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Yesterday's Students in Today's World—Open and Guided Inquiry Through the Eyes of Graduated High School Biology Students

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Abstract Educational policy bodies worldwide have argued that practicing inquiry as a part of the K-12 curriculum would help prepare students for their lives as adults in today's world. This study investigated adults who graduated high school 9 years earlier with a major in biology, to determine how they perceive the inquiry project they experienced and its contribution to their lives. We characterized dynamic inquiry performances and the retrospective perceptions of the inquiry project. Data was collected by interviews with 17 individuals—nine who engaged in open inquiry and eight who engaged in guided inquiry in high school. Both groups shared similar expressions of the *affective point of view* and *procedural understanding* criteria of dynamic inquiry, but the groups differed in the expression of the criteria *changes occurring during inquiry* and *learning as a process*. Participants from both groups described the contribution of the projects to their lives as adults, developing skills and positive attitudes towards science and remembering the content knowledge and activities in which they were involved. They also described the support they received from their teachers. Results of this study imply that inquiry, and particularly open inquiry, helps develop valuable skills and personal attributes, which may help the students in their lives as future adults. This retrospective point of view may contribute to a deeper understanding of the long-term influences of inquiry-based learning on students.

Keywords Dynamic inquiry · Guided inquiry · Inquiry-based learning · Long-term learning · Open inquiry

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Introduction

Policy makers in science education have many goals. One of the most central of these, as reflected in many standard documents, is to prepare students for their lives as adults. This includes not only preparing students for future science-related careers but also for their roles as scientifically literate citizens in today's technologically and scientifically rich world (Department for Education 2014; European Commission 2015; House of Commons 2017; National Research Council- NRC 2012a, b). According to the American National Research Council (2012a), one of the reasons that these goals have not been achieved so far is that K-12 students were not provided with engaging opportunities to experience how science is actually done, such as inquiry (NRC 2012a). However, inquiry has been interpreted in different ways, resulting in a lack of consensus regarding how it should be carried out (Jiang & McComas 2015; NRC 2012a).

Many studies have found that inquiry learning, both open and guided, has positive learning outcomes, including promoting meaningful learning and developing practices and skills that would probably help prepare students for their lives as adults (NRC 2012a, b; Pedaste et al. 2015; Rönnebeck et al. 2016). Therefore, this study aims to investigate the way that adults, who graduated high school with a major in biology, perceive the inquiry project they experienced, 9 years after graduation. Looking at the inquiry process from a retrospective point of view may contribute to a deeper understanding of the long-term influences of inquiry-based learning on students.

Theoretical Background

Preparing High School Students for Today's World

Learning science and understanding its concepts are essential for every citizen in the twenty-first century. Many facets of modern life are touched by science and technology, which also hold the key to meeting many of humanity's current and future challenges. Economic development has become dependent on advances in science and technology, creating demand for scientists, technical workers, and a scientifically literate public (House of Commons 2017; Liu 2009; NRC 2012a). As a result, several educational policy bodies throughout the world have stressed that success in the twenty-first century requires acquiring key competences, such as critical thinking, creativity, problem solving, collaboration, and listening competencies, rather than simply learning facts in science. These will promote meaningful learning and will prepare students for their lives as adults and for their roles as citizens in the technology and scientifically rich world (Department for Education 2014; European Commission 2015; NRC 2012a, b). According to the National Research Council, one of the reasons that K-12 science education fails to achieve these outcomes is that the current curriculum "does not provide students with engaging opportunities to experience how science is actually done" (NRC 2012a, p. 1).

As a result, a main concept in the new guideline is the reduction of the amount of details to be mastered, which is intended to give time for students to engage in scientific investigations and argumentation and put more emphasis on scientific practices (NRC 2012a, b). In other words, a central element in the new science curricula worldwide, which is intended to better prepare high school students for their lives as adults in today's and tomorrow's world, is inquiry.

Inquiry-Based Learning

Many educational policy bodies worldwide have emphasized the importance of inquiry-based learning (e.g., Australian Curriculum Assessment and Reporting Authority 2012; Department for Education 2014; European Commission 2007, 2015; NRC 2012a). Inquiry plays a central role in science education in several ways: first, as a necessary part of the science curriculum, demonstrating science as practiced by scientists and, second, as a pedagogical tool through which students can learn science content knowledge, concepts, and practice through experiencing the process of inquiry itself (Jiang & McComas 2015). Indeed, various studies support the effectiveness of inquiry-based learning as an instructional approach, such as increasing cognitive achievements and developing conceptual understanding, process skills, critical thinking skills, and more (see reviews in Pedaste et al. 2015; Rönnebeck et al. 2016). Inquiry-based science learning has also proved its efficacy in increasing students' interests and attainment levels (European Commission 2007). Teachers are therefore encouraged to engage students in authentic scientific investigations of making hypotheses, designing and applying experimental procedures, and interpreting data and evidence, rather than focusing narrowly on the learning of content knowledge (Morrison 2014). Furthermore, recently, the new framework for K-12 science education in the USA, the Next Generation Science Standards, emphasized the importance of other essential elements in scientists' work. According to these standards, the dominant activity is investigation and empirical inquiry, but students should also engage in construction of explorations and evaluation, using reasoning, creative thinking, and models (NRC 2012a; Yang et al. 2016).

Despite vast recognition of the value of inquiry-based learning, there is no consensus regarding how it should be carried out. Inquiry teaching has been interpreted in different ways that represent a broad suite of strategies (Jiang & McComas 2015; NRC 2012a). One example is the debate regarding the degree of teacher's involvement and students' autonomy in the inquiry process (Banchi & Bell 2008; McConney et al. 2014; Rönnebeck et al. 2016; Zion & Mendelovici 2012). In this context, this article will focus on two different approaches—open inquiry and guided inquiry.

Open Versus Guided Inquiry Learning Approach

Inquiry-based activities encompass a broad spectrum, ranging from teacher-directed structured and guided inquiry, to student-directed open inquiry (NRC 2000). The lowest level of student-direction is structured inquiry, during which the students investigate a teacher-formulated question through a prescribed procedure. The students receive complete instructions at each stage, leading to a predetermined discovery. At the intermediate level, guided inquiry, the students are given an inquiry question and possible procedures by the teacher, making later determinations as to both processes and solutions. In some cases, students may choose an inquiry question from a databank of predetermined questions. This process is also known as coupled inquiry. Although in guided and coupled inquiry the questions are given by the teacher, the students are the ones to lead the inquiry process itself. Thus, although the teacher most likely has an idea what results to expect, unexpected results can still be obtained and students often come up with self-conceived conclusions based on scientific knowledge. The highest level of student-directed inquiry is the open inquiry, in which the teacher defines the knowledge framework in which inquiry is conducted, but the students formulate a wide variety of inquiry questions. During open inquiry, the students make their own decisions throughout each stage of the process. Students investigate topic-related questions that they have formulated themselves and the investigation is carried out through procedures the student designed or selected. There is an obvious potential uncertainty for the teacher, in terms of the expected results, conclusions, and procedures. Nevertheless, the teacher is there as a guide for the students, assisting them in making decisions throughout the different stages of inquiry (Blanchard et al. 2010; Zion & Mendelovici 2012).

Although both guided and open inquiry can be effective in developing students' practices and critical thinking, there is still a debate as to which type of inquiry is more relevant to science education in high school. Some claim that open inquiry presents a higher level of inquiry, in which students are required to reach a high-order level of thinking. It represents science as practiced by professional scientists to a greater extent than the other types of inquiry (Banchi and Bell 2008; Zion et al. 2007). Various studies have shown that students who were engaged in open inquiry projects demonstrated learning gains, such as learning scientific content and skills, internalization of scientific thinking habits, and developing a sense of ownership and responsibility for the investigation, as well as passion, interest, and agency about science (Kapon 2016). During open inquiry, students employed inquiry skills, engaged in higher-order thinking (Krystyniak & Heikkinen 2007), and enhanced creative thinking skills, including fluency, flexibility, and originality (Kadir & Satriawati 2017). Open inquiry showed the most positive outcomes regarding learning outcome, preparation time, time spent in the laboratory, and students' perceptions of the experiment (Berg et al. 2003). On the other hand, researchers agreed that guided inquiry-based teaching helps students learn science content and master their scientific skills and inquiry abilities (Blanchard et al. 2010; Bunterm et al. 2014; Fang et al. 2016; Quintana et al. 2005). Some researchers stress that while open inquiry leads to high cognitive load and thus cannot be effective (Kirschner et al. 2006), guided inquiry prevents a "waste of time," reduces students' frustration due to achieving undesirable results or experiencing failure, and reduces students' fear of the unknown (Furtak et al. 2012; Trautmann et al. 2004). The amount and type of teacher support needed for high school students are still debated and still under investigation (Arnold et al. 2014).

Open and Guided Inquiry as Dynamic Processes

Following an action research study lasting 3 years, Zion et al. (2004) characterized the elements of the dynamic inquiry learning process, as one where learning is a process of continuous and renewed thinking that involves flexibility, judgment, and contemplation, as part of the changes that occur during the course of inquiry. Furthermore, characterizing the dynamic inquiry process emphasized the perspectives of critical thinking and change, reflective thinking about the process, and affective aspects such as curiosity, which are expressed in situations involving change and uncertainty. The elements of dynamic inquiry were grouped into four main criteria, each of which including several defined categories—changes that occur during inquiry, learning as a process, procedural understanding, and affective points of view. Changes occurring during inquiry include those arising as a consequence of field conditions or a literature search, where new ideas emerged and induced changes, and understanding the need to solve technical problems. Learning as a process includes knowledge that is acquired in the course of reviewing documentation, researching additional professional literature, and devoting adequate time throughout the course of the inquiry. Procedural understanding develops with understanding the importance of controlling variables, learning how to approach a question from different research perspectives with different working methods, along with controlling, repeating, and maintaining statistics. Affective points of view that develop during the process include, among other concerns, those of curiosity, frustration, surprise, perseverance, and coping with unexpected results.

Both guided and open inquiry students develop their performances in these aspects of dynamic inquiry. However, quantitative content analysis using a dynamic inquiry performance index that was based on the characteristics described above revealed some significant differences between the two inquiry learning approaches. Open inquiry students applied significantly higher levels of performance in the *changes during inquiry* and *procedural understanding* criteria. For example, only students who experienced open inquiry exhibited a detailed reference to changes occurring throughout the project and referred to reasons for and implications of change—changes that occur during work because of field conditions, new ideas that arise and may be implemented during the process, and technical problems that emerge and require students to devise practical solutions. Students who experienced guided inquiry generally referred changes to *the situation* or to the teacher's instructions. As for *procedural understanding*, most students who exhibited a low level of procedural understanding (e.g., repeating and controlling variables) were from the guided inquiry group. Their reference to the inquiry process was superficial, ignoring the components of inquiry or ascribing their actions to teacher's instructions. The results of the study indicated no significant differences in the criteria of *learning as a process* and *affective points of view* (Sadeh & Zion 2009).

The Current Study

As discussed above, several respected educational policy bodies (e.g., European Commission 2015; NRC 2012a) have argued that practicing inquiry as a part of the K-12 curriculum would prepare students for their lives as adults in today's world, providing them with the skills and practices required to become scientifically literate citizens in the twenty-first century. Although inquiry learning has been found to have positive outcomes in various studies (see review in Pedaste et al. 2015), we are not aware of any study that investigated the benefits of inquiry, open and guided, from the point of view of adults who engaged in scientific inquiries as high school students.

The current study investigated how adults, who graduated high school 9 years earlier with a major in biology, perceive the inquiry project they experienced. The investigation included two main aspects. The first was a characterization of the way adults retrospectively perceived their high school inquiry project—its contribution to their lives as adults, its long-term affective influences, and the role played by their teachers. The second aspect was a characterization of the inquiry project as a dynamic inquiry. Both aspects were investigated and the investigation included making comparisons between open inquiry and guided inquiry.

More specifically, we asked the following research questions:

1. What are the characteristics of the open and guided inquiry learning processes, in terms of dynamic inquiry, as perceived by adults who experienced those processes, as students?
2. What do students remember about their inquiry projects and their teachers, years after graduation?
3. What is the contribution of the inquiry project, as perceived by adults who experienced it as students?

Investigating the contribution and characteristics of inquiry from a retrospective point of view of adults who live and function in today’s world would contribute to our understanding of the long-term influences of inquiry-based learning. This would shed light on inquiry as an educational approach in science.

Methods

The High School Biology Inquiry Project

In Israel, high school biology students who take the final examination must perform lab assignments (20%) and conduct a practical inquiry project (20%), in addition to their theoretical studies (60%). The Israeli Biology Syllabus for high school students who major in biology offers two different teaching approaches for the project; the teacher chooses either guided or open inquiry (Israeli Ministry of Education 2006). In both types of inquiry, the projects begin by identifying phenomena in the field and then continue either on site or in the lab. Students are required to document each step in their projects, working in teams of up to three students. In addition, in both types of inquiry, topics may be the same, the written assignment is similar, and its submission is followed by an oral examination.

Despite these similarities, there is a difference in the roles of teacher and student. In the Israeli high school open inquiry project, the students are expected to function autonomously from the stage of finding the investigated phenomenon to raising the inquiry question and then answering it, while the teacher functions as a facilitator, directing and focusing the learning throughout the entire process. In contrast, in the guided inquiry project, the teacher presents the students with the phenomenon they will research and then dictates the inquiry questions (sometimes as a list from which the students choose their question) and explains how to gather information. The students begin to work autonomously only after the information-gathering stage. The most significant point of difference between guided and open inquiry occurs at the critical stage of asking the inquiry questions. At this stage, inquiry students must take responsibility for project management, and they must make their own decisions (Zion & Mendelovici 2012).

The participants in the current study were adults who, as high school students, were engaged in either open or guided inquiry projects that had the characteristics described above.

Participants

Seventeen individuals, with an average age of 27 ± 1.27, participated in this study approximately 9 years after high school graduation. All participants studied biology as a major in high school for 2 years (11th and 12th grades), fully completing their inquiry projects and taking the matriculation exams in biology. Nine participants (four females and five males) engaged in open inquiry, while eight (six females and two males) engaged in guided inquiry. Participants of both groups had several characteristics in common. The participants, as high school students, had similar sociocultural background and academic achievements; in both schools, to be accepted to biology class, there were prerequisite requirements, including appropriate math and biology grades in the previous year. Students of both groups studied in well-established high schools in the center of Israel, with experienced biology teachers. The participants who engaged in open inquiry studied together in the same high school biology class, which included 24 students who graduated in 1999. Their high school was in a major city in the center of Israel and served students from middle class neighborhoods. Their biology teacher held a PhD in biology, had 5 years of biology teaching experience, and had prepared students for matriculation exams five times. The participants who engaged in guided inquiry studied together in the same high school biology class, which included 19 students who graduated in 2002. Their high school, as well, was in a major city in the center of Israel and served students from middle class neighborhoods. They were all taught by the same biology teacher, who held an MSc in biology (and who was, at that time, a PhD candidate), had 15 years of biology teaching experience, and had prepared students for matriculation exams ten times.

Due the long time that has passed since their graduation, a great effort was made to locate and contact the former students. The participants of this study are all the students who could be contacted and who agreed to participate.

Data Collection

Data was collected by interviews. The interviews of each group were performed 9 years after their graduation. That is, open inquiry students, who graduated in 1999, were interviewed in 2008, while guided inquiry students, who graduated in 2002, were interviewed in 2011. The purpose of the interviews was to obtain information that would help identify and characterize (a) dynamic inquiry performances developed by the students throughout their inquiry work, (b) retrospective perceptions of the inquiry project and teacher support, and (c) perception of the contribution of the inquiry project.

The participants were questioned in a semistructured setting. During the interviews, the participants were encouraged to describe in detail the learning process they engaged in during the inquiry project and the role of their biology teacher. Further questions were asked according to the four criteria and defined categories of dynamic inquiry, which were characterized by Zion et al. (2004). Table 1 presents the questions on which the interview was based (adapted from Sadeh & Zion 2009). Participants were encouraged, during the interview process, to provide, as part of their responses, examples from their own high school inquiry process. Typically, interviews lasted 1 h, although this varied from individual to individual. The interviews were recorded and transcribed, in accordance with the participant's approval.

Data Analysis

Data collected in the interviews was analyzed in order to characterize the expressions of the following aspects, among participants of each research group: (a) dynamic inquiry performances developed by the students throughout their inquiry work and (b) retrospective perceptions of the inquiry project, its contribution, and the teacher. Two researchers independently assessed and analyzed the transcripts.

1.Dynamic Inquiry Criteria The participants' responses were classified into the four criteria of a dynamic inquiry. Within each criterion, the data were assigned to the different categories created by Zion et al. (2004). The participants' responses were further analyzed by looking for specific characteristics in each participant's response, as suggested by Sadeh and Zion (2009). These characteristics included deep understanding of the components of the criterion (expressed by explanations of stages and reasons or through detailed relevant

Table 1 Questions on which the interview was based

Criterion	Examples
Memories from the inquiry project	Describe your inquiry project. What was the subject? Do you remember the inquiry questions? How did you choose the inquiry question?
Teacher support	Describe your biology teacher and your interaction with her. How would you define the teacher's role during the inquiry?
Contribution of the project	In what ways did the inquiry project contribute to your everyday life after graduation? What were the most important things you learned through the inquiry process? Would you recommend that other students should perform the inquiry? Why?
Changes occurring during inquiry	Did the inquiry proceed as you had expected? Were there any changes? What changes occurred? Why did you have to change? Did you obtain a surprising result, one that did not match your expectation/hypothesis? What was it? If so—how did you handle this unexpected result? If a change was required and/or done – who initiated it?
Learning as a process	At what stage did you use the Internet or the library? Why? Did you use a logbook? When? Why? How did it help you? How much time did the inquiry process take? Why?
Procedural understanding	Do you remember any difficulties that made you understand the correct way to perform an inquiry, such as lack of control, repetitions, controlling the variables, etc.?
Affective points of view	Did you enjoy participating in the project? Describe any disappointments, frustrations, or hardships that you experienced during the process. Describe any sense of satisfaction that you experienced during the process.

examples), general references to the components of the criterion (expressed by merely mentioning stages or their importance or by providing general examples), or ignoring the component or referring it to the teacher or to instructions, without examples.

2.Retrospective Perceptions of the Inquiry Project and Teacher Support Since one of the main differences between the two inquiry approaches lies in the degree of students' direction (Sadeh & Zion 2012), participants' responses regarding their biology teachers were characterized by looking for words that imply the type of direction students received from the teacher. That is, the study sought to determine the extent to which the teacher was perceived as a guide and the degree of self-direction the teacher allowed her students, through the use of student comments that included words such as "guide," "let us," "told us," "lecture," or "demand." The analysis of the perception of the project and of its contribution was not theory-driven. The researchers looked for words and concepts that repeatedly appeared in several participants' responses. Those were used to identify common themes. Additionally, the participants' descriptions of their inquiry process were characterized by looking for the extent to which the participants remembered their project: Researchers wanted to find whether the participants even remembered their project, whether they remembered the general subject but not the specific inquiry question, whether they remembered the inquiry question, and whether they remembered additional details. Special attention was given to how detailed the participant's description was (e.g., if the names and other properties of the organisms or area investigated were mentioned), as well as whether, and what, specific emotions were discussed while describing the project. The researchers initially agreed in 90% of the cases. Upon disagreement, the researchers would discuss the case until an agreement was reached.

Results

The results are presented in two sections. The first section addresses the expression of the criteria of dynamic inquiry (Zion et al. 2004). This section focuses on the commonalities and differences that were found between the groups. The second section focuses on the way the participants perceived their inquiry project and their biology teacher years after graduation. Several examples from the interviews were selected to illustrate the results described in this paper. The examples that were selected were the ones that (a) represented ideas that were common in various interviews, (b) were well articulated by the interviewee, and (c) would be understandable to most readers, in addition to science teachers. In some examples, the key words are italicized by the authors, in order to stress their relevance to the criteria. Citations referring to the dynamic inquiry criteria are presented in Table 2, while citations referring to the way students perceived their project and their teacher are presented within the text.

Expression of Dynamic Inquiry Criteria

The research examined students' performances, as retrospectively perceived by the students themselves 9 years after graduation, according to four criteria—the affective point of view, procedural understanding, changes occurring during inquiry, and learning as a process (Zion et al. 2004). Both groups shared similar expressions of the affective point of view and procedural understanding. Differences between the two groups were found in two criteria: changes occurring during inquiry and learning as a process.

The Affective Point of View Curiosity, frustration, surprises, and disappointments, as well as enthusiasm and excitement, often mixed together. These feelings were all expressed, in a similar manner and to the same extent, by students of both groups. Most of them referred to these affective aspects in detail, giving examples and explanations as reasons for their moods.

Some students merely stated how they felt, providing general references only or no explanations at all. Although most students expressed the feelings described above, a few students said they did not experience any feelings of this sort or that they were indifferent to the project. Some said that they were interested in the project, but they were not enthusiastic about it, mostly because it was too demanding, especially when taken together with other school assignments (and other troubles of adolescence). Most of the students, from both groups, referred their feelings of satisfaction to the fact that they carried a real investigation and that they created something, a product of their own. They had a feeling of ownership for something they worked hard to achieve.

Procedural Understanding In both groups, only about half the participants referred to this criterion. Those who did, referred mostly to understanding the importance of control and repetitions. A few also mentioned the importance of reliable observations, limitations of isolating variables in the field, and maintaining constant conditions. However, most interviewees exhibited only general understanding of those inquiry components, simply stating that they are important, without providing explanations or examples. Most students from the guided inquiry group stated that they only understood the importance of those procedures at the end of the project, while summarizing the results, or even after graduation. However, one participant provided detailed examples of different components, thus demonstrating deeper understanding and critical thinking.

Table 2 Examples for expressions of dynamic inquiry criteria from both inquiry groups

Criterion	Level	Examples
The affective point of view	Deep understanding	"I *loved* the observations, it was *interesting* to actively go, check, first by observing and afterwards by bringing samples to the lab and *planning the experiment*. However, I remember it was hard for me to do the experiment itself. I didn't know a lot about the materials and equipment. I really felt *frustrated and helpless*... towards the end, I felt *satisfaction*, because I felt things were 'flowing' and I finally knew about things I had no idea about a year earlier and that I found interesting." (Leia G)
		"We were *very excited* about the leaves, the boxes we made and the results, because it's something we created and we proved it in the lab... we found out that the result was opposite [to what we expected]. We actually discovered that! We were *shocked!*" (Sara O)
		"To us it was '*wow*', because it's not regular school work. ... You try to discover new things... and when we finished it we were *proud* we did this kind of work. For us it was really something, that we have a *product*. It's something we went through together." (Alex G)
		"You were thinking about ideas and then you handed it out, the *product* you have *worked* so much time on. And it looks nice and it is appropriate …you are really *into it*, you did it, you *worked hard* on it, it gives you a lot and it gives you a sense of *satisfaction*... You get involved with it, you want it to succeed, it is something that is *unique* to you." (Nataly G)
	General references	"I remember the *excitement* when we came back for the second data collection and found the same birds that we marked in our previous visit..." (Iris O)
		"Sometimes you *expect* certain results and you get something *completely different*. How can that be?...It was *frustrating*, because—what? Do we have to start it all over again? It doesn't make sense; why did we get those results? It was *frustrating*... I also remember feeling *satisfaction*, but I can't recall anything specific." (Lilly G)
	Ignoring/referring to instructions	"I was really interested in it... *I didn't have the energies* to do it. We were 'schmoozing' with going out for the observations. We were kids in 11th–12th grade; we had other things on our minds." (Daniel O)
		"I didn't take it that seriously. I didn't feel any satisfaction. The only frustration I had was about having to do it. I didn't submit anything on time... the high school kid approach." (Roy O)
Procedural understanding	Deep understanding	"I learned to plan an experiment, it was very useful to know that you need *calibration and control*... Ideally, we had to perform the observations three days in a row in order to ignore the *influences* of the weather. Practically, we didn't do it well enough. One of these times was during the birds' migration season, which *influenced the results*. I think that afterwards we repeated it in a different season, and the results got fixed... I remember having a little argument with my teacher, she claimed we needed *repetitions*, that I had to seed the bacteria three times, and I said that there are millions of bacteria in each drop. I didn't understand what she wanted form me, 'I was right!'... Today I understand that as a way of thinking it is *good to have repetitions*. I understood the *importance* of *repetitions* and different samples, I learned to ask questions." (Daniel O)
	General references	"*Control group*. It took us time to understand what it is and what it means... every time the teacher mentioned it, I wasn't afraid to

Table 2 (continued)

Criterion	Level	Examples
		ask again. At some point, I finally got it... I believe in the end we did it right." (Anna G) "I think that because we did the work *outside* and there were *many variables* that we didn't take into consideration, or things we couldn't measure because we didn't have the means to do it, there were things that were not done properly. Like the *control*. I think that *when we wrote the final report* we realized that there were many things we did not consider. From that we understood their *importance* and what is a proper inquiry, more than we did at the beginning of the project." (Rachel G) "We learned that there are all sorts of *'background noises'*, phenomena that you may not think about in the beginning, but you have to plan the experiment in a certain way, so it would not be influenced by them." (Leia O)
Changes occurring during inquiry	Deep understanding	"I remember *we* had a hypothesis that the plant oils inhibit the growth of other plants in the area. The first time, *we* went to a park in Tel-Aviv, but they treat the lawn there and don't let nature work, so we were surprised. So, during the inquiry *we had the thought* that perhaps choosing a location, a park, where they treat the soil is not such a good methodology. So we went to *another place*, untreated." (Dana O)
	General references	"The idea was to use cigarettes… but the results were opposite to what we expected. We were shocked!… *we found* an article describing a different method." (Sara O) "The hard part was *to think how* to go past those obstacles, the ones that you encounter only in practical work. Books cannot prepare you for that. It is a skill that gets better with time, with experience and learning from mistakes." (Leia O) "I guess it was all of us—Anna, me and the teacher, but we were high school girls in 12th grade. Did we know anything? Really. We also wanted to get a good grade, so every single thing *we asked the teacher*. We didn't have any interest to make those decisions on our own." (Lilly G)
	Ignoring/referring to instructions	"…Suddenly *the teacher told us* we needed to focus on other things, so we did some more experiments…the *teacher told us* if anything should have been changed." (Abigail G) "I don't remember the details...it came from the *teacher*...I do remember that about two weeks after the project started *the teacher told us* that the type of data was not sufficient for justify a conclusion, so we needed to expand our research and to focus on more than one plant... so we did it, we investigated the whole habitat." (Tom G) "I remember that we got results that contradicted what we thought; we based our hypotheses on the literature, but we got the opposite. The observations we made were too few to prove it statistically... we *didn't make changes*, we just *explained* in the analysis part why it could have happened." (Ruth G) "There was something that didn't fit our hypothesis and we had to figure out why... I think we were the ones who were supposed to make the changes. I don't remember sharing the results with the teacher all the time... we *left it as is*, and we found an *excuse to explain* why it didn't come out as expected." (Rachel G)
The affective point of view	Deep understanding	"I *loved* the observations, it was *interesting* to actively go, check, first by observing and afterwards by bringing samples to the lab and *planning the experiment*. However, I remember it was hard for me to do the experiment itself. I didn't know a lot about the materials and equipment. I really felt *frustrated and helpless*...

Table 2 (continued)

Criterion	Level	Examples
		towards the end, I felt *satisfaction*, because I felt things were 'flowing' and I finally knew about things I had no idea about a year earlier and that I found interesting." (Leia G)
		"We were *very excited* about the leaves, the boxes we made and the results, because it's something we created and we proved it in the lab... we found out that the result was opposite [to what we expected]. We actually discovered that! We were *shocked!*" (Sara O)
		"To us it was '*wow*', because it's not regular school work. ... You try to discover new things... and when we finished it we were *proud* we did this kind of work. For us it was really something, that we have a *product*. It's something we went through together." (Alex G)
		"You were thinking about ideas and then you handed it out, the *product* you have *worked* so much time on. And it looks nice and it is appropriate …you are really *into it*, you did it, you *worked hard* on it, it gives you a lot and it gives you a sense of *satisfaction*... You get involved with it, you want it to succeed, it is something that is *unique* to you." (Nataly G)
	General references	"I remember the *excitement* when we came back for the second data collection and found the same birds that we marked in our previous visit..." (Iris O)
		"Sometimes you *expect* certain results and you get something *completely different*. How can that be?...It was *frustrating*, because - what? Do we have to start it all over again? It doesn't make sense; why did we get those results? It was *frustrating*... I also remember feeling *satisfaction*, but I can't recall anything specific." (Lilly G)
	Ignoring/referring to instructions	"I was really interested in it... *I didn't have the energies* to do it. We were 'schmoozing' with going out for the observations. We were kids in 11th–12th grade; we had other things on our minds." (Daniel O)
		"I didn't take it that seriously. I didn't feel any satisfaction. The only frustration I had was about having to do it. I didn't submit anything on time... the high school kid approach." (Roy O)
Procedural understanding	Deep understanding	"I learned to plan an experiment, it was very useful to know that you need *calibration and control*... Ideally, we had to perform the observations three days in a row in order to ignore the *influences* of the weather. Practically, we didn't do it well enough. One of these times was during the birds' migration season, which *influenced the results*. I think that afterwards we repeated it in a different season, and the results got fixed... I remember having a little argument with my teacher, she claimed we needed *repetitions*, that I had to seed the bacteria three times, and I said that there are millions of bacteria in each drop. I didn't understand what she wanted form me, 'I was right!'... Today I understand that as a way of thinking it is *good to have repetitions*. I understood the *importance* of *repetitions* and different samples, I learned to ask questions." (Daniel O)
	General references	"*Control group*. It took us time to understand what it is and what it means... every time the teacher mentioned it, I wasn't afraid to ask again. At some point, I finally got it... I believe in the end we did it right." (Anna G)
		"I think that because we did the work *outside* and there were *many variables* that we didn't take into consideration, or things we couldn't measure because we didn't have the means to do it, there were things that were not done properly. Like the *control*. I think

Table 2 (continued)

Criterion	Level	Examples
		that *when we wrote the final report* we realized that there were many things we did not consider. From that we understood their *importance* and what is a proper inquiry, more than we did at the beginning of the project." (Rachel G) "We learned that there are all sorts of *'background noises'*, phenomena that you may not think about in the beginning, but you have to plan the experiment in a certain way, so it would not be influenced by them." (Leia O)
Changes occurring during inquiry	Deep understanding	"I remember *we* had a hypothesis that the plant oils inhibit the growth of other plants in the area. The first time, *we* went to a park in Tel-Aviv, but they treat the lawn there and don't let nature work, so we were surprised. So, during the inquiry *we had the thought* that perhaps choosing a location, a park, where they treat the soil is not such a good methodology. So we went to *another place*, untreated." (Dana O)
	General references	"The idea was to use cigarettes… but the results were opposite to what we expected. We were shocked!… *we found* an article describing a different method." (Sara O) "The hard part was *to think how* to go past those obstacles, the ones that you encounter only in practical work. Books cannot prepare you for that. It is a skill that gets better with time, with experience and learning from mistakes." (Leia O) "I guess it was all of us—Anna, me and the teacher, but we were high school girls in 12th grade. Did we know anything? Really. We also wanted to get a good grade, so every single thing *we asked the teacher*. We didn't have any interest to make those decisions on our own." (Lilly G)
	Ignoring/referring to instructions	"…Suddenly *the teacher told us* we needed to focus on other things, so we did some more experiments…the *teacher told us* if anything should have been changed." (Abigail G) "I don't remember the details...it came from the *teacher*...I do remember that about two weeks after the project started *the teacher told us* that the type of data was not sufficient for justify a conclusion, so we needed to expand our research and to focus on more than one plant... so we did it, we investigated the whole habitat." (Tom G) "I remember that we got results that contradicted what we thought; we based our hypotheses on the literature, but we got the opposite. The observations we made were too few to prove it statistically... we *didn't make changes*, we just *explained* in the analysis part why it could have happened." (Ruth G) "There was something that didn't fit our hypothesis and we had to figure out why... I think we were the ones who were supposed to make the changes. I don't remember sharing the results with the teacher all the time... we *left it as is*, and we found an *excuse to explain* why it didn't come out as expected." (Rachel G)
Learning as a process	Deep understanding	"It *takes time* to perform the experiments and observations and to *document* it all in writing. Even if you write something that you already knew, the writing process helps you *arrange* the details and *gain a better understanding*… Obviously, you cannot count on your memory, even if at the time things looked so obvious and simple and that 'there's no way I'll forget that. 'Writing the diary allows you to *retrospectively see the development*—the changes that have occurred from the first time I documented a phenomenon to the last. Sometimes, only in that way do you discover an important detail that you may not have realized in the beginning." (Leia O)

Table 2 (continued)

Criterion	Level	Examples
		"You have to *invest a lot of time* in choosing the topic and in the writing itself. Because *it's not something you can do in one take*, to write a work and 'that's it I'm done.' It's not an essay in history. You go, investigate, write, collect data, and eventually try to gather it all into something coherent, continuous, and unified, which has a meaning. So this process is a *process that requires time*… We were very organized. I remember that we looked for everything and *documented everything*, just *like we should have*. First we had the question, and then we found evidence to support it. And the other way around—we investigated the subject and then we asked questions... at the end of the day, if you want a good product, you have to be accurate, to *give references and support* everything. But it was also one of the *teacher's demands*. She was super organized." (Nataly G)
	General references	"The documentation was done using drawings, cameras and more, and it *certainly contributed* to writing the final conclusions in the 'Biomind' report." (Iris O)
		"Being organized throughout the data collection and *documentation* are *critical*, so that when you eventually come to analyze your data and use them, you could *understand and remember* what you have done." (David O)
		"You don't start a research from scratch. You first go through the *literature*. Your *hypothesis is constructed* based on it. After all, if we started from scratch each time, we would never make *progress*… it is *important to document* and write. I'm sure we wrote it somewhere. I did not do it properly." (Roy O)
		"We had a notebook in which we wrote the date, the hour, which data were collected. [How did it help you?] This *allowed us to make graphs* at the end of the project... this is how you collect data. I don't think it was obligatory, but it was *necessary.*" (Rachel G)
	Ignoring/referring to instructions	"…Suddenly *the teacher told us* we need to focus on other things, so we did some more experiments and *we had to* look for more background in the literature... We had lists. Because we *had to* describe the observations we made. [How did it help you?] *It helped* a lot in writing the final essay. You cannot *remember* everything." (Abigail G)
		"We documented most of it, there were lists… it was one of the *demands* of the project." (Tom G)

Changes Occurring During Inquiry Within this criterion of dynamic inquiry, differences were found between the groups. In the interviews, the participants were asked to recall and describe changes that occurred during the inquiry process; most were also asked to refer specifically to the different categories of this criterion. Although,, in both groups the participants referred to the same categories, differences were found in the way participants of each group perceived these changes and the way they reacted to them. Only in the guided inquiry group did participants attribute the changes to the teacher's instructions. That is, when asked why changes were made, or who initiated the changes, half the interviewees in this group stated that the teacher told them to make a change. The other half said that even when they got unexpected results, or when they found out a change should have been made, they did not change anything in the experiment but rather ignored it or related to it in the discussion, making "excuses" for the unexpected results.

In the open inquiry group, while half the students did not remember having to make changes or who was the one who initiated those changes, the other half did describe changes that occurred. In contrast to the guided inquiry group, the open inquiry group did not refer the need to make changes to directions from the teacher but rather to "necessity." In addition, none of these participants reported ignoring the need for a change.

These examples, especially Leia's words, indicate that although the interviewees in the open inquiry group did not say so explicitly, the changes were initiated by the students and not by the teacher; they used the word "we," did not mention the teacher at all in this context, describing how the difficulty of the process, and that they had to think and made mistakes, from which they learned.

Learning as a Process Interviewees were asked about documentation, the time they dedicated to the project, and the time spent researching additional literature throughout the process of inquiry (see Table 1). In both groups, the majority of participants related mainly to the importance of the first two elements. Nevertheless, differences were found between the groups in the way they described the importance of these components.

In the guided inquiry group, more than half the interviewees merely stated that documentation, literature search, or time investment were parts of the demands of the program or came as an instruction from the teacher.

It is important to mention that some of the interviewees who stated that these process components came as a demand, did explain their importance, when asked to. However, they made only general reference. A few interviewees related to the importance of those components without referring them to the instructions they got. The same interviewee also referred to the time investment component. In contrast, in the open inquiry group, seven (out of nine) interviewees stated the importance of the process components without referring to it as a demand coming from the teacher. Some of them made only general references, like saying it was important and contributing without elaborating, but some of them exhibited deeper understanding of the importance of these components and provided detailed examples.

To summarize, results revealed that 9 years after graduation, there are similarities and differences between students who have experienced open and guided inquiry, in their expression of dynamic inquiry criteria. While the affective point of view and procedural understanding are similar for students of both groups, different expressions were found regarding changes occurring during inquiry and learning as a process. In both cases, the main differences related to the locus of control. The majority of interviewees who experienced guided inquiry as students referred changes and the importance of the process components to the teacher's instructions. In contrast, the interviewees who experienced guided inquiry as students referred these to themselves or to the actual necessities that arise during the project.

Retrospective Perceptions of the Inquiry Project and the Teacher Support

Students' Memories from the Inquiry Project The interviewees were asked to describe their project—the topic or inquiry question and anything else they remembered from it. In both groups, about half the interviewees described the topic and the specific inquiry questions, sometimes naming the organisms they investigated and including some details about the practical work or the specific habitat they were investigating:

> We measured the level of pollution on trees in Tel-Aviv. We mainly performed observations. We also made a very nice experiment—we put leaves in a box made of glass and we flew in polluting smoke. Then we checked how it affected the chlorophyll. We analyzed it with a microscope and took pictures showing spots on the leaves. I remember the smoke had an influence. (Sarah O[1])

> We looked at the relationships between a bush and the insects. We compared between two bushes—one that grew under direct sun and another one that grew in the shade. We observed the relationships, took pictures, and compared them. (Ruth G)

> We were investigating the "Retem" plant in its habitat at the entrance to the reserve... the main investigation was focused on its survival conditions. The primary issue was performing the observations; we even had one at night... if there were snails or caterpillars, and how the plant developed. At night, we checked which nocturnal animals hang out there... we took soil samples and checked them in the school's labs, like soil's acidity. (Tom G)

> It was about the life between two Eucalyptus trees, one of which was growing in the water and the other one out of the water... we have been investigating microorganisms. We would take water samples and soil samples and examine them in the school's labs. We also investigated and made lists of the plants and animals in this area, tadpoles etc. (Abigail G)

In both groups, the other half of the interviewees, in addition to the above, described their projects vividly and with more details. For example:

> Carlos and I investigated the influence of water pollution on life in the river—species abundance, species distribution and the pollution's general effect on the ecosystem. We did it in the "Yarkon" river: the polluted section, the less polluted section and the clean one. We compared the vegetation and the animals. That was the observation. We also made lab experiments: we took Daphnia—it's a water flea—in the winter pond. The Daphnia is transparent and you can easily see all of its inner parts. We collected Daphnias and water samples; we took them from different parts of the river—polluted, less polluted and clean. We looked at them through the microscope and checked their stress levels in comparison to Daphnia from fresh clean water. We checked stress by counting the number of heartbeats; in Daphnia you can see the heartbeats and you count one minute, half a minute… We added different concentrations of a detergent to the water… I think that at some point we killed it. (Daniel O)

> We investigated the "red gorge" next to the Iris-reservation. There were two aspects—one slope facing north and the other facing south, and because of that there were different climates, although they were only a few meters away. There were

[1] In the reporting of our research, we assigned single name pseudonyms for each student. We used the letter G to indicate that the student was a member of the guided inquiry group. We used the letter O to indicate that the student was a member of the open inquiry group. When we refer to statements of students, we follow the last sentence of that student's statement with their pseudonym and group letter, within parentheses.

differences in the plants, animals, and the entire ecological web there, in the area we investigated. Then we documented throughout the day the temperatures, the activity of the animals, which plants grew here and which on the other side. There were mainly observations, we hardly performed experiments. There was a "Ricinus" bush right in the middle; half of it was in the shade and the other half in the sun most of the day. There were very big differences between them in the moisture and the soil. The questions were about the differences in a-biotic and biotic factors; today there are foxes all over that area and the gorge is destroyed—the area where we did our project—they are paving a new road. But I cared about this place. (Rachel G)

Some participants referred to special experiences they went through. Some described how, as adults, they still feel a connection to the area or topic they investigated as kids:

For years I would go back to this pond. I told myself "this is where I did my project." I remembered the exact spot. (Abigail G)

…Every time I drive past this pond, I think "this is where I carried my investigation, and here, although not seen, live millions of microorganisms." (Lilly G)

One day we went to the "Antipatris fort" park. Daniel and I were there for several hours, investigating, and we got lost. It was really fun! (Carlos O)

It was amazing to go to the "Antipatris fort." I came back there alone afterwards. It's one of my favorite places. (Daniel O)

The Teacher Support As students brought up memories from high school, they were asked to describe their biology teachers and their roles. In both groups, the teacher was described as a guide, whose main role was to support her students and show them possible directions, rather than to dictate their actions or merely provide knowledge. For example:

My strongest memory from the project was the way our teacher helped us on her own time after school: to finish the project, with the graphs, explanations. She was amazing. We *consulted* with our teacher, she *accompanied* us through the process… but she didn't give us the answers, she *directed* us with questions—like "what would you do?"—And we got to the answers *on our own*. I really loved her way, for that reason I remember a lot. (Ruth G)

The teacher should be there to help you, to *direct* you but let you do it *on your own*. If there is a problem, you can turn to her and she would direct you again, so in the end of the process you would understand what you did… with our teacher it was exactly like this. (Alex G)

The teacher *directed* us in all stages of the project. She did give us some free space. After all, if she got involved in each step it would have been her project and not ours. She *guided* us when something went wrong… she was just there when we needed her, not as a cop, but as a *guide*… she made us work hard. Even when we wanted more help - and she was "bad" and didn't help us—we knew that she wanted to teach us how to think, and that we would benefit from it. (Lilly G)

The teacher gives the missions, like to decide upon the topic of the inquiry. She is the one with the knowledge, so she could tell you if you could do this (based on the time

> limit and your own abilities) … She lets the student work *independently, plan things*—but make sure that you do it right and within the time limits. If a control is missing, she just says it's missing—but not what exactly you should do. *Direct* the students so they won't wander around. (Roy O)

> One of the important things that the teacher did was that she made us *students do things*. Second thing—she was on guard all the time, that no one made mistakes… and of course—*inspired* us and led us… she gave us general ideas, but never told us "do this and that." (Daniel O)

As seen in the last example, some students also referred to their teachers' role in setting limits and goals. This included making sure the students were working properly and would eventually meet the requirements. It is interesting to note that some of them stressed that the teacher should have been stricter and should have given more instructions since, after all, the project was done by "kids":

> One of the most important things is to remind the kids to move themselves, and *set a* very *strict schedule*. (Daniel O)

> The teacher's job was to *direct* us, *support* us technically and professionally… to check that we constructed the inquiry as required, that our methods were applicable (as well as accepted and known)…to *follow us*, to see that we were involved in every stage, that we understood what we were doing. … This is important both for spotting potential mistakes and for motivating the student. (Sarah O)

> Someone needs to *supervise* and remind us to do things. It's very important, especially in cases of problematic kids. If you just let them do what they want, there's no way it would happen. (Jonathan O)

> Maybe our teacher gave us too much freedom. We were students in 11th and 12th grade. In high school the teacher should be more involved, to give directions in every step. If the kid asks you, it means he wants to learn, and you should give him the knowledge… teachers should not send kids to find knowledge on their own. (Ruth G)

The Contribution of the Inquiry Project Participants were also asked in which ways the inquiry project contributed to them. Similar answers were given in both groups. The most prevalent answers referred to experiencing "real science" and acquiring practical skills/science practices. Practical skills that were mentioned in the interviews included taking measurements, documentation, graphical presentation, writing skills, and information literacy. They also stated that some of these skills became useful in later stages of their academic studies, either science-related or not. Only two students of each group related to developing scientific thinking or general thinking skills. Few students added that this experience, which made them feel like real investigators, initiated their genuine interest and passion for science. For some, it was the trigger to choose a science-related career or academic studies, as adults:

> Later on, in university, you have different projects, but they all rely on this one. It was the first time I saw different kinds of graphs, and presented the data in the table in a way that reflects what I was doing. These are *tools you eventually use*—either in university or in your daily work—and those tools were first given to me in the bio-project in high school. (Nataly G)

> *When you are experiencing science and scientific thinking* for the first time, you acquire a type of *logic* that goes with you… it also planted in me *love* for this, *persistence*, it's a process—you don't get immediate results. (Dana O)

> The feeling that I am an *investigator*… a sense of *passion* for something that made me continue studying science. Not everyone gets out of high school with passion for something… it taught me to be an *independent worker*. Till then we were never independent and then we did this big project. (Ruth G)

Some students thought that the project had pedagogical value, advancing them by making them develop their own sense of responsibility, discipline, and persistence, as well as their ability to work both independently and in teams.

> This experience definitely teaches you a lot. Its pedagogical value is just as important [as acquiring skills and knowledge]—taking *responsibility* for a project, working on it for a long time and developing a sense of *commitment*. (Leia O)

> …We had never done it before, and to us it was *an investigation*… it also contributed to developing *independent* working skills, not relying only on the teacher. We had to organize it alone, take *responsibility and initiatives*. (Anna G)

Although the vast majority of interviewees stated that the project contributed to them, as demonstrated above, in each group, a few students said the project did not contribute anything or would contribute only to students who continue studying science in later stages of their lives. Some of them, when asked directly regarding specific potential benefits of the project, like teamwork or thinking abilities, said that these were not skills acquired from the inquiry project. However, these students mentioned that it was fun and different than regular frontal classes:

> …Now, when I think about it, it may contribute to a kid who does the project knowing that he would continue it later in his life. He would start looking at things differently, in terms of documentation and observations, but it is *only for someone who will continue studying science later*. If he doesn't continue—I don't know how and where he would feel the contribution. (Alex G)

> If the project contributed something, then I didn't notice that. I don't think I learned something from the project itself… No, I did learn—I learned that many times you can just make up stuff… but we were *active*. It wasn't just another assignment of sitting in a library—it was *nice to get outside* of those four walls. (Abigail G)

> I didn't get too much from it. Not because the project is not good, my attitude to it wasn't good. If they were supposed to teach scientific approach or scientific thinking—I didn't have it in this project... if you were given an experiment to perform, and without doing it you can write a lab report... for someone that knows what he's doing it would be a problem. (Roy O)

To summarize this section, participants of both groups shared similar perceptions of the inquiry project, its contribution, and the teacher support. Most remembered many details regarding their projects and their teachers and explicitly explained how influential they were. The vast majority of the participants felt influenced by the project, mostly by acquiring skills that served them later in their lives and by initiating their interest in science.

Discussion

Much has been said and written about the importance of inquiry in science education, including its role in preparing students to become scientifically literate and active citizens in today's world. The current study attempted to offer a new perspective on this issue, by investigating the perceptions of adults in today's world who had been engaged in open and guided inquiry projects as high school students. Results will be discussed in two sections. The first section addresses the first research question—the results of the characterization of the inquiry projects as a dynamic inquiry will be discussed, while highlighting the connection between the criteria of dynamic inquiry and skills required of a scientifically literate citizen in the twenty-first century. The second part addresses research questions numbered 2 and 3, discussing the observations about students' perceptions of the inquiry project, its contribution, and the science teacher. This will shed light on what the students actually took with them to adulthood.

Expression of Dynamic Inquiry Criteria

One purpose of this study was to explore the characteristics of dynamic inquiry in both open and guided inquiry projects, as retrospectively expressed by the students, years after graduation. These criteria overlap some twenty-first century skills (NRC 2012b)—those skills that are sought by employers in today's world (National Association of Colleges and Employers 2016; Sarkar et al. 2016)—and therefore can reflect on the benefits of the inquiry projects to these adults. These skills will be discussed for each criterion.

Although participants of both groups—open and guided inquiry—referred to all the criteria of dynamic inquiry, there were differences between the groups in the expression of some of these criteria. While similar expressions were found in the *affective point of view* and *procedural understanding* criteria, the groups differed in the expression of *changes occurring during inquiry*, and *learning as a process*. Sadeh and Zion (2009) compared the influence of open versus guided inquiry learning approaches on dynamic inquiry performances and expression among high school biology students. In their study, open inquiry students expressed significantly higher levels of performance in the *changes during inquiry* and *procedural understanding* criteria, while no significant differences were found in the criteria *learning as a process* and *affective points of view* criteria. The differences found between the results of that study and the current one may imply that time does make a difference, and the characteristics that were found in high school students may not always apply to adults. Thus, if we claim that inquiry (or any other method) can help in promoting science literacy or any set of skills in adults, we ought to observe not only high school students but also the adults they have become.

The Affective Point of View The affective aspects of dynamic inquiry are derived from the dynamic and eventful character of the inquiry process itself. Difficulties, unexpected results, and successes often lead to feelings of surprise, frustration, and satisfaction (Zion et al. 2004). Results of the current study indicate that both groups showed similar expressions of this criterion. Nine years after graduation, the participants of both groups could clearly recall the feelings they experienced throughout the process of inquiry. They expressed a mixture of curiosity, frustration, surprise, and disappointment, along with enthusiasm and excitement. Similar results were observed in a study that compared the influence of open versus guided inquiry on dynamic inquiry performances among high school biology students. In that study, like the current one, no differences were found between students of both groups in the expression of the affective point of view (Sadeh & Zion 2009). Indeed, the affective characteristics of inquiry—both open and guided—were found in various previous studies (e.g., Kapon 2016; Kawalkar & Vijapurkar 2015; McConney et al. 2014). Some have also suggested that they are developed especially during outdoor learning (e.g., McGlashan et al. 2007; Orion 2007), like both inquiry projects in the current study. Studies stressed the importance of the affective influences of inquiry on science learning and on attitudes towards science (Kapon 2016; Kawalkar & Vijapurkar 2015). However, these studies were performed during or right after the inquiry process took place. The current study offers new insights by showing that the affective dimension of the inquiry experience and its impacts extend beyond the immediate influences. The students carry these experiences with them into their adult lives. They remember the inquiry experiences and how they made them feel. This is important because students' emotions and attitudes about inquiry are important for preparing them to become active participants in society. As adults, these attitudes affect their reaction to issues that influence them and society, along with the extent to which they support proposed political decisions (Ornstein 2006). Unfortunately, the affective aspects of learning and of skills, such as intrapersonal and interpersonal skills, are often ignored (Drew & Mackie 2011) and are less investigated than cognitive skills (NRC 2012b). Given their importance and their long-term influences, it is suggested that further research would give more attention to the affective aspects of science learning.

Procedural Understanding Procedural understanding constitutes a large part of the inquiry projects in high school. It includes knowledge about methods—when, how, and why to use them—and their limitations. It may also be described as the *thinking behind the doing* or *knowing why*, in addition to performance itself (Arnold et al. 2014; Roberts 2001). In the current study, most participants, of both open and guided inquiry, exhibited only general understanding of the importance of different inquiry components (such as repetitions, control, limitations of isolating variables). In contrast, in the study conducted by Sadeh and Zion (2009), open inquiry high school students reached significantly higher levels of performance of procedural understanding than did guided inquiry students. The similarity between the groups of adults, in contrast to the differences found between high school students, may be due to new perspectives the participants gained with time. For example, several interviewees related that they forgot many things about their inquiry, while some students from the guided inquiry group explicitly said that they only understood the importance of the procedures at the end of the project or after graduation. One way or another, 9 years after graduation, only half the students of both groups referred to procedural understanding. Furthermore, those who did exhibited only general understanding of those inquiry components, usually simply stating that they were important, without providing explanations. These results suggest that procedural understanding and the *knowing why* behind the procedures need to be given stronger emphasis by science educators, and perhaps specifically taught, to consolidate them and make them less likely to be forgotten over time.

This is important because procedural understanding has an educational value and supports science literacy (Roberts 2001; Roberts et al. 2010). First, we, as educators, want students to understand why they are doing what they are doing. Only then can meaningful learning be obtained (NRC 2012b). Second, procedural understanding includes the comprehension of concepts such as validity, reliability, objectivity, reproducibility, and generalization. These should be applied within different contexts or situations, and they are key components not only in planning an investigation but also in critically interpreting and evaluating data from investigations (Arnold et al. 2014; Roberts et al. 2010). These skills, which are often related to information literacy, are necessary for citizens in the twenty-first century (House of Commons 2017; NRC 2012a).

Changes Occurring During Inquiry The current study shows that as adults, individuals remember the way they handled unexpected results and changes that needed to be made. Adults who experienced open inquiry remember how they overcame their hardships and reacted to unexpected events due to reality's necessities. They remember doing it by making a change that required thinking and hard work, while learning from their own mistakes. On the other hand, those who experienced guided inquiry remember ignoring the need for a change, making excuses or acting on their teacher's instruction. Moreover, some students even said that the main lesson they learned from the inquiry project was that excuses can cover up for lack of knowledge or lack of action. There is no doubt which of these approaches to life we, as educators, would like to foster. Dynamic and unexpected results are not only important aspects of scientific endeavor (Khishfe and Abd-El-Khalick 2002) but also other important aspects in life. Some of the twenty-first century skills refer to the ability to face unexpected results; these skills include creativity, problem solving, decision making, flexibility/adaptability, initiative, and self-direction (NRC 2012b). Therefore, as results indicate a greater expression of these skills among open-inquiry participants, these considerations should be taken into account when discussing the type of inquiry appropriate for high school students. Similar differences between open and guided inquiry have already been reported for high school students (Sadeh & Zion 2009). Nevertheless, the current observation that adults carry these experiences with them further emphasizes the importance of approaches that would encourage students to cope with unexpected results.

Learning as a Process In this study, differences were found between the open inquiry and guided inquiry participants in the way they expressed their understanding of the components of learning as a process and their importance. Similar to the findings regarding changes occurring during inquiry, in the guided inquiry group, most interviewees merely stated that the process components were parts of the demands of the program or came as an instruction from the teacher. In the open inquiry group, however, most interviewees explained the importance of the process components without referring to them as demands coming from the teacher. Furthermore, the guided inquiry participants that did relate to the importance of the process components made only general references about their benefits for writing the final assignment. Open inquiry participants related to the importance they felt to understand the process. Some open inquiry participants also referred to the importance of the process components, which allowed them to see the project as a continuous dynamic process, to reevaluate their knowledge and actions, and to make progress. Therefore, results of this study imply that open inquiry students gained better understanding of learning as a process. Understanding the importance of these elements may reflect the development of process skills that include management (of time and human resources), information retrieval and processing, critical thinking, and oral and written communication (Brown 2010). Developing process skills means that in addition to learning discipline-specific concepts, students simultaneously develop transferrable skills, which is a key element in preparing students for their lives as adults in the twenty-first century

(Bailey et al. 2012). To conclude, findings imply that open inquiry has promoted the development of these transferable skills to a greater extent than has guided inquiry.

Retrospective Perceptions of the Inquiry Project and the Teacher

Although we assume that the skills discussed above are developed during inquiry, little is known about what students actually take with them or appropriate from the inquiry process (Patchen & Smithenry 2013). In order to get an additional perspective, we specifically asked these adults what they actually remember from their projects and teachers and how they perceived the projects' contribution to their lives. Looking back at their inquiry projects and the science teachers, 9 years after graduation, participants of both groups expressed similar perceptions. These will be discussed in this section.

Students' Memories In both groups, most of the participants described their inquiry projects in detail. Some referred to special experiences that had affective influences and made them feel connected to their project. Unlike their *regular* classes, the inquiry process was a unique encounter to them, which summoned these special experiences. It is possible that remembering the project in detail is related to these feelings of connection and affective influences. Studies showed that emotions influence learning and performance. They affect cognitive processes, information processing, storage, and retrieval; memory often depends on emotions experienced when information was stored (see review in Kim & Pekrun 2014). Furthermore, outdoor learning was found to influence students' attitudes to science, and the degree of long-term knowledge retention, of both activities and contents (Fägerstam & Blom 2013). These findings further stress the importance of the affective aspect of inquiry, which was discussed in the previous section. The fact that the inquiry project and the knowledge or concepts acquired during this process are remembered 9 years after graduation all indicate that this process does contribute to science literacy of adults. For example, a student like Lilly, who is not a scientist today, still remembers the presence of microorganisms around us.

Science Teacher's Support In both groups, the teacher was described as a guide, whose main role was to support her students and show them possible directions, without dictating the specific way to go. This description is in concordance with the new approach to the role of the teacher, according to which the teacher shifts from the traditional instructing position in order to encourage students to take responsibility for their learning (NRC 2015). When it comes to inquiry, this approach allows students to understand that they are responsible to solve problems and have opportunities to take charge of scientific inquiries (Patchen & Smithenry 2013). Feeling responsible for their own inquiry was indeed expressed by the interviewees. Interestingly, this notion was shared by students of both groups, although when describing the specific characteristics of the inquiry, guided inquiry students referred many of their actions to teacher's instructions. This implies that although the teacher may have directed the guided inquiry students, the students felt responsible for the process. The similarity between the groups exemplifies that in dynamic classrooms, the distinction between the different levels of inquiry is not always clear-cut. Despite the initial intentions of the teacher to establish the level of students' autonomy, class dynamics may influence the actual level of guidance. Factors like the goal a teacher has for inquiry, characteristics of her teaching context, and skill level of the students all shape the level of inquiry that can be optimally and practically employed (Blanchard et al. 2010). Some researchers have questioned the level of guidance and support that open inquiry provides to the students' learning and claimed that this lack of teacher's guidance does not allow an effective learning (Kirschner et al. 2006). Although some interviewees did say that the teacher should have been stricter and given more instruction, these voices were heard in both groups and represented the minority of interviewees. All in all, findings of the current study revealed that both guided and open inquiry students felt they got guidance and support from their teachers. The importance of teacher guidance is not denied, to the contrary, it is supported by these findings. The impact science teachers have on their students was further revealed in this study. Nine years after graduation, participants described their teachers' behavior in detail, saying how significant their support was for them, and appreciating their efforts to make them succeed and make them feel successful. Sometimes, it was the main thing they remembered from the inquiry project. Science teachers should be aware of the impact they have on their students.

Contribution of the Inquiry Project In both groups, participants mostly referred to experiencing *real science* and acquiring practical skills. They explicitly said these skills helped them later in their academic studies or jobs, not necessarily those that were science-related. In other words, the participants described what they perceived as the development of transferable skills. The ability to evaluate scientific information (i.e., Information literacy) was also mentioned as a contribution. Some mentioned pedagogical values like developing responsibility, discipline, and persistence, as well as independent and teamwork abilities. These attributes may contribute to the performance of adults in today's world, and the last two are considered as twenty-first century skills (NRC 2012b). Finally, participants said that one of the contributions of the project was love for science, which led some of them to choose science-related careers. Creating positive attitudes to science and encouraging students to engage in science careers are stated as central goals in many documents that set forth teaching standards (e.g., House of Commons 2002; NRC 2012a). These findings match and further support our findings regarding the dynamic inquiry criteria and the development of skills they reflect. These findings concur with findings from previous research. For example, in a study conducted by Sadeh and Zion (2012), the majority of both open and guided inquiry high school students said that the inquiry project was beneficial for them, referring to cognitive and affective aspects. They mentioned the same affective benefits as the ones mentioned by adults in the current study. Nevertheless, the high school students referred mostly to cognitive benefits that were more specific to science and scientific inquiry, while adults in the current study referred also to more general skills and attributes, as described above. This difference supports the notion that observing adults offers another perspective on science education and may shed more light on learning outcomes.

In this study, we investigated the benefits of inquiry-based learning, as expressed by the participants themselves and as reflected in the way they related to the dynamic inquiry criteria. It would be interesting to further investigate how inquiry activities specifically improved skills, by investigating the current state of proficiencies of adults who experienced inquiry projects in school. Further investigations of this subject can also include the use of quantitative tools, to support the results of this study and allow us to see a broader picture.

Conclusion

Through the eyes of adults who were engaged in open and guided inquiry projects as high school students, both types of inquiry presented the characteristics of dynamic inquiry. As discussed above for each criterion, these characteristics can reflect the development of skills that can be valuable for science-literate adults in today's world. Indeed, although the criteria of dynamic inquiry are not explicitly mapped as twenty-first century skills, there is an overlap (NRC 2012b). Results of this study may indicate that both inquiry approaches similarly promoted the development of interest, persistence, procedural understanding, information literacy, and science literacy. All of the above stress the importance of inquiry-based learning in both guided and open inquiry levels.

However, we suggest that open inquiry may promote the development of process skills, initiative and self-direction, decision making, flexibility, and adaptability to a greater extent. Acquiring some of these qualities was also explicitly mentioned as the main inquiry project contributions to the adult lives of the participants. Some of the qualities listed above are not only valuable skills for science-literate citizens in today's world (Australian Curriculum Assessment and Reporting Authority 2012; European Commission 2015; House of Commons 2017; NRC 2012a, b), but they are also listed as the top attributes that employers seek in their employees. For example, the recently published Job Outlook Survey by the National Association of Colleges and Employers (2016) found that ability to work in a team, problem solving skills, initiative, and flexibility/adaptability were rated among the top ten attributes sought by employers. These qualities were also rated as the top five skills sought by employers in science-related jobs (Sarkar et al. 2016). In addition to developing skills, adults who were involved in inquiry projects developed positive attitudes and passion for science; remembering the content knowledge and activities they were involved in and the support of their teachers. Therefore, results of this study imply that inquiry, and particularly open inquiry, helps develop valuable skills and personal attributes, which may help the students in their lives as future adults.

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