yoon, Bennett, Mendez & Hand (2010) elaborate on the optimal conditions and specifications needed for classroom discussions using the SWH strategy. They claim that a non-threatening learning environment, where students feel comfortable to express themselves, to accept criticism, to listen to others, and to observe teachers who serve as models, provides MODIFIES ENVIRONMENT optimal conditions for encouraging discourse, thus leading to the development of argumentation.

Sampson, Grooms, and Walker (2011) explored how a series of laboratory activities designed using a new instructional model, called Argument-Driven Inquiry (ADI), influences the ways students participate in scientific argumentation and the quality of the scientific arguments they craft as part of this process. They found that the students had better disciplinary engagement and produced better arguments after the intervention.

ARGUMENTATION AND THE NATURE OF THE EXPERIMENTS IN THE CHEMISTRY LABORATORY

Two recent studies reported in the literature discuss the nature of the experiments as a platform for evoking argumentation both quantitatively (the number of arguments) and qualitatively (the level of arguments). Kind, Kind, Hofstein and Wilson (2011) in the UK investigated the quality of argumentation among 12 to 13-year-old students in the UK in the context of the secondary school physical science program. Their study explored the development of students' argumentation regarding who undertook three different designs of laboratory-based tasks. The tasks described in their paper involved the students in the following: collecting and making sense of data, collecting data for addressing conflicting hypothesis, and paper-based discussions in the pre-collected data phase about an experiment. Their findings showed that the paper-based task (the 3rd one in the above task list) generated the larger number of arguments in a unit of time compared with the two other abovementioned tasks. In addition, they found that in order to encourage the development of high-level and authentic argumentation, there is a need to change the practice that generally exists in the science laboratories in England. They suggested that more rigorous and longitudinal research is needed in order to explore the potential of the science laboratory as a platform for developing students' ability to argue effectively and in an articulated way.

The second study was conducted in Israel in the context of 12 years of research and development of inquiry-type laboratories in the context of upper secondary school in grades 10-12 (for more details about the philosophy and rationale of the project, see Hofstein et al., 2004). The implementation and effectiveness of this project were researched intensively and comprehensively and were reported in a series of manuscripts (Barnea, Dori & Hofstein, 2010; Dkeidek, Mamlok-Naaman & Hofstein, 2011; Hofstein, Levy Nahum & Shore, 2001; Kipnis & Hofstein, 2008).

The is highly relevant to our current paper (Katchevich, Hofstein & Mamlok-Naaman, 2013) focuses on the process in which students constructed arguments in the chemistry laboratory while conducting different types of experiments. It was found that *inquiry-type* experiments have the potential to serve as an effective platform for formulating arguments, owing to the special features of this learning environment. The discourse conducted during inquiry-type experiments was found to be rich in arguments, whereas that during *confirmatory-type* experiments was found to be sparse in arguments. In addition, it was found that the arguments, which were developed during the discourse of an inquiry-type experiment, were generated during the following stages of the inquiry process: hypothesis-building analysis of the results, and drawing appropriate conclusions. On the other hand, confirmatory-type experiments revealed a small number of arguments. In addition, the arguments that were posed in the confirmatory-type experiments had low-level characteristics. Whereas the study reported in Katchevich et al. (2013) was mainly comparative in nature (inquiry vs. confirmatory-type experimentation), the research described in this manuscript focuses on the degree of complexity of inquiry-type chemistry experiments.

As mentioned in previous studies, based on a detailed analysis of the discourse in the chemistry laboratory, we can conclude that the open-ended inquiry experiments stimulate and encourage the construction of arguments, especially the stages of defining hypotheses, analysis of the results, and drawing conclusions. Some arguments were raised by individuals and some by the group. Both types of arguments consist of explanations and scientific evidence that link the claims to the evidence. Therefore, it is suggested that learning environments of open-ended inquiry experiments serve as a platform for raising arguments. In this study we wanted to point out the main factors that stimulate raising arguments in open-ended inquiry experiments, as well as to characterize situations in which argumentation develops significant discourse.

METHODOLOGY

The research method used and described in this manuscript is mainly based on the use of qualitative tools. Some of the qualitative findings were analysed quantitatively. The qualitative approach enabled us to describe in detail the phenomena and processes that occurred in the laboratory and that are related to constructing arguments. Quantitative analysis of the qualitative findings enabled us to describe the magnitude of the phenomena that we identified.

RESEARCH POPULATION

The research population consisted of five classes of 11^{th} and 12^{th} grade chemistry students (N=82) in 5 different high schools in Israel. Note that each class was taught by a different teacher. The students study in an advanced placement chemistry program that consists of a laboratory unit (about 20% of the total program including students' final grades in the matriculation examination). All teachers involved in this study underwent a continuous and intensive professional development program. The laboratory unit lasts two years and includes a series of twelve experiments, some of which are open-ended-type inquiry experiments, whereas others are more confirmatory experiments. In this study we will report only about the open-ended-type inquiry experiments.

ACTIVITIES IN THE LABORATORY

The open-ended inquiry experiments include the following: Students perform open-ended-type inquiry experiments in which they are exposed to a phenomenon; they ask questions about it, select the research question, write a hypothesis related to the research question, plan an experiment in order to examine their hypothesis, and then perform the experiment, organize their results and draw conclusions, as well as analyse and summarize the inquiry experiment (please see instructions for this type of activity in appendix 1).

RESEARCH TOOLS

The research tools consisted of the following: criterion-based observations in the laboratory and semi-structured interviews with the students.

Observations in the laboratory

Laboratory observations were conducted during laboratory sessions and focused on the discourse related to the experiments that took place in the laboratory while students performed the experiments. The discourse was audio-taped and the parts «constructing a rational hypothesis», «analysing the results», and «drawing conclusions» were transcribed. These parts included interactions between the group members, and sometimes interactions between the group members and the teacher, who approaches and interacts with them.

The discourse was analysed according to the following criteria: the components of the basic argument: claims, evidence, and scientific explanations. The analysis to identify the components of the argument was performed using Toulmin's model (Toulmin, 1958).

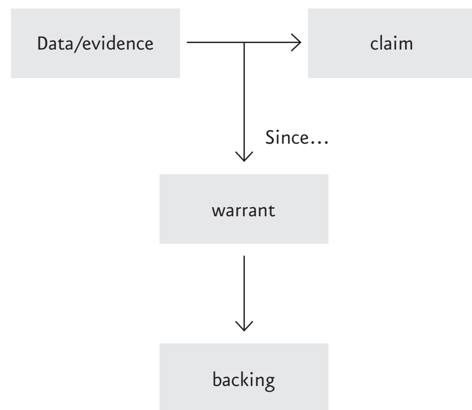

Figure 1 – Toulmin's model for the components of an argument

Toulmin's model places more emphasis on the generic features of the argument, in line with our interest in argumentation in general. In addition, Toulmin's model has been used to characterize argumentation in science lessons and is implicit in using the coding system of others (Bell & Linn, 2000; Driver et al., 2000; Erduran et al., 2004; Jiménez-Aleixandre et al., 2000; Kuhn et al., 1997; Sandoval, 2003). Following these authors, we therefore used the Toulmin framework to focus on the epistemic and argumentative operations adopted by students. In order to assess the level of the arguments, we chose a tool that refers to the various elements of an argument (see Table 1). This tool was chosen from among many assessment tools appearing in the literature; it was reviewed in Sampson and Clark's (2008) paper. This tool is in line with the discourse style of the laboratory experiments and with Toulmin's model; it is based on other tools suggested in former studies (Erduran et al., 2004; Osborne et al., 2004; Simon & Johnson, 2008). During the discourse, the students suggest different explanations for the various phenomena that they observe during the experimental procedure and then analyse the data and present arguments. The reliability of the coding of the argumentation discourse components was tested in two ways: encoding the components of the argumentation in 20% of the transcribed discourse, by three experts. The percentage of agreement between the experts ranged from 85% to 90%. For encoding in which the experts do not agree, the judges discuss the matter until they reach a consensus. In addition, the researcher repeated the encoding after a while; the correlation between the early and late coding system was 0.95.

The components	Symbol	level	Examples of arguments at different levels
Claim	C	1	Nurit: The more powder there is the faster the raisins move, and over time [claim].
Claim + Data or Claim + Warrant	CD CW	2	Nira: The more reactants that there are in the system, the greater the concentration of solution B, more products will be obtained, more gas will be generated, more bubbles will be created, and more raisins will rise [claim + explanation].
Claim + Data + Warrant or Claim + Data + Rebuttal or Claim + Warrant + Rebuttal	CDW CDR CWR	3	Moriah: As we increased the concentration of the solution, there was a greater amount of sediment [evidence]. Gil: The more we increased the concentration of the solution, the more the quantity of the products increased. We found this by analyzing the quantity of the solid [claim + evidence]. Moriah: Because the reaction has more reactants, there are more collisions between the particles of the reactants and consequently, there are more fertile collisions [explanations]. Gil: And then more of the product that forms the solid that we obtained is created and the solution obtained is more turbid [continued explanation combined with evidence].
Claim + Data + Warrant + Backing	CDWB	4	Noam: I want to state that a higher temperature will result in a more frequent occurrence of the reaction [claim]. [He draws a graph] there is an increase in ΔH since this is an endothermic process [evidence]. Alon: There is an increase in ΔS as gas is generated; thus, this is a descending graph [evidence + claim]. Noam: At a higher temperature ΔG is more negative and the reaction will be more spontaneous, according to the graph [he points to the graph that was drawn in the report]. Alon: The spontaneity will be expressed in a broader dispersion of the gas and, as a result, the gas spreads more, because it has greater energy. Ohad: The greater dispersion of the Iodine will be expressed in a greater area that crystallized on the large test-tube [explanation + backing].
Rebuttal that includes Claim + Data + Warrant	CDWR	5	Yarden: In the first system, there was no reaction at all [claim] Bennie: Not so! There was a reaction, but not like in the other systems. Insufficient gas was generated in order to raise the raisins [refutation based on evidence + explanation].

TABLE 1

The levels of the arguments posed by the students are presented in Table 1. Two major aspects are referred to: (1) those components that form the basis of the argument (claim evidence and scientific explanations), and (2) the presence of rebuttal or counterclaims. When the argument includes many components, its level is higher. An argument at level 3 includes the classic elements of an argument: a claim, evidence, and a scientific explanation that connects them.

On the other hand, during an argumentative discourse, there is an additional dimension that includes a counterclaim or refutation, the presence of which serves as evidence of a high argumentative discourse level. Consequently, this element is taken into account when determining argument levels. The highest level of an argument, level 5, includes a refutation based on accompanying scientific evidence and explanations. The discourse analysis was validated by 3 experts. Note that during the analysis of the argument components, we used a scientific explanation expression instead of a warrant because students tend to explain the evidence supporting their arguments by using scientific explanations based on their previous chemistry content knowledge.

The discourse during the experiments was transcribed, and used for two additional goals: (1) Finding evidence of students' wiliness to explain their arguments, and (2) tracking students' questions during the dialogue.

The experiments conducted by the students were categorized according to the following criteria: (1) simple / complex experiments, and (2) experiments in which the students obtained results that matched or did not match the suggested (posed) hypotheses. An experiment was defined as complex based on the above criteria, namely, consisting of one of the following: The experiment is not aligned with the concept or topic taught at that time in the chemistry classroom, and/or is based on a scientific background that is not part of the compulsory chemistry curriculum in Israel.

RESULTS

In this section of the paper we will refer to those factors that might affect the scope of the arguments posed by the students during the discourse of an open-ended inquiry experiment. In addition, we will discuss the other features related to the level of the experimental arguments. Based on the results, we found two main factors that affect the scope of the arguments in the discourse of open-ended-type inquiry chemistry experiments.

ASSIGNMENT REQUIREMENTS AND ASSESSMENT

During the course of experimentation the students are involved in various inquiry skills such as formulating a hypothesis, analysing results, and drawing conclusions, which are categorized as high-order thinking skills. More specifically, hypothesis is a claim based on the preliminary experimentation and on relevant scientific information and explanations. Students are generally aware of the task requirements and the assessment rubric.

Table 2 presents three criteria for assessing the hypotheses that appear in the students' written reports. The total score is 10 points (out of 100) for the whole assignment.

Criteria
The students write an hypotheses regarding the research question which they chose
The students explain hypotheses regarding the research question which they chose
The students base their hypotheses on a scientific and relevant knowledge

TABLE 2 — CRITERIA FOR ASSESSING THE HYPOTHESES

We found some evidence in the discourse for the students' awareness of the task requirements. A discussion between two students will serve as an example (among many others). One of the students claimed: We discussed our hypothesis, and even wrote it in our report. Her colleague answered: «It is not enough! In the instructions it was written that we need to reason and explain each hypothesis.» Even from the above minor episode, we can conclude that the students developed an awareness of the requirements and instructions of the assignments.

THE DEGREE OF COMPLEXITY OF THE INQUIRY-TYPE EXPERIMENT

It is suggested that if the task presents a more complicated phenomenon than is found in other tasks, it provides a higher probability for posing arguments. In addition, if the inquiry experiment consists of scientific concepts that are not an integral part of the formal syllabus or the experiment, then once again, it may provide a wider and more articulated argumentative discourse.

In attempting to characterize the experiments according to their complexity (simplicity), we adopted the categories detailed in the methodology section of this paper. The level of the complexity was content validated by several teachers and science educators in the Department of Science Teaching. This enabled us to conclude which experiment could be declared a simple chemistry experiment and which a more complex one.

All together, the researchers conducted fourteen classroom laboratory observations on a group of students, of which eight were conducted in complex inquiry-type experiments and six in more simple ones. The average number and level of the arguments in simple and more complex experiments are summarized in Table 3 using the Kruskal-Wallis test (nonparametric test).

	Mean level of the argument(*SD*)	Number of arguments per experiment (*SD*)
complex inquiry-type experiment	2.3 (0.54)	6.5 (0.75)
simple inquiry-type experiments	2.5 (0.11)	2.7 (0.82)
Ÿ^{2}(1) (p)	2.5 (N.S)	10.2 (0.001)

TABLE 3 – THE AVERAGE NUMBER AND LEVEL OF THE ARGUMENTS IN SIMPLE AND COMPLEX EXPERIMENTS

Note that regarding the level of the arguments, no significant differences were revealed when comparing simple and more complex experiments. It is assumed that the level of arguments in the rather simple experiments is related to the students' background knowledge to which they were exposed in the chemistry classroom. Thus, they do not have to build a new knowledge gestalt (or framework).

THE NATURE OF THE DISCOURSE IN WHICH THE ARGUMENTS WERE POSED

In addition to the factors identified as affecting the argumentation during the open-ended experimental discourse, we found two features of the inquiry process that influenced (developing) and posing of arguments: asking questions and unexpected results.

Asking Questions

The nature of the discourse in which arguments were posed is highly based on the questions that were posed during the experimental discourse. During the discourse conducted among the students themselves and between the students and their respective teachers in the small group, one can identify three distinct types of questions: questions that stimulate discussions, questions aimed at clarification and understanding the issues related to the experiments, and questions posed for the purpose of obtaining information (in most cases technical ones). In this paper we will refer to the first two, where it is suggested to initiate and drive the group's discourse and thus have the potential for developing arguments or enhancing the development of more high-level-type arguments. The following are examples of these two types:

> Questions that stimulate a discussion: «What would happen, in your opinion, if we continue to heat up the beaker?»
> Questions aimed at clarification: «What did you mean you said we need to extend the level of the concentration?»

Altogether, sixty-two questions were revealed during the observations that included fourteen experiments (six groups conducted simple open-ended inquiry experiments and eight conducted more complex open-ended inquiry experiments) with small groups of students who were involved in conducting open-ended inquiry experiments. Forty-one questions were categorized for discussion or were questions for the purpose of understanding. In those groups conducting simple experiments, seven questions were posed, whereas in the more complicated one thirty-four questions were posed. In addition, high and significant correlation (Spearman correlation) was obtained ($r=0.80$ $p< 0001$ was found between the number of questions asked and the number of resulting arguments). Thus, we assumed that there is a clear relationship between these two variables.

Unexpected Results

The experiments were classified into two categories: experiments in which results that correlate with the hypothesis were obtained and those in which the results were unexpected and are not aligned with the hypothesis. An analysis of the discourse in these experiments revealed that the average number of arguments per group in experiments in which unexpected results were obtained was significantly higher than the number in the experiments in which the anticipated results were obtained ($\chi^2=6.7$ $p=0.017$). In the experiments in which anticipated results were obtained, only 7% of the arguments included episodes of refutation; however, about 30% of the experiments in which unexpected results were obtained included episodes of refutation.

DISCUSSION AND SUMMARY

In the experiments that were observed during the open inquiry experiment in the chemistry laboratory, the students are indeed given a platform for constructing arguments, both as individuals and as part of a group. This is the result of the special features of this learning environment: working in small groups that enable the students to conduct an argumentative discourse. It includes the need to provide explanations for the phenomena observed, select inquiry questions, formulate a hypothesis, provide results and draw conclusions, and initiate a group discussion during which arguments are raised. The arguments raised rely on the evidence collected during the experiment and are usually based on either a scientific explanation studied in classroom or knowledge accumulated during the group discussion regarding concepts that were not learned in class. Furthermore, the students are allocated time to execute all the aforementioned so that their potential can be exploited (Katchevich et al., 2013; Lazarowitz & Tamir, 1994).

In this research study we found two factors that affect the existence and extent of the argumentative discourse while conducting an open inquiry experiment. The first is the task requirements and the reason for assessing the task. The students are aware of the reason and the task requirements. The strict instructions of the work for the students and indicators for assessment dictate the conduct of the inquiry activity in the laboratory. There is evidence in the group discourse for this argument. The students read the instructions out loud and conducted the activities stage by stage. They also examined the compatibility of executing them with the indicated requirements. This awareness is the result of imparting work skills and habits by the teachers, which were also revealed in the discourse.

In order for the students to conduct a discourse that includes established arguments, they have to master the scientific background that supports the arguments relating to the experiment (Von Aufschnaiter, Erduran, Osborne & Simon, 2008). However, on the other hand, in order to conduct a productive discourse, they must include «something beyond» this scientific knowledge. The requirement in the experiment has to be in the ZPD (Zone of Proximal Development) field so that during the discourse, the group will propose possible explanations for these exposed phenomena and, while raising arguments and refutations, the knowledge of the group and its individuals will be formulated (Vygotsky, 1978).

In our study we found that when the task presents a complex phenomenon, which includes concepts that are beyond the curriculum, or alternatively, a full enquiry experiment with a scientific background that links a number of content subjects, the discourse is more meaningful and includes many more arguments. On the other hand, in experiments that are not complex (simple) and that are related directly to the concept studied in the formal curriculum material, generally, students know the answer to the inquiry question raised in advance and, consequently, the hypothesis writing, results analysis, and drawing conclusions stages are not controversial but rather, formulate an established argument with a scientific background similar to the findings of Kind et al. (2011).

Apart from those factors that encourage constructing arguments, the task requirements and their related complexity, we found additional features in the inquiry activity on which an argumentative discourse developed. We found that when students obtained unexpected results in a preceding experiment, or in the experiment that they are planning, the discourse that develops includes more arguments and even refutations. The unexpected results generate a cognitive conflict among the students, which requires them to re-examine what they already know, ask themselves why this knowledge does not form a sufficient basis for explaining the results and whether they have to expand their knowledge or propose explanations based on another scientific background that they had not thought of previously, or that was unknown to them. The conflict is resolved by the group discourse, which is sometimes guided by the teacher. This is a discourse in which the students raise empirical arguments that they perceived in the framework of the experiment (Osborne, 2010).

An additional feature associated with how an argumentative discourse develops is raising questions during the discourse. In addition to the questions that deal with receiving information, the discourse includes questions that require clarification or questions that open up a discussion. These questions generate attention from the group's members and, therefore, have a very important function in developing an argumentative discourse. We also found that in complex experiments, the students ask more questions and, consequently, many more arguments arise. This finding correlates with the *Questions and Argumentation Model* proposed by Chin and Osborne (Chin & Osborne, 2010). In this model, the investigators perceive questions as a factor that motivates discussions. Sometimes the questions are directed at the questioner himself and, sometimes at his peers in the group. However, the need for providing a reply serves as the catalyst for developing the discourse.

To sum-up, it is recommended that when teachers select experiments for their classes, it is advisable that they be aware of the potential of these experiments for constructing arguments. Furthermore, they should be aware of the additional features that are likely to contribute to argumentative discourse, such as raising questions that generate a discussion both by themselves and by the group members.

REFERENCES

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, *30*, 1945-1969.

Andriessen, J., & Schwarz, B. (2009). Argumentative design. In N. Muller-Mirza & A. N. Perret-Clermont (Eds.), *Argumentation and education* (pp. 145-174). New York: Springer.

Barnea, N., Dori, Y. J., & Hofstein, A. (2010). Development and implementation of inquiry-based and computerized-based laboratories: Reforming high school chemistry in Israel. *Chemistry Education Research and Practice*, *11*, 218-228. doi: 10.1039/C005471M.

Bell, P., & Linn, M. (2000). Scientific arguments as learning artifacts: Designing for learning from the Web with KIE. *International Journal of Science Education*, *22*, 797-817.

Bybee, R. (2000). Teaching science as inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 20-46). Washington, DC: American Association for the Advancement of Science.

Cazden, C. (2001). *Classroom discourse*. Portsmouth, NH: Heinemann.

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: Case studies in science classrooms. *Journal of the Learning Sciences*, *19*, 230-284.

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socio-scientific issues in high school genetics. *Research in Science Education*, *40*, 133-148.

Dkeidek, M., Mamlok-Naaman, R., & Hofstein, A. (2011). Effect of culture on high-school students' questions-asking ability resulting from an inquiry-oriented chemistry laboratory. *International Journal of Science and Mathematics Education 9*, 1305-1331.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education*, *76*, 543-547. doi: 10.1021/ed076p543.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*, 287-312.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*, 39-72.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*, 915-933.

Fradd, S. H., Lee, O., Sutman, F. X., & Saxton, M. K. (2001). Promoting science literacy with English language learners through instructional materials development: A case study. *Bilingual Research Journal*, *25*, 479-501.

Gott, R., & Duggan, S. (2007). A framework for practical work in science and scientific literacy through argumentation. *Research in Science & Technological Education*, *25*, 271-291.

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

Hodson, D. (1993). Re-thinking old ways: Toward a more critical approach to practical work in school science. *Studies in Science Education*, *22*, 85-142.

Hofstein, A., & Kind, P. (2012) Learning in and from science laboratories. In B. Fraser, K. Tobin & K. McRobbie (Eds.), *Second Handbook of Research in Science Teaching* (pp. 189-208). Dordrecht Nl: Springer.

Hofstein, A., Kipnis, M., & Abrahams, I. (2013). How to Learn in and from the Chemistry Laboratory. In A. Hofstein & I. Eilks (Eds.), *Teaching Chemistry – A Study book* (pp. 153-182). Rotterdam: Sense Publishers.

Hofstein, A., Kipnis, M., & Kind, P. (2008). Learning in and from science laboratories: Enhancing students' meta-cognition and argumentation skills. In C. L. Petroselli (Ed.), *Science education issues and development* (pp. 59-94). New York: Nova Science.

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.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education*, *98*, 28-54.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman. R. (2005). Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching*, *42*, 791-806.

Hofstein, A., Shore, R., & Kipnis, M. (2004). Providing high school chemistry students with opportunities to develop learning skills in an inquiry-type laboratory: A case study. *International Journal of Science Education, 26*, 47-62.

Hohenshell, L. M., & Hand, B. (2006). Writing-to-learn strategies in secondary school cell biology: A mixed method study. *International Journal of Science Education, 28*, 261-289.

Jiménez-Aleixandre, M. P. (2008). Designing argumentation learning environments. In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 91-115). Dordrecht, The Netherlands: Springer.

Jiménez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). «Doing the lesson» or «doing science»: Argument in high school genetics. *Science Education, 84*, 757-792.

Katchevich, D., Hofstein, A., & Mamlok-Naaman, R. (2013). Argumentation in the chemistry laboratory: Inquiry and confirmatory experiments. *Research in Science Education, 43*(1), 317-345.

Kelly, G. J., Druker, S., & Chen, C. (1998). Students' reasoning about electricity: Combining performance assessment with argumentation analysis. *International Journal of Science Education, 20*, 849-871.

Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching, 36*, 1065-1081.

Kind, P., Kind, V., Hofstein, A., & Wilson, J. (2011). Peer Argumentation in the School Science Laboratory – Exploring effects of task features. *International Journal of Science Education, 33*, 2527-2558.

Kind, P., Wilson, J., Hofstein, A., & Kind, V. (2010, March). Stimulating peer argumentation in the school science laboratory: Exploring the effect of laboratory task formats. Paper presented at the meeting of the *National Association for Research in Science Teaching*, Philadelphia.

Kipnis, M., & Hofstein, A. (2008). The inquiry laboratory as a source for development of metacognitive skills. *International Journal of Science and Mathematics Education, 6*, 601-627.

Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentative reasoning. *Cognition and Instruction*, 15, 287-315.

Lazarowitz, R., & Tamir, P. (1994). Research on using laboratory instruction in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 94-130). New York: Macmillan.

Lemke, J. (1990). *Talking science: Language, learning, and values*. Westport, CT: Ablex.

Lunetta, V. N. (1998). The school science laboratory: Historical perspectives and context for contemporary teaching. In B. Fraser & K. Tobin (Eds.), *International handbook of science education* (pp. 249-262). Dordrecht, The Netherlands: Kluwer.

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in school laboratory: An analysis of research, theory and practice. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 393-441). Mahwah, NJ: Erlbaum.

McElhaney, K. W., & Linn, M. C. (2011). Investigations of a complex, realistic task: Intentional, unsystematic, and exhaustive experimenters. *Journal of Research in Science Teaching, 48*, 745-770.

Osborne, J. F. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*, 463-466.

Osborne, J. F., Erduran, S., & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41*, 994-1020.

Richmond, G., & Striley, J. (1996). Making meaning in classroom: Social processes in small group discourse and scientific knowledge building. *Journal of Research in Science Teaching, 33*(8), 839-858.

Sadler, T. D. (2004). Informal reasoning regarding socio-scientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*, 513-536.

Sampson, V., & Clark, D. B. (2008). Assessment of ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education, 92*, 447-472.

Sampson, V., & Gleim, L. (2009). Argument-driven inquiry to promote the understanding of important concepts & practices in biology. *American Biology Teacher, 71*, 465-472.

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-Driven Inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Education, 95*, 217-257.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of the Learning Sciences, 12*, 5-51.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction, 23*, 23-55.

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3-103). Cambridge, MA: Harvard University Press.

Simon, S., & Johnson, S. (2008). Professional learning portfolios for argumentation in school science. *International Journal of Science Education, 30*, 669-688.

Tien, L. T., & Stacy, M. (1996, April). The effects of instruction on undergraduate students' inquiry skills. Paper presented at the meeting of the *American Educational Research Association*, New York.

Tobin, K. G. (1990). Research on science laboratory activities; in pursuit of better questions and answers to improve learning. *School Science and Mathematics, 90*, 403-418.

Toulmin, S. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*, 101-131.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wilson, C. D., Taylor, J. A., Kowalski, S. M, & Carlson, J. (2010). The relative effects and equity of Inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. *Journal of Research in Science Teaching, 47*, 276-301.

Yoon, S. Y., Bennett, W., Mendez, C. A., & Hand, B. (2010). Setting up conditions for negotiation in science. *Teaching Science, 56*, 51-55.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*, 35-62.

APPENDIX – OPEN-ENDED INQUIRY EXPERIMENT
THE CONTACT BETWEEN LIQUIDS

NOTE: PROTECTIVE GLASSES AND GLOVES MUST BE WORN!

GENERAL INSTRUCTIONS:

- **Read** all the instructions well before beginning the experiment.
- **Check** that you have all the necessary equipment and materials at your disposal in order to conduct the experiment.

PAY STRICT ATTENTION REGARDING:

- **fulfilling the instructions** for carrying out stage A precisely
- **recording** as many **observations** as possible
- **reporting** the **observations** clearly and in a well-organized manner
- **participation** of all the group members in carrying out the various tasks
- using correct and precise **scientific language** throughout the course

EQUIPMENT AND MATERIALS:

a Petri dish
about 30 ml of colored water
about 30 ml ethanol
3 Pasteur pipettes
A bottle of liquid soap

STAGE A: THE PRE-INQUIRY EXPERIMENTS

1. Drip colored water with a Pasteur pipette into a Petri dish until it will cover about half the area of the base of the plate. Be sure that the other regions are dry.
2. Drip Ethanol with a new Pasteur pipette into the dry part of the plate until the two fluids meet.
3. Describe all the observations. If necessary you can add Ethanol.
4. Drip a drop of soap solution into the part where the colored water meets the Ethanol.
5. Describe what is happening

STAGE B: THE INQUIRY STEP

I.

1. **Formulate** 5 varied, relevant questions that arose following the observations that were made.
   - **Choose** one of the questions that you would like to investigate.
   - **Formulate** this question clearly as an inquiry question, and to the extent possible, as a link between two variables.
   - **Clearly formulate** a **hypothesis** that relates to the question that you chose to investigate.
   - **Give reasons** for your hypothesis, based on correct and relevant scientific knowledge.

2. **Plan** an experiment that will check the validity of your hypothesis.
   - **Detail** all the steps of the experiment, including the control stage.
   - **List** the equipment and materials needed on the equipment request form.
   - **Consult** with the teacher and make changes if necessary.
   - **Submit** the list of equipment and materials to the laboratory technician.

II.

3. Get the teacher's approval for the proposed experiment.
   - **Carry out** the experiment that you proposed after receiving the teacher's approval.
   - **Present** the observations and the results in an organized form (table, diagram, graph, etc.)
   - **Analyze and interpret** the results.
   - **Draw conclusions** as much as possible based on the experimental results and rationalize them.
   - **Examine** the connection between the inquiry question and the conclusions.

4. In the summarizing group discussion
   - **Express your opinion** about all the stages of the inquiry (limitations, precision, etc.).

- To the extent necessary, **point out** the changes desirable in the inquiry process.
- **List** additional questions that arose following the whole process.
- **Prepare** your group's summary of the experiment for **presentation** before the class.

5. In the summarizing class discussion
    - **Relate** to our experiment by considering the reports of all the other work groups.

6. **Ensure** that the report is well organized, aesthetic, and readable.

Enjoy the work!

*

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