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Teacher views on inquiry-based learning: the contribution of diverse experiences in the outdoor environment

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Abstract

In this study, we challenged science teachers' views of inquiry-based learning as being merely experimental, causal, and controlled. We studied science teachers enrolled in professional development programs that consisted of three different inquiry-based learning experiences in the outdoors: ecology, sociology, and archeology. These three cycles of investigation included online collaborative planning, fieldwork and collaborative online data analysis, and online communication. Data collection included pre- and post-PD, open-ended questionnaires, interviews and written reflections. Qualitative content analysis was informed by the literature referring to procedural and epistemic aspects of inquiry-based learning. Other themes that emerged from the data included the place of collaborative learning, the use of technology, and the contribution of the outdoor environment. We found a clear shift in teachers' views about inquiry which ranged from vague explanations and descriptions of inquiry as merely student-centered learning, to more sophisticated views. The teachers valued the outdoor environment highly for learning and provided interesting insights into how to integrate in-school and out-of-school learning. Collaborative learning supported by technology was perceived as an effective vehicle for meaningful learning. An incomplete shift into the highest epistemic explanations is explained by insufficient opportunities for face-to-face explicit discussions about scientific inquiry and inquiry-based learning.

Keywords: Inquiry learning, Outdoor, Epistemic, Procedural

Introduction

In the last decades, scholars believe that learning which is driven by meaningful questions about phenomena that students investigate themselves has the potential to enhance better understanding and higher order thinking (Crawford 2014; NRC 2012a, b; Osborne and Dillon 2008). As science teachers are key figures in advancing all forms of project-based and inquiry-based learning, they need to have good knowledge about inquiry and inquiry learning, and the dispositions to teach through inquiry. As shown in the next section, an underdeveloped view of inquiry, in the epistemic level, can often lead to associating inquiry learning only with the natural sciences, or to adopting a narrow approach to inquiry as expressing a single scientific method—the experimental method—with controls, replication, and isolating and controlling the variables. This can lead to an overemphasis of procedures and technicalities rather than on the intellectual work and the curiosity and creativity that characterize scientific work. In Israel, where this study took place, such an approach is reinforced in official documents from the Ministry of Education (Levin-Peled and Tal 2015) that guide science teachers to enact causal, experimental, comparative, and quantitative inquiry projects in their classrooms.

In our study, we challenged this reality, and investigated how involving science teachers in collaborative, inquiry-based learning experiences in different fields and genres, and in out-of-school environments could promote the development of complex views about inquiry-based learning. To follow-up on the changes in the science teachers' views, we addressed the following research question:

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To what extent do different experiences of inquiry affect teachers' views of inquiry regarding a) the nature of inquiry (inquiry genres, inquiry in different disciplines or fields, and inquiry as a collaborative effort), and b) outdoor inquiry?

Literature review

Research literature on inquiry-based learning and on outdoor education, which was the context in which we challenged teacher views framed our study. In this section, we focus on epistemic aspects of inquiry-based learning, on teaching inquiry and on the challenges teachers face in their classroom practice.

By "inquiry", scholars in science education refer mainly to two activities: to what researchers do in their everyday work (i.e., scientific research), and to inquiry-based learning. However, as Furtak et al. (2012) argue, science educators mean different things when referring to inquiry-based learning or teaching. Generally speaking, integrating inquiry-based learning as a teaching approach aims to develop the understanding of scientific ideas and the nature of science (NOS), the understanding of and the use of scientific practices in conjunction with learning subject matter ideas and principles, and thinking skills (Duschl and Grandy 2008). In the social and cognitive domains, teaching inquiry requires engaging the students in collaborative tasks that involve reading, asking questions, planning the means to enable answering the questions, collecting and interpreting data, drawing conclusions, and offering new understandings. According to this approach, students ought to be engaged in evidence-based meaning-making, in developing explanations, and in representing knowledge (Bybee 2000; Furtak et al. 2012; Hmelo-Silver et al. 2007). Yet, despite much evidence on the merits of inquiry-based learning, and worldwide calls to introduce and practice inquiry learning (NRC 1996, 2000; Furtak et al. 2012; McNeill and Krajcik 2008; Zohar 2000), many teachers avoid teaching through inquiry in their classrooms or outside their classrooms for many reasons. They struggle with epistemological, procedural, pedagogical and organizational challenges that prevent meaningful fulfillment of inquiry learning as will be discussed in a following section (Crawford 2007; Minstrell and Van Zee 2000).

Moreover, Hodson (1998) argues that because inquiry can be regarded as either literature or media based, field based or laboratory based, decisions have to be made about the objects, events and phenomena to be studied, about the sources of information, the experimentation and so forth. These conceptual and epistemic decisions should be negotiated between teachers and students. This ongoing negotiation requires the development of interpersonal competences (NRC 2012b) that are associated with the social dimension of inquiry (Duschl 2008).

With respect to inquiry as "what researchers do", we know that researchers work in a variety of fields, and their studies represent a range of genres and methodologies that reflect the type of questions they ask and the theories that frame their studies. In the science education literature, the question of how knowledge is created is an epistemic aspect commonly addressed as the nature of science. Despite the range of fields, genres, and methodologies, being used in research, there is broad agreement about basic cross-field principles such as clarity, consistency, and transparency in all fields. One can expect, therefore, that inquiry-based science education should reflect the nature of scientific inquiry, or the epistemologies of science as expressed in its diverse forms. However, again, the research literature shows that teachers struggle with understanding the nature of inquiry-based learning and with teaching non-prescriptive inquiry to their students (Crawford 2014; Furtak et al. 2012; NRC 2012a) and that students struggle with epistemic characteristics of inquiry (Sandoval 2005). According to the K-12 Framework for Science Education, science education should not only focus on preparing future scientists and engineers, but also expose students to the beauty of science and to how scientific knowledge is generated (NRC 2012a). Thus, learning science should equip learners with tools that enable them to use scientific principles in personal and public decision-making processes, and take part in discourse about science and technology (Sandoval 2005). Science education should encourage students to continue to learn about science outside school in their everyday life as well. inquiry-based learning and project-based learning can uncover a variety of opportunities to teach, through experiencing a range of methods in which knowledge is both created and communicated (Crawford 2014; Duschl 2008; Osborne 2014a).

Teaching inquiry-based science

A great body of literature indicates successful inquiry-based and project-based learning (Bell et al. 2010; Marx et al. 2004; Sadeh and Zion 2009; Zohar 2004). Although the leadership of the teacher in the process is crucial (Crawford 2000; Hmelo-Silver et al. 2007), many science teachers struggle with the main goals of inquiry learning and with structured prescriptive practices, even such that use a hands-on approach (Abd-El-Khalick et al. 1998; Osborne 2014a; Wee et al. 2007). As Crawford and Capps (2018) argue, research findings indicate that the majority of teachers hold limited views of inquiry-based instruction and of the nature of science in general, and these views are reflected in their teaching practice. Many teachers focus on teaching the technical skills of measurement, documenting data, and the conditions for assuring a successful experiment, and often, any hands-on activity seems sufficient to fulfill the basic requirement of the curriculum. Less attention is given to the conceptual and epistemic aspects of the inquiry design and the data analysis processes, to interpretation and reasoning, to the relationship between evidence and explanations, and to the meaning-making activities. In more extreme cases, inquiry is seen as being equal to conducting laboratory experiments, which are frequently prescriptive and guided by a manual. Such approach is a teacher-initiated and teacher-centered process, even if students are active (Crawford and Capps 2018). Although Furtak et al. (2012) found higher effects in studies of students engaging in the epistemic domain of inquiry and in studies where the procedural, epistemic, and social domains were combined, commonly, the procedural aspects of inquiry are better taught than the epistemic ones (Osborne 2014a; Sandoval 2005).

Despite the recent tendency in the USA to refrain from using the term "inquiry" as an isolated activity, and preferring scientific practices to be integrated with core scientific ideas and crosscutting concepts, in this study we use the term "inquiry" for two main reasons. First, inquiry-based learning has been central to science education from its early beginning, and it encapsulates the history of meaningful science education despite the above-mentioned difficulties. Second, inquiry-based teaching is advocated worldwide and even in the US, scholars are engaged in promoting and supporting inquiry- or project-based learning.

Teaching inquiry and professional development in various disciplines

In light of the above, and based on other scholarly work, it seems that the simplistic views of inquiry-based learning and inadequate understanding of the goals of inquiry-based learning create a few obstacles in teaching inquiry (DeBoer 2004; Sandoval 2005). Professional development programs (PD) can help teachers overcome such obstacles by developing their concept of inquiry-based learning and by enabling them to practice the teaching of inquiry in supported environments. The research literature shows that it is important to connect the PD activities to teachers' everyday practice, and to involve them in doing inquiry (Blanchard et al. 2009; Darling-Hammond and McLaughlin 1995; Loucks-Horsley et al. 2009). inquiry-based learning conducted in a PD program promotes the implementation of inquiry by teachers (Roehrig et al. 2012), but when there is insufficient support, implementation is poor (Wee et al. 2007). Unfortunately, it is much harder to find empirical research on inquiry-based learning in other (than science) disciplines taught in K-12 education, such as social sciences and the humanities. One such example is a study conducted on teaching history, in which the authors argued that a thorough understanding of history implies the recognition that several possible causes and consequences may be invoked when reconstructing the past, often with no certain or "true" conclusion (Del Favero et al. 2007). For students, it may be very difficult to manage such complexities, especially if they are neither prompted nor prepared to do so; therefore, they may view history as the memorization of facts in chronological order. In examining the place of "objectivity" in various school disciplines, Seixas (1993) used the teaching of history to show how teachers become mediators between the scientific communities and the learners' communities, assuming that the teachers have the capacity to understand both discourses and be able to bridge them. In the area of philosophy, Burgh and Nichols (2012) suggested that inquiry could be an important addition to science education, specifically, by transforming classrooms into communities of philosophical inquiry by bringing the method of science into philosophy, and by embedding philosophical inquiry into science education. Burgh and Nichols claimed that philosophical inquiry offers more than scientific inquiry, insofar as it is not limited only to concerns over empirical problems, but extends to the nature and scope of knowledge (including scientific knowledge), conceptual problems, esthetics, ethics, and social and political questions, all of which may or may not have a direct bearing on scientific matters. In accordance with Seixas (1993), Burgh and Nichols (2012) see the idea of communities of inquiry as central to inquiry-based learning pedagogy. Finally, Briggs et al. (2006) suggest that ecologists and archeologists need to understand each other's research and even collaborate to address mutual scientific challenges. They argue, for example, that both disciplines changed the basic assumptions about dynamics and stability, and that collaborative research between ecologists and archeologists can expand our understanding of ecology in a number of ways, especially with respect to the long-term human impact on ecosystems. We employed this idea, and in the program we developed, teachers went through archeological, ecological and sociological inquiry-based learning with an aim to develop deeper understanding of inquiry learning, as will be described later on.

Inquiry-based learning and the outdoor environment

The 'Inquiry and the National Science Education Standards: A Guide for Teaching and Learning' (NRC 2000) opens with a beautiful example of a complex scientific research of the phenomenon of a dead forest near Washington State shores that used data from various sources. Yet inquiry-based learning is commonly taught in the laboratory through experimentation (Duschl and Grandy 2008; Hodson 1998). More than the opportunity to engage in other forms of inquiry, the outdoor environment offers a variety of real phenomena to investigate and possible inquiry questions to ask, according to students' interests and choices. Outdoor inquiry can be done in social studies (Shih et al. 2010), ecology (Sadeh and Zion 2009), environmental sciences (Tal and Argaman 2005) and other fields as well, and it can focus on real socio-scientific problems and conflict. inquiry-based learning in an outdoor environment is challenging because natural phenomena cannot easily be represented by simple relationships between variables, and the deductive approach, as used in school labs, cannot provide a "one-fits-all" procedure to follow. However, outdoor environments offer many opportunities for social interactions between learners, between learners and teachers, and possible interactions with experts or parents, all of whom promote learning (Bamberger and Tal 2008; DeWitt and Storksdieck 2008; Dillon et al. 2006; Tal 2012). Effective outdoor learning addresses the unique features of the environment and makes connections between school-based learning and the students' life experiences. It should enable some choices for the students, encourage their social interactions, and should be mediated by teachers who take the role of facilitators rather than as transmitters of knowledge (Bamberger and Tal 2007; Lavie Alon and Tal 2017).

In this study, we used the outdoors as complex environment that enables investigating natural, social and historical phenomena in an authentic setting. We engaged the teachers, as learners, in three outdoor inquiry experiences. Each inquiry was conducted in a different discipline and research genre, and involved the teachers in a variety of scientific practices aimed at expanding their views of inquiry-based learning. We used the above-mentioned challenges to show how to portray inquiry-based learning, and how to conduct an effective collaborative outdoor learning experience.

Method

This study involved three groups of middle and high school teachers in three inquiry-based learning experiences, each representing a different discipline and research genre. The main methodology was qualitative content analysis as will be described later.

In Israel, where our program took place, the education system is centralized under the Ministry of Education, which publishes the national curriculum, supervises the teachers, and is responsible for periodic reforms, national testing, and ongoing teacher PD. In recent years, 'meaningful learning' and learning through inquiry have become central to the ministry's work. There is great pressure on districts and schools to implement advanced pedagogies that encourage meaningful learning and inquiry-based learning and thus to foster student-centered learning. The program we developed, within this context, was offered to secondary school teachers (middle and high school—grades 7–12, age 12–18).

The program: goals and design

As already stated, the main goal of the professional development program (PD) was to challenge teachers' views of inquiry and enable them experiencing and practicing a range of inquiry contexts, questions and methodologies. To achieve this goal, we designed three inquiry activities in the outdoors. We concur with Crawford (2014) that despite differences in models of inquiry, in all cases there should be a central question that leads to exploration and investigation (Singer et al. 2000). We then follow ideas of project-based approach in promoting collaborative work, use of technology and creating artifacts and encourage the use of science practices and meaningful data as referred by Crawford (2000) as authentic science. Since we provided the teachers with diverse experiences in few fields of knowledge, we refrained from explicit definitions of inquiry learning that are rooted in the natural sciences. The outdoor environment allowed investigating the phenomena and questions in an authentic context. The three sites where the inquiry learning took place were in close proximity, which allowed us to refer to the past or future investigations by seeing the three sites from any one of them.

The activities were in the fields of ecology, sociology, and archeology, representing the study of the natural world and its relationship with humans, the study of human societies, and the study of the material world of ancient cultures. Except for ecology, which is taught in both middle and high school, the archeological and sociological investigations were not related to the school curriculum. In fact, they were purposefully used to challenge traditional conceptions of inquiry as an experiment.

To support the teachers' inquiry-based learning in each of the fields, we applied the supporting outdoor inquiry learning (SOIL) scheme (Kali et al. 2018): (a) employing various scientific practices, (b) applying outdoor teaching pedagogical principles, (c) acting in multiple physical settings and (d) working within various social activity structures. Table 1 demonstrates these ideas. In addition, we applied the following:

1. Investigation of real natural, social, and historical phenomena, following what Crawford (2014) describes as authentic science. All the activities were carried out in one particular area to develop a more profound understanding of the relationships between

Table 1 The three inquiry-based activities

	Scientific practices	Social structure	Examples of activities		
			Ecology investigation	**Sociological investigation**	**Archeological investigation**
Preparation (online)	Asking questions Obtaining, evaluating, and communicating information Planning and carrying out investigations	Individual	Analyzing maps	Reading abstracts of social science studies and identifying their characteristics	Reading about the differences between history and archeology Reading an excavation report to learn about methods
		Group	Reading background materials on ecological methods and suggesting initial research questions Designing the group's study: data collection instruments	Reading about the villages, summarizing the information in a collaborative presentation, and asking inquiry questions to study one or both villages	Arranging findings by archeological periods
Field investigation	Planning and carrying out investigations	Individual	Guided observation on the ecological investigation site	Meeting with community representatives and getting background information	Archeological survey Archeological excavation
		Group	Identifying interesting phenomena and refining the questions; asking more questions and discussing hypotheses; describing the area, photographing Consistent measuring of abiotic and biotic factors	Collecting data using questionnaires, interviews, and observations in the communities Photographing and documenting the village environments	Logging the data in a collaborative database Photographing and documenting
Wrap-up (online)	Analyzing and interpreting data Obtaining, evaluating, and communicating information Constructing explanations. Engaging in argument from evidence	Group	Comparing habitats, quantitative graphical representations Writing conclusions Creating a collaborative e slide presentation	Identifying cultural characteristics, conflicts, identities Designing scientific poster or a conference abstract to communicate results	Using typological map to arrange the artifacts Data analysis and writing explanations Designing and making a video-clip to present the twofold study
		Individual	Critiquing other groups' presentations and writing feedback (peer review) Writing reflections based on prompts	Peer review of the abstracts and posters Writing reflections based on prompts	Peer review of the video-clips Writing reflections based on prompts

the physical, the historical, and the social layers of a system. This included discussions of the teachers' inquiry questions with respect to the *how* and *why* (to investigate) that relate to the procedural and epistemic domains of inquiry learning.

2. Collaboration (Singer et al. 2000). Teachers were engaged in collaborative learning, carried out in various "spaces" (in the field, at home, and using technology) by working mainly in small groups of three or four individuals. This aspect expressed the social domain of inquiry learning.
3. Outdoor learning. To depart from the image of inquiry-based learning as experimentation (NRC 2000), the inquiry activities were conducted outdoors. To support learning in the outdoors, activities were arranged according to Orion and Hofstein's (1994) model: every outdoor activity was preceded by preparation to reduce the "novelty space" and was followed up by a wrap-up activity.
4. Reflective learning. Acknowledging the value of reflection in learning processes (Gray and Bryce 2006), each of the inquiry activities was summarized by answering reflection questions regarding the process the teachers went through.
5. Technology. We view technology as a driving force that enables collaborative learning in various learning environments, and especially in inquiry-based learning (Bell et al. 2010). We designed a simple website with integrated mobile applications, specifically to support the program and the learning approaches we used. This was similar to the technology described by Levy et al. in earlier work (2015). The website was designed to support the teachers' inquiry by providing a range of scaffolds (De Jong 2006; Kali and Linn 2007) that included social infrastructure to encourage deeper learning through collaborative work (Bielaczyc 2006) on worksheets, in presentations, and through reflection (Kali and Linn 2007). The website also supported the bridging of the different indoor and outdoor learning environments (Kali et al. 2015). The mobile applications were chosen to support data collection and documentation in the outdoors.

The following sections of this paper describe the three outdoor investigations—ecological, social, and archeological—as also described briefly by the authors (Tal et al. 2016). The PD staff comprised four facilitators: two experts in outdoor education, one of whom has a background in ecology, an archeologist with great experience in outdoor education, and an educational technologist. Two of the facilitators are co-authors of this article. In describing the inquiry experiences, we provide few descriptions, which are based on teachers' work in the PD website.

a. The ecology investigation

Preparation Because there was no meeting in the classroom prior to the first investigation, each participant and the PD staff created personal introduction slide for collaborative presentation. The teachers were each asked to analyze various maps—geological, soil, vegetation, demographic, and archeological. Afterwards, based on the collaborative slide introduction, they formed small groups of three to four in which they worked throughout the investigation. The groups were requested to read background material on the methods of ecological investigations that we had uploaded to the website, recommend other valuable readings or resources they found on the web, and suggest possible research questions. This was done on the website, which allowed sharing and learning from each other. We used the term "inquiry questions" and "research questions" interchangeably to avoid using only 'school terminology', and to emphasize our expectation that the questions would be open-ended, meaningful, and complex, rather than prescriptive. On the website, we presented a range of measuring instruments, data collection instruments, and methods that the teachers could choose from to design their group's study.

The outdoor investigation This was the first face-to-face meeting between the teachers and the facilitators. The first half an hour was dedicated to personal introductions and to a short introductory explanation about the area to be used in the study. We then climbed up the hill to the archeological site (which was investigated in a following event) for geographical orientation. On the way to the hilltop, we encouraged the teachers to identify "interesting phenomena" and ask questions about them. This part of the day ended with observing the ecological investigation site from a distance, and identifying two different habitats that the teachers had detected in the map analysis task. One side of the hill was covered by low, natural Mediterranean chaparral-type vegetation, and the other side was covered by densely planted pine trees. Later on, at the investigation site, this observation encouraged more questions and a discussion on hypotheses. Most of the proposed investigations were to compare these two habitats, after which each group could discuss and revise its inquiry question in the light of what they actually saw at the site. The facilitators provided measuring tapes, pH meters, LUX meters, thermometers of various types, hygrometers, plant and animal field guides, and so forth. In advance, the teachers had been asked to download various data collection apps to their smartphones including a data collection sheet in Google Forms to use in the field. Each group collected data to address its inquiry question and held a short discussion on its initial findings.

The wrap-up activity This home activity was done in the groups and required the teachers to analyze their data together, generate a collaborative document, prepare a PowerPoint presentation summarizing their investigation, and upload it to the website. Each individual then had to choose one other presentation and provide feedback on it. Finally, each teacher was requested to fill an online reflection form that addressed the entire experience: the preparation, field work, the teamwork, the learning experience, further questions about inquiry, and the contribution of technology. These reflections summarized the investigations and were one of the sources of our data.

b. The social investigation

The Galilee region, where our program took place, is geographically and demographically diverse. There are Jewish cities and villages and Arab cities and villages in close proximity to each other. There are religious and ethnic differences between and within the Arab villages and towns, and there are religious and secular communities within the Jewish villages. In this investigation, we focused on two villages: an affluent, religious Jewish village and a big Bedouin-Muslim village. Most of the Bedouin villages in the country are characterized by their low socio-economic status. The vast majority of the residents of the Jewish village have college degrees, while the vast majority of the Bedouin residents have not completed high school education. Only recently, the Bedouin community took pride in its children's growing interest in enrolling in higher education.

Preparation Given that our teachers were all science teachers, we wanted to expose them to the characteristics of social sciences research. They were asked to choose one abstract from a research paper in the social sciences, and identify the research goal, the research questions, the methods used, the analysis, and the main findings. After this individual work, the groups were asked to suggest their own research questions for the study of one or both villages.

The field investigation In each community, the Jewish and the Bedouin-Muslim, we arranged a whole-group meeting with a representative that took about 45 min. The representatives gave background information about the community, and answered the participants' questions. Afterwards, each group reviewed its initial inquiry questions, consulted with the PD staff, and in some cases changed the questions, as will be described in Findings section below. Then, through questionnaires, interviews of residents, and observations in one or in both villages, the groups collected data to answer their research questions.

The wrap-up activity The wrap-up activity required each group to collaboratively analyze the data, and create and upload to the website either a scientific poster presenting their study, or a "conference abstract" of 250 words, as another means of scientific communication.

c. The archeological investigation

This investigation took place at a (mostly Roman) archeological site. Unlike the social investigation, for which the teachers could suggest a variety of questions, the given archeological site already limited the questions that could be asked to "Who were the inhabitants of the ancient settlement?", "What public buildings can be found?", "What evidence tells us the story of the settlement?", and "How did the ancient inhabitants make their living?"

Preparation In this activity, the teachers were requested to read a real excavation report of the site from an earlier season. They were asked to learn about research methods in archeology, such as surveying and digging, and about the kinds of evidence these methods provide. To model part of the archeologists' work, the teachers were asked to go out in small groups and take photographs of a few objects around them that were small enough to put in a basket. They were then asked to make a slide presentation that showed what can be learned about our current period (for instance, climate, lifestyle, and culture) from the photographed objects. Another group preparation task was to create a classification scheme of archeological periods, to which each group contributed information about two of the periods.

The field investigation In the field, we worked in two larger groups: one doing an archeological survey and the other digging. Each group did both activities. Much time was dedicated to teaching about and discussing consistency when collecting artifacts (the data), and making sure that the teachers worked accordingly, marking every specimen they found accurately. Both groups went through all the stages of digging and marking.

The wrap-up activity This included filling a collaborative findings and artifacts table, preparing a typological chart, and drawing group conclusions. In addition, each group was requested to make a multimedia clip of about 5 min and upload it to YouTube. A summary of all the inquiry-based activities is presented in Table 1.

Participants

Altogether, 44 science teachers from various junior high schools (years 7–9) and high schools (years 10–12) took part in the PD in three groups during two consecutive years. Most of them enrolled to the PD sessions voluntarily. One group of 10 teachers (group 2) came from one middle school as part of the principals' effort to enhance meaningful learning in her school. The teachers represented heterogeneous schools from both the Jewish and the Arab sectors in Israel. They all had at least a bachelor's degree, and most of them were experienced teachers (5–25 years). Since we did not find differences between the findings with respect to groups, we combined them in the analysis.

Data collection and analysis

Data collection comprised pre- and post-PD questionnaires, the teachers' reflections which were submitted after every activity, and semi-structured interviews with 12 teachers that took place after the PD. Not all teachers volunteered to be interviewed, and we selected 12 out of 15 who agreed based on their availability. Those 12 well represented the entire group in terms of previous experience in inquiry teaching, their engagement in the PD and prior teaching experience.

The part of the questionnaire relevant to this study included open-ended questions asking teachers for their explanations of what inquiry-based learning is, and what characterizes it. In Israel, inquiry learning is advocated in all school levels and a guiding document on inquiry learning in all disciplines was published by the Ministry of Education about a decade before this study took place.

In the interview, we asked the teachers whether they enacted inquiry learning/project-based science in their classrooms, about what they see as inquiry-based learning and what characterizes it. We probed by asking if a pre-service teacher observes an inquiry-based learning, what is she going to report about. We asked about possible different ways to do inquiry, and about future plans for teaching inquiry-based science. All interviews were audio recorded and transcribed.

Online reflection sheets were submitted after every experience. The teachers were asked more specifically about the activities, about their own group's work, the challenges they faced in different activities and during the different stages, the collaborative work, the artifacts they produced, and what they had learned at different stages.

Qualitative content analysis was performed on all data. Following Krippendorff (2004), we see content analysis as a qualitative-interpretative method that seeks the understanding of texts above the level of sentences, meaning how particular phenomena are represented, described, and explained by the subjects themselves. We were guided by the epistemic, procedural and social domains (Duschl 2008; NRC 2007; Furtak et al. 2012; Osborne 2014a, b) that we used in the analysis, but allowed other themes to inductively emerge from the data. As Krippendorff (2004) and Miles et al. (2013) have argued, findings can be quantified and frequencies can be presented to show differences and patterns.

As indicated, our initial categorization was to the procedural and epistemic aspects of inquiry. Following others (e.g., Duschl 2008; Furtak et al. 2012; Osborne 2014b), by procedural knowledge we mean understanding of scientific procedures, or strategies of scientific inquiry; concepts of measurement, ways of assessing uncertainty, understanding variables, ways of handling and analyzing data and so forth. By epistemic knowledge, we mean the nature of reasoning used in science, the nature of scientific observations, hypotheses, models and theories, what constitutes a scientific question and appropriate data and so forth. Eventually, we defined a "complex views" category that consisted of both procedural and epistemic views vs. "superficial views". Superficial views included what we called partial procedural and descriptions of inquiry as merely student-centered learning. Partial procedural included one procedure or strategy, and incomplete or vague explanation. Another category that emerged was "meaningless responses"—which we defined as either the use other words with the root "inquiry", but with no explanation (such as "inquiry is inquiring about something"), simple copy and paste of formal definitions taken from elsewhere, or irrelevant answers. Teachers' views of the contribution of the outdoor environment and the contribution of collaborative learning emerged from the data as well.

Results

Views of inquiry learning

> *What characterizes scientific inquiry more than everything else is the question "Why does it happen?" Or in other words, the will to find explanations of what happens. The nature of science or the scientific method includes creative and critical investigation of natural phenomena and constructing and re-constructing new knowledge about the world. The scientific method is founded on observations, experiments, measurements, and creative and critical thinking processes (Elly, post-PD interview).*

In this 'epistemic response', it is clear that the teacher addresses the *Why* question. She refers to how knowledge is being constructed and re-constructed, to the creativity of researchers and then to the *How* question—observations, experiments and so forth.

Table 2 Teachers' views of inquiry-based learning

View		Teacher quotes
Complex views of inquiry	Epistemic aspects	Inquiry-based learning is a process that encourages critical thinking. The learner controls the learning process, comes up with questions and hypotheses and examines their accuracy through learning the content… The student only develops an understanding of concepts that were already investigated, and does not necessarily develop new knowledge
	Procedural aspects	Inquiry-based learning is consistent: defining a goal, hypothesis, procedure, results presented in tables or graphs, conclusions, control and repetitions Inquiry is asking questions, designing the investigation, presenting the results, in diagrams, for example, and offering recommendations. It is lots of things… The basis for every inquiry is a certain question, and the goal is to find an answer. You can use qualitative tools, or quantitative and experimental to find the answer
Superficial views	Partial procedural views	Collecting information from various resources. The teacher will explain the collected information Inquiry-based learning is meaningful to the student: asking questions and trying to answer them by using information resources
	Every student-centered learning	When students are engaged in inquiry, they are independent learners, and they have high motivation to learn We get a more independent learner who investigates. We don't really teach her, but rather support her in every stage…
Meaningless answers		Inquiry-based learning, is a curriculum that integrates inquiry, and uses inquiry to teach scientific concepts Inquiry-based learning is to inquire about a phenomenon

The three response categories, complex, superficial, and meaningless, that represent the teachers' views of inquiry-based learning as analyzed in the questionnaire, are demonstrated in Table 2. In the table, by "epistemic" we mean answers that reflect the teachers' thoughts about the nature of science, types of research, interactions between scientific research and society, forms of reasoning, and so forth.

Unlike the way the term 'procedural' is intuitively perceived, it is not merely prescriptive, nor is it only technical or linear. The emphasis in procedural responses, as we referred to them, following others (Duschl 2008; Furtak et al. 2012; Osborne 2014a, b), is on the process, on asking questions, and finding ways to answer those questions using scientific practices. Teachers could have addressed open-inquiry as well, but they focused on the process and on the ways to record findings and make conclusions. We decided, eventually, to include epistemic and procedural responses in a bigger category—complex views—as often, it was not easy to distinguish between the two, and because the same teachers provided answers that related to both the procedural and the epistemic categories.

The distribution of statements of the 44 teachers by the main three categories of views about inquiry-based learning: complex, superficial and meaningless, is presented in Fig. 1. Examples are presented in Table 2.

Figure 1 shows that the percentage of teachers with complex views of inquiry increased significantly after the PD (from 34.1 to 70%; $\chi^2(1) = 9.207$, $p < 0.005$).

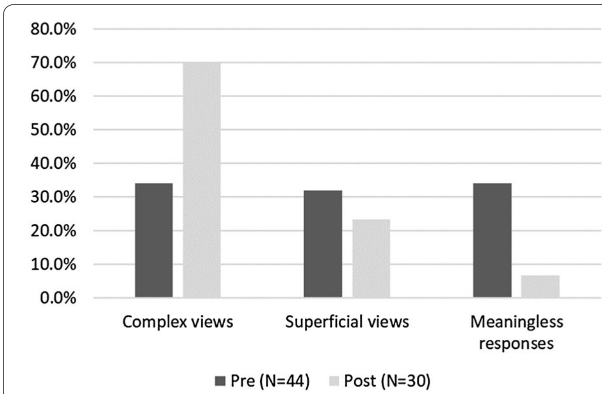

Fig. 1 The distribution of teachers' statements by the main three categories about inquiry-based learning

The superficial answers have somewhat decreased ($\chi^2(1) = 0.632$, $p = 0.427$), and the meaningless answers decreased significantly (from 34% to less than 7%; $\chi^2(1) = 7.581$, $p < 0.01$).

More findings indicating the development of teachers' views towards the more complex view of inquiry-based learning after PD come from the responses to the question asked in the reflection sheet at the end of the intervention: "Have you learned anything new after the three inquiry experiences, about inquiry-based learning?" The majority (60% of the 44 respondents) reported that following the inquiry experiences they acknowledged characteristics of inquiry they had not considered before. Some participants addressed broadening ideas about what Osborne (2014a) refers to as the "concept of measurement" within procedural knowledge. Some examples from the final reflections are

> *"Yes, it added many things such as methods I never used in my work." (Mona, group 1)*

> *"I learned to construct a survey for a social investigation, and in the archeological (inquiry) I learned about the complexity of typology and the management of the excavation site." (Hannah, group 1)*

> *"In the past, I did many experiments in the lab, but this was different." (Ronny, group 2)*

> *"I understood how different data analysis is in the social sciences. I learned a lot from the archeological methodologies—digging and a survey. I never imagined how orderly and consistent their work is." (Shai, group1)*

Others addressed the nature of an appropriate design for a given scientific question, such as experimental, field based, or pattern seeking.

> *"I learned a lot from these three experiences, because their enactment was totally different from processes I did before. The pattern is the same but data collection or hypotheses testing are different." (Ronny, group 2)*

> *"I learned that inquiry-based learning is much more complex than I anticipated. You can do inquiry in many areas. In every inquiry-based learning there are similar things such as asking questions and data collection, but the way to get them is different." (Dan, group 1)*

In addition, there were teachers who addressed common ways of abstracting and representing data, while acknowledging the limited ways they were used to.

> *"The outcome can be different in various fields of inquiry. In biology, we are used to graphs and tables, but you can present data in a video too." (Gal, group 1)*

> *"In my group, in the sociological inquiry, we presented our findings in a scientific abstract, as one block with no separate paragraphs, but from group 1, I learned that you can present a scientific poster where you can add visualizations, a graph and a table, so it is more interesting." (Shira, group 2)*

Contribution of the different genres to views of inquiry learning

The first field investigation was in ecology—a well-known area to science teachers. In the second activity—the social investigation—at first, almost all the inquiry questions asked by the groups were comparative: comparing the leisure time activities in the two communities, comparing recycling dispositions and actions, comparing education and employment patterns, and so forth. Only a few groups suggested non-comparative designs and focused on only one community. Only after further discussion in the group, and after a meeting with representatives of the two communities, did some groups ask to revise the question to concentrate more deeply on a specific phenomenon rather than comparing the villages. Eventually, about half of the groups chose to focus on one village only, arguing that they could learn more about the community, and that a comparison between such different groups would be of little value. Another transition was from the more classical social sciences study that looks at relationships between variables and uses survey data, to ethnographic studies that require teachers to find people to talk with. Yet most of the groups did look at the relationships between variables, even when the sample was very small, for example, the relationship between marriage within the family and education in the Bedouin village, or the relationship between education and recycling habits.

Similarly, in the whole-group discussion at the end of the archeological investigation, many teachers expressed their surprise about how scientific, consistent, and transparent the archeological work needed to be for artifacts to be regarded as evidence. They talked about these themes repeatedly while discovering the scientific aspects of the archeological research, and while making references to the other two investigations.

More evidence for more complex views of inquiry comes from the answers to the question in the reflection: "Do all three experiences represents inquiry-based learning?" At the end of the intervention, 93% of the respondents ($N=43$) believed that the three experiences, ecological, social, and archeological, were all forms of inquiry-based learning. They gave explanations based on procedural aspects (70%) and epistemic aspects (33%). The overall is more than 93% because some gave both epistemic and procedural explanations. Few participants included both procedural and epistemic aspects while addressing the nature of an appropriate design for a given scientific question (e.g. experimental, field based or pattern seeking) (following Osborne 2014a).

> *"A scientific inquiry as a way to learn about a phenomenon. This is exactly what we did throughout the PD, but the instruments and methods changed*

accordingly. We identified a problem, asked questions and went out to investigate. We first learned the background and theory, then went out to collect data, analyzed the data, concluded and presented. This is scientific inquiry." (Havva, group 1)

"Every activity was scientific inquiry, since we came up with questions, selected the most suitable method and executed it. This was true in the three experiences." (Miri, group 2)

"From every data collection, their arrangement and classification we were able to make conclusions in all areas, though the conclusions are limited by the limited data collection." (Dan, group 1)

Some teachers specifically emphasized that the three investigations had made them realize that inquiry has similar characteristics, but that inquiry is discipline dependent and offers a variety of genres.

"I experienced inquiry-based learning, which is different from what I am used to, such as archeological inquiry, which I never saw as inquiry before in which you ask questions, collect data and make conclusions." (Vered, group 1)

"Investigating the question in Hoshaya [one of the villages] made me realize how different studying people's populations is than in the laboratory. It was amazing how rigorous the archeological investigation was." (Keren, group 1)

However, 7% of the respondents still thought that inquiry is a soley quantitative method in which only the relationships between variables from the natural world are investigated.

"Scientific inquiry was only in ecology. In the social inquiry we used a qualitative tool—a survey [open-ended]. In ecology it was quantitative." (Hala, group 2)

Views of inquiry-based learning as a collaborative endeavor

The research literature strongly advocates collaborative learning as a major element of project-based learning (e.g., Furtak et al. 2012; Hmelo-Silver et al. 2007; Singer et al. 2000). The participating teachers' responses to the questionnaires about working in teams show a range of explanations about the contribution of collaboration to project-based learning. We classified the questionnaire responses according to the following five themes that emerged from the data through inductive analysis. Each theme is followed by a representative quote.

a. Collaboration for deeper learning (in line with the social domain, following Duschl 2008): teamwork as enhancing learning and understanding. Some of the teachers addressed labor division as well, but they specifically pointed to synergism, and the contribution of each participant to the group products and group knowledge.

   "The interactions in the teams elevates the work so the products are better than in individual work." (Havva, group 1)

   "When people share different views, it enables critical discussions and broaden their understanding." (Vered, group 1)

   "Teamwork enables developing thinking skills: critiquing, convincing, getting feedback, pointing to things we never thought of..." (Michal, group 3)
b. Teamwork enables division of labor: saving time and enabling the expression or use of personal skills.
   "There is division of the work according to each one's strengths" (Dan, group 2).
   "It is easier to split the work between team members" (Shira, group 2)
   Teamwork to develop interpersonal/social skills.
   "Social skills—in teamwork there is mutual responsibility and fair negotiation on tasks." (Vered, group 1)
   "Team inquiry could improve social skills and handling challenging tasks." (Yossi, group 3).
c. Teamwork to increase motivation.
   "Motivation to complete the tasks increases." (Michal, group 2)
d. No explanation or a generic explanation.

"It is possible and even preferable that students will work in teams." (Miriam, group 3)

Figure 2 presents the distribution of responses regarding collaboration and teamwork.

Even before the intervention, most of the teachers found an advantage in teamwork, but 23% did not provide explanations. After the intervention the percentage of teachers who addressed the more complex aspects of sharing knowledge, significantly increased (53.8% to 85.7%; $\chi^2(1)=7.505$, $p<0.01$), and the percentage of teachers who addressed the contribution of social skills had more than tripled (12.8% to 42.9%; $\chi^2(1)=7.766$, $p<0.01$). Teachers' responses about the contribution of a simple division of labor insignificantly decreased (41.0% to 25.0%; $\chi^2(1)=1.857$, $p=0.173$). The motivational category appeared only after the intervention. More detailed responses were obtained in the interviews. Such a response describes the advantages of

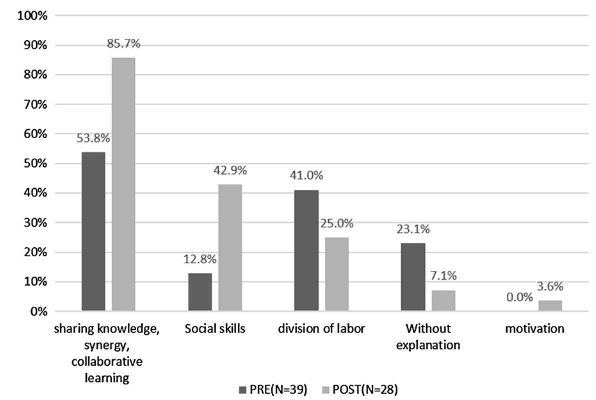

Fig. 2 The distribution of teacher responses with respect to collaboration and teamwork

collaborative, inquiry-based learning, and specifies its targets.

> *"The social context is important to our students. Learning from each other. Nowadays, technology supports this. Shared documents or mutual artifacts that they produce in technological environments. Students can learn from each other about the inquiry process itself and about what each gained…" (Rina, group 1)*

Disadvantages of collaborative learning were stated as well. Some were addressed directly, such as referring to "unequal contributions", and to "hitchhikers" who enjoy their peers' work or power struggles among team members. Other teachers addressed what they viewed as disadvantages, but could be seen as advantages as well, such as disagreements in negotiating during some stages of the investigations that needed to be resolved, or possible multiple interpretations they believed should have been resolved. Two examples are

> *"a disadvantage is that the individual motivation is affected by the team. Some of them trust others 'you do the task'" (Nadia, group 2)*

> *"Not everyone learns everything, like if one student don't want to do the experiment" (Mona, group 1)*

These two examples raise the questions about what is wrong in trusting teammates, and why everyone has to learn everything.

Overall, the intervention and the three team-investigations produced articulate and sophisticated explanations that supported collaborative learning in teams.

The contribution of the outdoor environment

The three investigations took place in the outdoors to demonstrate that inquiry learning can take place everywhere, and to distance the three experiences provided in the PD from conventional lab-based experimentation. Although we did not discuss the use of the outdoor environment explicitly in the PD, and we did not ask the teachers specifically about it in the interviews or in the questionnaires, 29 out of 44 (66%) respondents to the reflection questionnaire addressed the effect that the outdoor environment had on them as learners. Some addressed outdoor learning from the teacher's point of view as well, and discussed its pedagogical merits (see Table 3). Three well-known characteristics of out-of-school learning appeared in the responses: (a) affect, curiosity, and fun; (b) learning (cognitive), and (c) social interaction. As teachers, they viewed outdoor learning as authentic and active learning. By authentic, following Crawford (2014), we mean investigation of real and phenomena. By active, teachers referred to all forms in which they were active: raising questions, collecting data, hands on learning and so forth.

In the following quote, from the reflection, Maya (group 1) talks about learning from evidence, attempting to figure out, enhancement of curiosity and happiness.

> *"The essence of going to the outdoors and to nature and being exposed to the pieces of evidence (such as the remains of an ancient oven, finding a cactus, wildlife traces) and the continuous enhancement of curiosity in an attempt to understand what's going there make you happy and content." (all three aspects)*

Rebecca (group 1) refers to how touching real artifacts and working with an archeologist changed her vision and understanding.

> *"I especially loved seeing and touching artifacts 2000 years old (a piece of a Hellenistic bowl). I never imagined such things could be found just lying there on the ground. I enjoyed wearing the "archeological lenses" for a moment, and getting the experts' support changed my vision and understanding." (learning)*

Even in the more familiar field of ecology, discovering the benefits of outdoor learning made a difference, according to Rachel (group 2).

> *"I learned what fieldwork is all about. I have taken part in many investigations, but they were all in labs. I have participated in many field trips too, as a student, but I was always a passive observer and listener. There is no doubt, when you're an active learner outdoors, learning is more meaningful because you use your five senses to do the work and then you understand better—like I really understood the difference between the planted pine forest and the Mediterranean chaparral." (learning)*

Table 3 Contributions of outdoor learning and teachers' quotes

	Outdoor learning contribution	Teachers' quotes
Impacts	Affective (72.4%)	The activity outdoors and the exploration were fascinating
		Incorporating inquiry in a field trip/field study was a wonderful experience, educative and enriching. The experiential learning leaves the insights and learning for long time and makes you want to experience this again
		The essence of going to the outdoors and to nature and being exposed to the "minor evidence" (such as the remains of an ancient oven, finding a cactus, wildlife traces) and the continuous initiation of curiosity in an attempt to understand what's going there make you happy and content
	Cognitive (65.5%)	I will always remember our results. If I had only read about Hoshaya village instead of being there, I would never remember and know so much
		Learning from the environment gives you insights and perspectives which are different than "couch learning" (books, computers etc.)
		… it gives you a system perspective—integration of humans with the environment, adaptation of plants and animals, thoughts about harmony in nature…
	Social (24.1%)	Sharing knowledge and experiences was throughout all activities
		I liked the way we collaborated in our team. Each and every one was responsible for everyone's learning
Teaching	Authentic learning (58.6%)	In an ecological inquiry, you need to use the near environment for teaching, and reduce formal (classroom) teaching, to let the students explore and investigate the real outdoor environment. I've always taught using pictures and physical models of the ecosystem. In the future, I'll teach them outside
		I especially loved seeing and touching artifacts 2000 years old (a piece of a Hellenistic bowl). I never imagined such things can be found just lying there on the ground. I enjoyed experiencing how wearing the "archeological lenses" for a moment and getting the experts' support changed my vision and understanding
	Active learning (55.2%)	We looked for evidence ourselves. We had to figure out the meaning of each piece of evidence, which was a challenge
		I learned what fieldwork is all about. I have taken part in many investigations, but they were all in labs. I have participated in many field trips too, as a student, but I was always a passive observer and listener. There is no doubt, when you're an active learner outdoors, learning is more meaningful because you use your five senses to do the work and then you understand better—like I really understood the difference between the planted pine forest and the Mediterranean chaparral
	Social interaction (24.1%)	Sharing knowledge and experiences was throughout all activities
		I liked the way we collaborated in our team. Each and every one was responsible for everyone's learning

Rachel indicates the innovation, compared to her experiences in doing lab experiments. She referred to meaningful learning when using all senses, and better understanding of the scientific phenomenon. Finally, she said:

> *"The integration of inquiry with a field trip was a wonderful enriching learning experience. The affective learning makes learning and deep insights for long period, and motivates you to do it again." (affect, learning)*

Overall, affective aspects of doing outdoor inquiry were addressed by 72%, cognitive gains by 66%, authenticity by 59% and active learning by 55%. These references to the contribution of outdoor learning to better understanding of inquiry learning are encouraging.

Discussion

Our findings show an increased complexity in the way teachers viewed inquiry-based learning, and a better acknowledgment of the "scientific" work done by archeologists and sociologists. The findings also show an increased understanding among the teachers of the important role of collaboration when doing inquiry—as continuous negotiation, as sharing, and as a generative human activity. Finally, the findings show a more focused view of the context of inquiry-based learning—acknowledging the opportunities that the authentic outdoor environment creates for meaningful investigation of natural and social phenomena.

We showed how involving teachers in collaborative, inquiry-based learning experiences in different fields and genres in out-of-school environments, promoted the development of more complex views of inquiry-based learning. The aspects presented included the nature of inquiry, the place of collaboration, and the value of the outdoor environment. We agree that teaching inquiry is strongly influenced by the ways teachers understand the nature of scientific inquiry and by their ability to choose strategies that will promote the goals of inquiry-based learning (DeBoer 2004). In light of all the limitations and challenges teacher face, that we presented in the literature review, it is very important to find ways to develop teachers' conceptions of inquiry and inquiry-based learning by enabling them to practice inquiry-based learning strategies in a variety of settings making teachers wonder about the epistemic aspect of inquiry. In this study, we used the context of outdoor inquiry in three different fields and genres and showed that teachers' views have indeed changed.

Commonly, sociology and archeology are not perceived as "science", or at least not associated with teaching science in schools. However, we assumed that going beyond the natural sciences into such fields would expose epistemic aspects, further develop procedural aspects and, in general, promote more profound discussion about the nature of scientific inquiry as an intellectual and social activity rather than as a set of steps to follow.

Shulman (1997), writing about communities of learners, asks why generative and collaborative learning, in which students investigate worthwhile problems, is so rare. His answer to the question is that such learning environments are less predictable and thus might undermine teacher control and order in the classroom. In the same vein, Singer et al. (2000) propose that the classroom structure is a limiting factor when conducting extended inquiry-based learning projects. Therefore, engaging in unknown research designs can cause confusion or discomfort for teachers. To avoid such feelings and to emphasize the main ideas behind inquiry and inquiry-based learning, we provided a consistent structure to the inquiry experiences by applying several processes, such as Preparation–Field work–Wrap-up; reducing the novelty space; integrating individual and collaborative work as multiple social activity structures; and using a non-linear model for doing the investigations.

The online support and structure for collaborative work during the PD demonstrated how this support can address teachers' concerns about control and order. The access to students' work that the online environment provides throughout the inquiry process allows teachers to interact with their students by tracking their work and give feedback. Conducting the inquiry in the outdoor environment confronted the teachers with ill-structured environment but it reduces limitations that the classroom dictates, as Singer et al. (2000) noted. Integrating the online environment into the learning process helps teachers to regain some of the control that might be lost when going outdoors (Dillon et al. 2006).

Another reason for using the outdoor environment was to break the link or equivalence between inquiry and the laboratory. We did not aim to develop the teachers' outdoor teaching skills, so in the interviews, the reflection sheets, and in the questionnaires, we did not ask explicit questions about the impact of the outdoor environment on teaching. Yet, with no special prompting, the teachers themselves identified many benefits of learning in the outdoors—cognitive, social, and affective. They addressed pedagogical aspects and referred to outdoor learning as authentic and as promoting active learning. The research literature provides much evidence to the benefits of outdoor learning (Ballantyne and Packer 2009; Dillon et al. 2006; Dillon 2012; Tal 2012; Tal et al. 2014, 2016). However, because of the artificial divide between formal and informal learning environments (Dillon 2016) there is too much emphasis on distinctiveness rather than on complementarity that outdoor inquiry can offer. We concur with Dillon (2016), who challenged unnecessary definitions of (formal vs. informal) learning and learning environments, as they are obscure, they neglect a huge body of research on organized learning activities in out-of-school environments, and they do not promote meaningful learning. What is important in the context of this study is that the teachers recognized the "big ideas" that relate to inquiry, regardless of the physical environment—a laboratory, a hill slope, a village, or ruins. This conceptual change occurred as a result of the teachers' first-hand experience of scientific practices at home (while getting prepared), in the field (collecting data), and at home again (analyzing data and making artifacts). They worked individually and collaboratively, obtaining information, suggesting explanations, discussing the explanations, and using diverse forms of reasoning. Moreover, they realized that the design of an inquiry project is related primarily to its goals and framework, regardless of where it happens or what tools are being used.

Finally, we believe that these insights into broadening teachers' conceptions about inquiry and outdoor learning can be attributed to the structure of a PD program that integrated inquiry-based learning, outdoor learning, and the use of technology, at home and in field, individually and collaboratively. This PD program offered three different, consecutive, authentic inquiry experiences, framed by

1. the principles for good outdoor learning, such as the three-stage spiral structure of Preparation–Field-work–Wrap-up, and decreasing the novelty space in the preparation phase (Orion 1993), thus allowing first-hand experiences and active learning (Tal et al. 2014), and
2. the principles for good inquiry-based learning, such as articulating what inquiry is; engaging in real inquiry projects; understanding and mastering science practices; enacting sophisticated pedagogies (Crawford and Capps 2018); collaborating; using

technology tools, and producing artifacts (Singer et al. 2000).

Conclusions

Our study shows that science teachers lack a broader perspective of what constitutes research and scientific work. They tend to see experimental methods as the only scientific method, ignoring other forms of reasoning which are more prevalent in historical sciences. When confronted with their view through experiential learning and inquiry in other fields such as archeology and sociology, the teachers develop a more realistic and inclusive perception of inquiry learning. The outdoor learning experience had an additional value.

Teachers identified many benefits of learning in the outdoors—cognitive, social, and affective. They addressed pedagogical aspects and referred to outdoor learning as authentic and as promoting active learning. Finally, the technology used to support learning enhanced collaboration, mutual planning and active participation in the various spheres of the PD: home, classroom and fieldwork.

Limitations and further research

The main limitation of the intervention we planned and studied is that there were insufficient opportunities to discuss the epistemic aspects of inquiry-based learning. Such discussions should have been more explicit. We hoped that participation in the three complex investigations, each of which included preparation, fieldwork, and wrap-up, individual and collaborative work, not limited by time or place, and written reflections after each investigation, would be enough for the teachers to develop and adopt a more sophisticated view inquiry-based learning. In fact, we found substantial improvement in the procedural aspect, but less responses represented epistemic aspects. Unfortunately, the timeframe did not allow us to face-to-face discussions about what inquiry-based learning is, either before or after each investigation. In addition to the time limit, we thought that explicit discussions might influence what the teachers themselves understood after going through the three inquiry experiences. Consequently, in a follow-up study, we include extra face-to-face meetings with the teachers after each of the investigations to allow further discussion on the ideas discussed and the practices used outdoors. In the meetings, we help the teachers construct and organize their knowledge about inquiry-based learning and its implementation, and plan short inquiry-based units. In addition, the teachers identify the factors that make inquiry a human endeavor in general, and an intellectual activity and a teaching strategy in particular. We hope that these additional discussions will further develop the epistemic aspects of inquiry-based learning, such as how scientific claims are supported by data and reasoning in science; the function of different forms of empirical inquiry in establishing knowledge; their goal (to test explanatory hypotheses or identify patterns) and their design (observation, controlled experiments, correlational studies), and the nature of reasoning used in science.

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Authors' contributions

RL-P: research design, data collection and analysis. KSL: data analysis. TT: the PI. Research design and coordination, leading the PD and leading the writing of the paper. All authors read and approved the final manuscript.

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Availability of data

All raw data are in Hebrew and will not be translated into English. Moreover, until the entire work is completed, even Hebrew transcripts and questionnaire would not be available. Our commitment to the IRB is that all data will be erased after completing publication.

Competing interests

The authors declare that they have no competing interests.

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