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Promoting the asking of research questions in a high-school biotechnology inquiry-oriented program

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Abstract

Background: Asking questions is an important scientific practice, and students around the world are expected to learn how to ask their own research questions while performing inquiry. In contrast to authentic scientific inquiry, in most simple inquiry tasks that are carried out in schools, the research questions are given to the students. Here, we characterized the teaching and learning of research-question-asking in the context of an innovative inquiry-oriented program for high-school biotechnology majors, focusing on two case studies of lessons in which students were expected to formulate their research questions.

Results: In-depth examination of students' questions, written during the two lessons, revealed that only in one of the lessons students' ability to ask research questions improved. A connection was found between the more student-centered, dialogic, and interactive teaching strategy and the development of students' ability to ask research questions in that class. Most of the research questions that were investigated by the students originated from a peer-critique activity during the student-centered lesson, unlike the teacher-focused lesson from which none of the students' suggested research questions were selected for investigation.

Conclusions: It can be concluded that a student-centered, dialogic, and interactive teaching strategy may contribute to the development of students' ability to ask research questions in an inquiry-oriented high-school program. Encouraging teachers to implement dialogic and interactive classroom discourse in authentic inquiry could be a meaningful tool to support the teaching and learning of scientific abilities such as asking research questions.

Keywords: Biotechnology education, High school, Inquiry learning, Question-asking

Background

Asking questions is considered a crucial component in developing scientific literacy, as emphasized in various policy documents worldwide (Australian Curriculum Assessment and Reporting Authority [ACARA] 2012; European Commission 2007; National Research Council [NRC] 2012; United Kingdom Department of Education 2013). Students' questions play an important role in promoting their scientific habits of mind and their understanding of scientific knowledge (Chin and Osborne 2008). Students are expected to ask their own research

questions while participating in inquiry learning (Lombard and Schneider 2013), and teachers are expected to teach their students to ask research questions that are feasible for investigations, by providing them with inquiry environments that encourage asking research questions (Hartford and Good 1982). The teacher's assistance is required in scaffolding students' learning, transforming their questions into research questions that are appropriate for authentic scientific inquiry (Wayne Allison and Shrigley 1986). However, in most simple inquiry tasks that are carried out in schools, the research questions are given to the students, in contrast to authentic scientific inquiry, where scientists are expected to develop and explore their own research questions (Chinn and Malhotra 2002). In light of the need for a better understanding of the processes contributing to the development of students'

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ability to ask research questions, we explored the teaching and learning of this ability in an innovative inquiry-oriented program entitled Bio-Tech. We demonstrate that a student-centered teaching strategy that includes a peer-critique activity during the lesson on how to ask research questions improved students' ability to formulate research questions that are appropriate for investigation in the Bio-Tech program.

Inquiry-based science teaching

Engaging students in scientific inquiry is one of the principal goals of science education, recommended by researchers and in various policy documents (Bybee 2000; European Commission 2007; National Research Council [NRC] 1996, 2000).

One of the commonly accepted definitions of scientific inquiry is the one published in the National Research Council (NRC) (1996): "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (p. 23). The NRC further elaborates on the components of scientific inquiry: "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations" (p. 26). We base the research presented in this article on the above definition of inquiry.

The NRC (2000) suggests five features that best define the teaching and learning of inquiry. Engaging in scientifically oriented questions is one of these features. Asking questions is also one of the eight crucial scientific practices suggested in the recent framework for K-12 science education (NRC 2012). Students around the world are required to learn about and gain an understanding of the inquiry process and develop their understanding of scientific practices by experiencing authentic inquiry in an active learning environment (Abd-El-Khalick et al. 2004; Bybee 2000; European Commission 2007; National Research Council [NRC] 1996). By practicing inquiry, students are expected to cultivate scientific habits of mind, practice logical scientific reasoning, develop critical thinking abilities in a scientific context, and experience meaningful learning of scientific concepts and processes (Chinn and Malhotra 2002; Harlen 2004; Hmelo-Silver et al. 2007). However, a

debate still exists regarding the goals, methods, and strategies used to incorporate inquiry into the science-education classroom (European Commission 2007; Tamir 2006; Windschitl et al. 2008), and many issues remain unclear regarding the learning goals and suitable strategies for teaching scientific inquiry (Furtak et al. 2012; Minner et al. 2010).

Asking research questions

Asking questions is a core scientific practice required for gaining scientific literacy and developing students' critical thinking and their understanding of the inquiry process (Cuccio-Schirripa and Steiner 2000; Dori and Herscovitz 1999; Hartford and Good 1982; National Research Council [NRC] 2012; Pedrosa-de-Jesus et al. 2012). The goals of teaching how to ask questions are to direct students' knowledge construction, foster communication, help them self-evaluate their understanding, and increase their motivation and curiosity (Chin and Osborne 2008). Asking questions is an integral part of the practice of critiquing, which is important for developing students' scientific literacy (Henderson et al. 2015).

Research questions, also termed researchable questions (Chin and Kayalvizhi 2002; Cuccio-Schirripa and Steiner 2000), investigable questions (Chin, 2002), or operational questions (Wayne Allison and Shrigley 1986), are questions that call for hands-on, manipulative, operational actions and can lead to a process of collecting data to answer them (Hartford and Good 1982). Research questions should be meaningful, interesting, and challenging for the students, providing them with opportunities to demonstrate their knowledge, skills, and abilities and also encouraging them to exercise their critical and creative thinking (Chin and Kayalvizhi 2002). To answer the research questions, they must be appropriate to the student's cognitive developmental level and the procedures should be accessible and manageable to the student (Keys 1998). Students' research questions should be investigable within the limitations of time and materials. The inquiry process that is required to answer research questions should not be too expensive, complicated, or dangerous to perform (Chin and Kayalvizhi 2002). Furthermore, research questions should lead to genuine exploration and discovery of previously unknown knowledge (Cuccio-Schirripa and Steiner 2000).

Students are expected to ask their own research questions while participating in scientific inquiry (Cuccio-Schirripa and Steiner 2000). These questions should help students progress to the next stages of the inquiry process (Chin 2002) and develop their procedural and conceptual knowledge (Chin and Brown 2002). Students are expected to formulate their own research questions during their school science learning (National Research Council [NRC] 2007). In addition, students

should be able to distinguish between research questions and other types of questions and to refine their empirical questions that lead to open investigations (National Research Council [NRC] 2000). Harris et al. (2012) investigated fifth-grade teachers' instructional moves and teaching strategies while teaching students how to ask research questions. They found that although the teachers displayed a student-centered and dialogic approach, they experienced challenges in developing their students' ideas into investigable questions. Lombard and Schneider (2013) found that high-school biology majors' ability to write research questions appropriate for investigation improved while maintaining their ownership of the inquiry process. Some of the students' ability to write appropriate research questions was achieved by employing structured teacher guidance while engaging students in peer discussions (Lombard and Schneider 2013). Considering the above, there is a need to explore means of promoting the learning of how to ask research questions in science classrooms. This study aims to explore the development of students' ability to ask research questions while participating in an inquiry-oriented program.

Classroom discourse and communicative approach

Examining classroom discourse is a powerful tool for evaluating the development of students' scientific understanding and abilities (Osborne 2010; Pimentel and McNeill 2013). The discourse that is carried out in most secondary science classrooms is teacher-centered (Newton et al. 1999), as it is difficult for teachers to shift from the traditional teacher-centered instruction to more student-centered discursive teaching strategies (Jimenez-Alexandre et al. 2000; Lemke 1990).

One of the methods of investigating classroom discourse is the communicative approach. The communicative approach analytical framework was developed by Mortimer and Scott (2003) to examine and classify types of classroom discourse. This approach focuses on the teacher–student interactions that serve to develop students' ideas and understanding in the classroom. The framework is based on sociocultural principles, according to which individual learning and understanding is influenced by the social interaction context (Scott 1998; Vygotsky 1978) and the role of language during classroom talk (Lemke 1990).

Central to the communicative approach are the dialogic/authoritative and interactive/non-interactive dimensions. The dialogic/authoritative dimension determines whether the teacher acts as a transmitter of knowledge embodied in one scientific meaning or adopts a dialogic instruction that encourages exploration of different views and ideas to develop shared meaning of new knowledge (Scott 1998). In an authoritative discourse, the discussion is “closed” to other voices, having a fixed intent and

controlled outcome. In a dialogic discourse, the teacher encourages the students to express their ideas and debate their points of view. The discussion is “open” and may include several different views. The intent of the dialogic discourse is generative, and the outcome is unknown. Scott et al. (2006) suggested that there is a necessary tension during classroom discourse between the authoritative and dialogic dimensions. The teachers may shift between approaches, according to their teaching purposes and goals (Scott et al. 2006). The interactive/non-interactive dimension determines the students' involvement level during the discourse. In interactive discourse, many students participate in the discussion, whereas in non-interactive discourse, the number of students participating in the discussion is limited to one or a very few.

The communicative approach examines the patterns of interaction during classroom discourse. These are represented by the triadic dialog, comprised of the Initiation-Response-Evaluation (I-R-E) structure (Mehan 1979). According to this pattern, each dialogic sequence usually starts with teacher initiation (mostly in the form of a question); this is followed by a response from a student (an answer to the question), and the sequence closes with a teacher evaluation of the response. This short and closed-chain triadic sequence dominates most teacher-centered classroom discourse and is very common in high-school classrooms (Lemke 1990; Scott et al. 2006). Mortimer and Scott (2003) suggested that interactive discourse is characterized by long and open non-triadic patterns, in which the teacher refrains from immediate evaluation of the student's response and instead may prompt the students to further elaborate on their ideas or encourage other students to critique their ideas.

The discursive moves used by the teacher during the lesson are pivotal in navigating the classroom discussion and promoting meaningful discourse (Pimentel and McNeill 2013), as well as for providing collaborative feedback (Gan Joo Seng and Hill 2014). Among the various teacher moves, teachers' questions play an important role in students' learning, as they scaffold students' thinking and understanding and encourage their involvement in the classroom discourse (Chin 2007; Kawalkar and Vijapurkar 2011). One way of classifying teachers' questions is as open or closed. Open questions, in which the teacher probes for students' ideas without expecting a specific known answer, promote dialogic discourse and increase students' involvement in the discussion. In contrast, closed questions require the students to recall factual knowledge and lead to authoritative discourse that does not promote students' meaningful learning (Chin 2007). This research focuses on the discourse in two classrooms during whole-class discussions in lessons designed to teach students how to ask their research questions. Examining the communicative

approaches and teachers' moves allowed analyzing the possible connections between the teachers' instructional strategies and students' learning to ask questions.

In light of the important role of asking research questions on students' learning in authentic scientific inquiry environments, we characterized the teaching and learning of this ability in the context of a high-school inquiry-oriented biotechnology program. We focused on both the teaching of asking research questions, as reflected in the two teachers' teaching strategies described in the case studies, and on students' learning, as reflected in the analysis of the research questions they generated during the lesson. Students' ability to ask research questions, which differ from other questions by being manipulative, feasible, and meaningful for the students, was evaluated before and during a lesson that was designed to support students in formulating research questions to be investigated. Specifically, we asked:

1. Did—and how did—the Bio-Tech students' ability to ask research questions change during the lessons?
2. What teaching strategies, mostly concerning teachers' actions, dialogic moves, and time management, were used by the Bio-Tech teachers during the lessons?

Methods

This is a mixed-methods case study comparison research that involves mixed methods—both quantitative and qualitative. It involves non-random case studies of two teachers and their classes. The collected data include a pre-lesson questionnaire, students' written sheets during the lessons, audio-recordings of class observations, and interviews with the class teachers.

Research context: the Bio-Tech program

The inquiry-oriented program that served as the context for this study was an inquiry program of 11th-grade biotechnology majors, entitled Bio-Tech. The Bio-Tech program is an optional part (1 credit out of a total of 5 credits) of the Israeli matriculation examinations. Bio-Tech is a year-long program, carried out in both the school and a research institute. At the beginning of the school year, the Bio-Tech classroom lessons are devoted to the study of Adapted Primary Literature (APL) scientific articles (Yarden et al. 2001) which present the students with the background content knowledge as well as the methods, tools, and procedures carried out in their designated research group. About 2 months into the Bio-Tech program, the class goes to the research institute for a preliminary experiment. At this stage, the students meet a scientist from one of the participating research laboratories and visit that laboratory. They learn about the research institute's structure, departments, and main fields of

research. They take part in small-scale preliminary experiments, where they are familiarized with the program's tools and methods.

Following the preliminary visit to the research institute, the students are divided into groups of two or three students and start to plan their inquiry experiment under their teacher's guidance, with occasional assistance from a scientist and science educator. At this stage, the students are expected to formulate their own research questions to be investigated in the main experiment. The experiment is restricted to the tools and methods available in the research institute laboratories and needs to be relevant to the research content. Once all of the students have planned their experiments and have had them approved by the teacher and scientist, the class returns to the research institute laboratories for 2 days to perform their experiments. The students then collect the data and begin to analyze and interpret the results. Once back at school, students continue to analyze the data, write up the research essay, and prepare for a final oral exam, assisted by their teacher.

Lessons in asking research questions

As already noted, students are expected to ask research questions that will lead them to the planning and execution of inquiry in the Bio-Tech program. This task usually takes place after learning the APL article and the preliminary visit to the research institute, where students are introduced to the researchers and to the laboratory techniques that will be used in their research. Back in the classroom, the teacher is expected to teach the students how to ask research questions that are appropriate to the Bio-Tech program and the class's specific research topic. Students are expected to generate their own research questions, with the teacher's support, which will lead them to the hands-on experiments conducted at the research institute. Here, we focus on lessons in which students were taught how to ask research questions, including an activity in which they formulated research questions and critiqued the questions formulated by their class peers. The teachers who took part in this research were asked to include the peer-critique activity in their question-asking lesson. This activity was designed as a pedagogical tool to encourage the asking of research questions and to promote the students' communication and collaboration abilities by writing research questions in groups and having them reviewed by their peers, as recommended by Henderson et al. (2015).

The peer-critique activity was based on a written sheet received by each group. First, the students were asked to write down three research questions that they would like to investigate in the Bio-Tech program. Then, they chose one of the questions and asked it as a research question, according to what they had learned in the previous part

of the lesson. The groups then exchanged their written question with another group. The students were asked to critique the other group's question, based on the research-question characteristics they had learned. These characteristics include the following: (i) the question should be related to the research topic, (ii) the question should consist of dependent and independent variables and the relationships between them, and (iii) the question should be appropriate for research under the limitations of complexity, available equipment, and time. The critiquing students were also asked to rewrite the research question so that it would be appropriate for the Bio-Tech program. Subsequently, the original groups got their reviewed question back, wrote their response to the other students' critique, and formulated their final research question. Taken together, this interactive activity offered the students an opportunity to independently formulate their own research questions and to evaluate their own and their peers' questions. Collected data included students' written questions in the pre-lesson questionnaire, questions during the peer-critique activity, and final research questions which were investigated by the students later in the program.

Participants

Two biotechnology teachers and their students were chosen for this study by convenience sampling. The teachers, Sam and Rebecca (not their real names), were experienced biotechnology and biology teachers. Their students participated in the Bio-Tech program during the 2012/2013 academic year. The two teachers were chosen for this research because they were both experienced biotechnology teachers with many years of experience in teaching different inquiry programs (Table 1). Most of the students were of middle to high-middle average socio-economic background, based on the teachers' report and the 2006 Israeli Central Bureau of Statistics report, in which the local municipalities were ranked 139 and 147 for the average socio-economic ratio out of 197 (197 being the highest socio-economic ranked municipality, <http://www.cbs.gov.il/www/publications/pw77.pdf>).

Observations, recordings, and artifacts of the lessons

The teaching and learning of how to ask research questions in the Bio-Tech classes that participated in this study

were facilitated by a lesson that included explanations and examples of appropriate research questions and the peer-critique activity. The teachers, who volunteered to use the peer-critique activity, were trained to use the activity and asked to incorporate it in their planned lessons. Prior to the lesson on how to ask research questions, students were given a questionnaire in which they were asked to write at least three research questions that they would like to explore. The pre-lesson questionnaire was filled out by individual students, while the peer-critique activity was performed by the designated research groups. The results presented in this study were taken from lessons of the two Bio-Tech teachers, Sam and Rebecca, who performed the activity in the 2012/2013 academic school year. Collected data included students' written sheets and audio-recordings of the lessons. Students' written questions during the peer-critique activity were collected, analyzed, and compared to the students' questions in the pre-lesson questionnaire and to their final research questions, investigated in the Bio-Tech program.

Interviews with the teachers

Semi-structured interviews with the two Bio-Tech teachers were performed right after the lesson on how to ask research questions, at the end of the school year, and 1 year later. In the interviews, the teachers described their teaching strategies and goals for the asking of research questions in the Bio-Tech program and addressed specific cases from the analyzed lessons that were presented to them.

Parts of the interviews that address the teaching and learning of asking research questions were transcribed and analyzed. Teachers were prompted to describe their approach when teaching students how to ask research questions, the process that the Bio-Tech students experienced during the program when formulating and investigating their research questions, and other opportunities the students may had to engage in asking research-question practice in school. Teachers' answers which addressed these issues were transcribed and used to determine teachers' attitudes towards their teaching approach and students' learning of asking research questions in the Bio-Tech program. Another science-education researcher validated emerging attitudes, and consensus was reached for determining teachers' attitude.

Table 1 Teacher, school, and class characteristics of the study participants

Teachers	Scientific background	Teaching experience (years)	Experience in the Bio-Tech program (years)	Number of students in the class	Bio-Tech topic
Sam	MSc in Life Sciences	13	3	27	Unfolded protein response (UPR) in yeast (Cox and Walter 1996)
Rebecca	BSc in Life Sciences	26	2	19	Bacterial expression of paraoxonase 1 (PON1) enzyme (Aharoni et al. 2003)

Analysis of students' written questions

Students' written questions in the pre-lesson questionnaire and in the peer-critique activity sheet were classified as research or non-research questions, based on the definition of Cuccio-Schirripa and Steiner (2000). To be classified as a research question, the following criteria are required: (i) answering the question requires a hands-on investigation and data collection; (ii) the question includes a specific measurable dependent variable, a specific manipulated independent variable, and the connection between them; and (iii) the answer to the question is unknown to the student. Questions that did not meet all of these criteria were classified as non-research questions. For example, one of the students' suggested research question was as follows: "The effect of LDL on dismantling of neural toxic gas." This question was classified as a non-research question, since it is not specific and does not include measurable variables. Another example was the following question: "What is the difference between the effect of Tetracycline and Kanamycin antibiotics in the growth medium on the growth of the bacteria that contain the PON1 gene?" This question was classified as a research question, since it required hands-on investigation, includes measurable variables, and the answer is not known to the students.

Students' questions were statistically analyzed using Pearson's χ^2 test of independence. Effect size was calculated for standardized differences between two means of percentage of research questions in each class using Cohen's *d*. Students' questions prior to the lesson were matched and compared to the research questions they wrote during the peer-critique activity and to the final research questions that they investigated during the Bio-Tech program. Classification of the students' questions was validated by four science-education researchers who rated a sample of about 10 % of the questions. Raters were asked to classify the questions as research or non-research. More than 80 % agreement was achieved between the raters. Debatable questions were further discussed among the authors until full agreement was reached.

Analysis of the classroom discourse

The communicative approach analytical framework (Mortimer and Scott 2003) was chosen to examine the classroom discourse during the lesson on how to ask research questions. Audio-recordings of this lesson were fully transcribed and divided into episodes and utterances. The episodes were divided according to the content discussed in each part of the lesson. Each utterance included one speech turn. Some speech turns were divided into several utterances according to their content. Each utterance was coded and classified according to the communicative approach framework (Mortimer and Scott 2003).

Utterances were analyzed according to the I-R-E patterns of interaction (Lemke 1990; Mehan 1979).

Frequencies of dialogic sequences were calculated for each examined lesson part. Dialogic interactions that were interrupted or not completed were classified as "truncated chains." Dialogic sequences that included only the triadic pattern were classified as "closed I-R-E chains." Dialogic sequences that included the teacher's prompting and delayed evaluation were classified as "long open chains." The teachers' instructional moves were coded into the following categories, based on Pimentel and McNeill (2013): open questions (questions with many possible answers, aimed to expose students' ideas and thoughts), closed questions (questions with one possible answer that is known to the teacher), probing (asking the student to clarify or elaborate on his/her response, avoiding evaluation), elaborating (long teacher explanation following a short response from a student), toss-back (asking the students to comment on another student's response, avoiding evaluation), and re-voicing (repeating a student's response with slight changes, avoiding evaluation). Long speech acts were defined as teachers' utterances of more than 100 consecutive words. The percentage of teacher talk during the examined lessons was calculated by dividing the number of teacher words by the total number of words spoken during the examined lesson part. For validation purposes, about 10 % of the transcribed lessons were analyzed by five science-education researchers, and more than 80 % agreement was achieved between the raters. The debatable sequences were further discussed until a full consensus was reached.

Results

Development of students' ability to ask research questions during the lessons

To examine the possible development of students' ability to ask research questions, an in-depth examination of students' questions, written during classroom lessons, was performed. The Bio-Tech lessons of two teachers, Sam and Rebecca, were chosen for examination. These lessons included a peer-critique activity that was designed to engage students in collaborative discussions and critiquing. These lessons were assumed to be central to the students' learning to ask research questions in the Bio-Tech program. It is not suggested that this is the only factor that contributes to the development of the Bio-Tech students' ability to ask research questions; however, it might be a meaningful part of the program that contributed to the students' learning of this ability. Students' research questions, written during the peer-critique activity in the examined lessons, were compared to two sets of questions: (i) students' suggested research questions in the pre-lesson questionnaire and

(ii) students' research questions that were investigated in the main experiments of the Bio-Tech program.

Students' questions were categorized as research or non-research questions, based on the aforementioned definition of Cuccio-Schirripa and Steiner (2000). The percentage of research questions written by Rebecca's students significantly increased during the peer-critique activity (38.5 % in the pre-lesson questionnaire and 89.3 % in the peer-critique activity, $\chi^2 = 15.45$, $df = 1$, $p < .001$). The percentage of research questions written by Sam's students remained low in the pre-lesson questionnaire and during the peer-critique activity (3.7 and 5.4 %, respectively, $\chi^2 < .001$, $df = 1$, $p = 1$). The effect size in Rebecca's class was high (Cohen's $d = 1.03$) compared to the low effect size in Sam's class (Cohen's $d = .08$), indicating that Rebecca's lesson improved her students' ability to ask research questions, in contrast to Sam's lesson (Fig. 1).

In Sam's class, 12 groups of students formulated their research questions during the peer-critique activity. However, none of the final research questions that were investigated by Sam's students in the Bio-Tech program were based on the questions that his students formulated during the lesson. In his interview, Sam mentioned that most of the research questions were given to the students prior to the main experiment at the research institute. He claimed that he tried to match the research questions to those suggested by the students during the lesson but that most of their questions were not appropriate or impossible to investigate at the research institute.

In Rebecca's class, nine groups of students wrote their suggested research questions during the peer-critique activity. Out of the five research questions that were investigated by Rebecca's students in the Bio-Tech program

(most of the questions were investigated by two groups, exploring different variants of the bacterial strains), four originated from the research questions formulated by the students during the lesson. The questions that were taken for investigation focused on the effect of the growth medium on PON1 enzyme expression level, the effect of PON1 competitive inhibitor levels on PON1 activity, the effect of the protein purification method on PON1 activity level, and the effect of PON1 expression on the protein activity level. Since most of the research questions written during Rebecca's lesson were subsequently used for the inquiry conducted by the students in the Bio-Tech program, it is assumed that Rebecca's lesson was fundamental to the students' acquisition of this ability. Nevertheless, in their interviews, both teachers mentioned that biotechnology students have numerous opportunities to practice this ability in other scientific learning environments, such as laboratory experiments and other projects.

The Bio-Tech teachers' teaching strategies during the lessons

In an attempt to explain the observed differences between Sam's and Rebecca's students' ability to ask research questions during the examined lessons, the teaching strategies during these lessons were examined for the following aspects: (i) the teachers' chosen lesson structure and (ii) the communicative approach and main teacher moves during the lessons.

Structure of the lessons on how to ask research questions

Sam's lesson was 64 min long. He devoted the first part of the lesson to a whole-class discussion (30 % of the

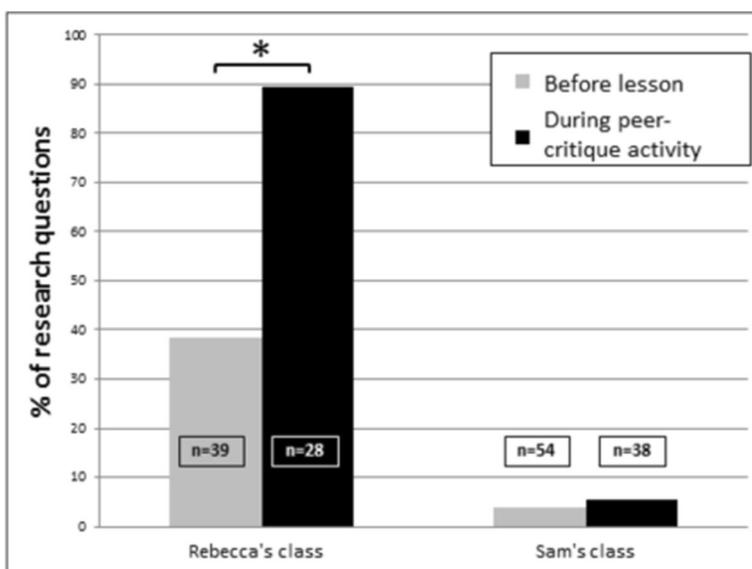


Fig. 1 A comparison of students' ability to ask research questions before and during the two lessons. * $p < .001$, n = number of questions

lesson duration), followed by the peer-critique activity (70 % of the lesson duration). In the whole-class discussion, Sam focused on the characteristics of research questions and on formulating a hypothesis that will lead to an experiment that may enable answering the question. Sam used a few examples of research questions which were unrelated to the Bio-Tech program to explain to his students how to formulate an appropriate research question and hypothesis. In his interview, Sam addressed the time limitation of the examined lesson, mentioning it as a restrictive factor in his teaching.

Rebecca's lesson was 100 min long. It included a whole-class discussion that focused on the requirements of a research question appropriate for the Bio-Tech program (40 % of the lesson duration), the peer-critique activity (38 % of the lesson duration), and another whole-class discussion dedicated to analyzing some of the students' chosen research questions (22 % of the lesson duration). The first whole-class discussion focused on the characteristics and components of research questions appropriate for the Bio-Tech program, and students were asked to propose possible research questions. In the whole-class discussion that followed the peer-critique activity, two of the groups presented their chosen research questions and the other students critiqued them in a whole-class discussion (Fig. 2).

Communicative approach during the lessons

Discourse analysis of the whole-class discussions that were performed at the beginning of the examined lessons was carried out, following the communicative approach analytical framework described by Mortimer and Scott (2003).

Sam's lesson

In the first part of the lesson, Sam focused on the characteristics of research questions and on the importance

of formulating hypotheses that can lead to experiments that may answer the research questions. Sam used several examples unrelated to the Bio-Tech topic to explain how to formulate appropriate research questions and hypotheses. Sam also emphasized the nature of science and the scientific method in several cases, as can be seen in the following teacher speech act taken from the whole-class discussion: "Based on the scientific method, the first thing I want to do is to ask myself the question, define the question."

Sam's communicative approach was mostly authoritative and non-interactive during the whole-class discussion. His authoritative approach was reflected in the fact that he presented students with only his views regarding the characteristics of research questions and hypotheses and did not allow the students to voice their own ideas. Sam's lesson included only a few teacher questions for the students (two closed questions with specific answers and only one open question), low student involvement during the lesson, and six long teacher speech acts (more than 100 consecutive words). In the long speech acts that occurred during the lesson, Sam did not ask questions and did not engage the students in the discussion. His voice was the only voice heard. Sam occasionally asked the students to confirm their understanding using rhetorical questions (e.g., "OK?...Right?"). Most of the discourse during the class discussion was Sam's (95 % teacher talk). Sam's students asked 13 questions during the whole-class discussion, most of them requests for clarification of the taught topic. These questions were answered by long teacher answers, as exemplified in Table 2.

In the few interactions initiated by Sam's questions, the canonical I-R-E closed-chain triadic interaction pattern was identified (Table 3).

All of the above demonstrate Sam's authoritative and non-interactive communicative approach. Sam acknowledged his teacher-centered approach during the examined lesson in his interview. He claimed that his teaching approach changes between the formal classroom lessons and the laboratory lessons. In the formal classroom lessons, he

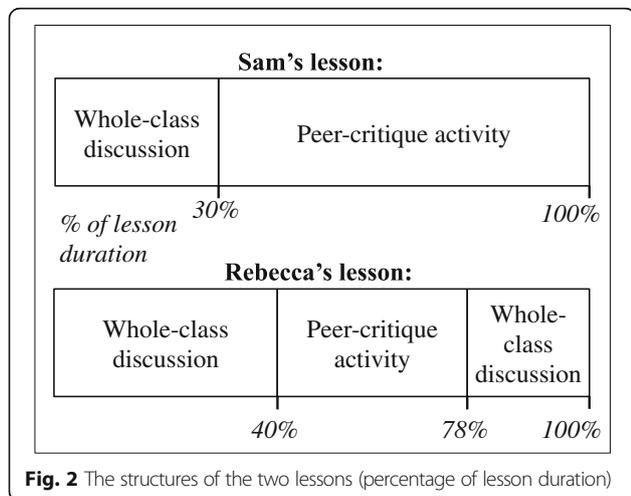


Table 2 Sam's answer to a student's question (9:05 in recording)

Turn	Speaker	Utterance
1	Student	"I have a question. In our research we will write a hypothesis that is opposite to our original hypothesis?"
2	Sam	"No, not necessarily. What is more important for me is that you will write a hypothesis which takes a stand. To write the hypothesis correctly, OK? This treatment will affect, or will not affect, what we see. OK? And eventually to address this in the discussion. In the discussion you go back and address the hypothesis, right? The primary [hypothesis]. If this was my hypothesis, now I've verified it, the experiment verified the hypothesis or disputed it. OK?"

Table 3 The closed-chain interaction in Sam’s lesson (5:48 in recording)

Turn	Speaker	Utterance	Pattern of interaction
1	Sam	“If I think that something is affecting, I usually use two treatments, right? In one treatment I provide the treatment to see that it affects. What would be the other treatment?”	Initiation
2	Student	“Control.”	Response
3	Sam	“That is correct; the other treatment would be the control, to compare.”	Evaluation

is usually in control of the discussion and tries to use the limited amount of time he has to cover as much content as possible. On the other hand, during the laboratory lessons, he allows the students to be more independent, promotes more open discussions, and encourages his students’ involvement. According to Sam, the students know they will have the opportunity to further discuss and elaborate their ideas in the laboratory lessons.

Rebecca’s lesson

Rebecca dedicated two parts of the lesson to whole-class discussions, focusing on the characteristics and components of research questions that are appropriate for the Bio-Tech program. In the first part of the lesson, she asked the students to propose possible research questions. She focused on the correct wording of research questions and the characteristics and components of research questions that are suited to the Bio-Tech program. Each episode during the whole-class discussion began with an open teacher question, inviting the students to share their ideas. Rebecca repeatedly connected the discussion to the Bio-Tech topic when discussing possible research questions, and available tools and methods, using the specific Bio-Tech subject-matter terms.

Rebecca’s communicative approach was mostly dialogic and interactive. The dialogic approach was demonstrated by the teacher’s moves, encouraging the students to voice their opinions and prompting them to elaborate on their ideas. For example, Rebecca asked: “What are the characteristics of a good research question?” Rebecca’s interactive approach was observed in her interactions with the students. She asked 77 questions during the examined whole-class discussion: 56 of them were open questions that encouraged the students to expand on their thoughts and give their own opinions, and 21 were closed questions that required specific answers. The interactions between Rebecca and her students were frequent during the class discussion, and the students were highly involved in the discussions (66 % teacher talk). Rebecca used interactive talk moves, such as re-voicing of students’ answers,

writing the students’ suggestions on the board, and asking students to elaborate on their answers. Some of the students’ ideas developed into a dialogic discourse between the students and teacher. It should be mentioned that Rebecca rejected students’ answers on three occasions during the examined discussion, as exemplified in Table 4.

Rebecca’s moves during the examined lesson included student-centered moves such as prompting questions, re-voicing her students’ ideas without evaluating, and tossing back some of the students’ questions to the other students. Most of the 21 questions asked by students during the analyzed lesson part were requests for clarification about the taught subject or requests for further elaboration and explanations from the teacher. The teacher’s responses to these questions were sometimes direct answers, but in some cases, she also replied by asking the students to elaborate or expand on their question, as exemplified in Table 5.

In the examined discussion, Rebecca demonstrated the triadic I-R-E pattern 5 times, while showing longer sustained interactions 21 times (e.g., I-R-P-R-P-R-E, P stands for Prompt). In doing so, Rebecca maintained longer chains of interactions with the students. In Table 6, an open chain of interactions is demonstrated. It starts with the teacher’s request for an example of a question that cannot be investigated (Initiation, turn 1) and a response from a student (Response 1, turn 2), followed by a teacher move of re-voicing the student and asking a probing question in the form of a request for an example (Prompt, turn 3). Only after the student’s second response (Response 2, turn 4) does the teacher provide her feedback to his suggestion (Evaluate, turn 5).

Taken together, it can be seen that Rebecca’s approach in the examined lesson was mostly dialogic and interactive. In her interview, she confirmed her student-centered, dialogic, and interactive approach. She viewed this approach as critical for supporting students’ understanding and for productive and meaningful discourse. In her interview following the lesson, Rebecca emphasized the importance of students’ involvement during the lesson. She allowed the students to think and explore their ideas during the lessons, even if they sometimes sidetracked from the main lesson plan. The main aspects

Table 4 Rejection of student’s answer in Rebecca’s lesson (20:07 in recording)

Turn	Speaker	Utterance
1	Rebecca	“You are examining the effect of the independent variable. What do you need to know about the wording [of the question]?”
2	Student	“The conditions?”
3	Rebecca	“No, I want to know about the dependent variable, how I measure it, what is the preferred method of measuring it.”

Table 5 Rebecca’s request for elaboration in response to student’s question (13:53 in recording)

Turn	Speaker	Utterance
1	Student	“Does the concentration, the amount of light that something is exposed to, can this affect it [the enzyme production]?”
2	Rebecca	“The question is if this is relevant. Do you think the light is relevant? Convince me that it is relevant to examine the light.”

of comparison between the two teachers’ communicative approaches and teacher moves are summarized in Table 7.

Discussion

To examine the possible development of students’ ability to ask research questions, their questions during lessons designed to formulate research questions appropriate for investigation in the inquiry-oriented Bio-Tech program were analyzed. The possible connection between the two Bio-Tech teachers, Rebecca’s and Sam’s, teaching strategy during formulating research-question lesson and the students’ ability to ask research questions was investigated. Rebecca’s students’ ability to ask research questions improved during the examined lesson, whereas that of Sam’s students remained low. Since most of Rebecca’s students’ research questions were subsequently used for the inquiry conducted by the students in the Bio-Tech program a few months later, it is assumed that Rebecca’s lesson was fundamental to the students’ acquisition of this ability and for its sustainability for a long period of time. Sam’s students did not demonstrate a significant increase in the number of written research questions during the lesson, and none of their questions that were formulated during the lesson were later investigated in the program.

The initial number of research questions in Rebecca’s class was higher than that in Sam’s class. This difference

Table 6 Open-chain interactions in Rebecca’s lesson (7:35 in recording)

Turn	Speaker	Utterance	Teacher’s move	Pattern of interaction
1	Rebecca	“Now, you may be asking why it [the research question] can’t be investigated. Give me one idea.”	Open question	Initiation
2	Student	“Risk.”		Response 1
3	Rebecca	“Risk. It could be risky. Give me an example of a risk related to PON1 enzyme.”	Re-voice, elaborate	Prompt
4	Student	“Toxic gas.”		Response 2
5	Rebecca	“Toxic gas may be a problem. Maybe we shouldn’t ask questions that are related to toxic gas.”	Re-voice	Evaluation

Table 7 A comparison of Sam’s and Rebecca’s communicative approaches during the examined lessons (following Pimentel and McNeill 2013 and Mortimer and Scott 2003)

Aspect of analysis	Sam	Rebecca
Communicative approach	Authoritative/non-interactive	Dialogic/interactive
Main teacher moves	Long speech acts, elaboration	Probing, re-voicing, toss-back
Duration of the examined lesson part (min)	19	40
Percentage of teacher talk (%)	66	95
# of long teacher speech acts	6	0
# of I-R-E closed chains	2	14
# of long open chains	0	28
# of closed teacher questions	2	21
# of open teacher questions	1	56

could be explained by the fact that Rebecca’s students had experienced inquiry and the asking of research questions on other occasions, besides the Bio-Tech program, as mentioned by Rebecca. Therefore, as suggested in other studies (Chin and Osborne 2008; Lombard and Schneider 2013), it is important to provide students with opportunities to learn and practice asking research questions in earlier years and in a variety of educational activities. Previous findings regarding the teaching and learning of how to ask research questions in authentic-inquiry environments suggest that students’ ability to ask research questions improve following explicit classroom instruction (Chin 2002; Chin and Osborne 2008; Cuccio-Schirripa and Steiner 2000; Roth and Roychoudhury 1993). Similarly, our results indicate that 11th-grade biotechnology students’ ability to ask research questions improved following explicit instruction on how to ask research questions in the lesson that included dialogic and interactive whole-class discussions.

Examining the communicative approach and main teacher moves during the lessons indicated that students’ ability to ask research questions developed in the student-centered, dialogic, and interactive lesson and not in the teacher-centered, authoritative, and non-interactive lesson. Most whole-class discussions are usually teacher-led (Newton et al. 1999), governed by the triadic I-R-E dialog (Duschl and Osborne 2002; Lemke 1990), and teachers tend to avoid probing and toss-back questions, resulting in limited and simple responses from the students (Pimentel and McNeill 2013). Dialogic interactions during whole-class discourse encourage students to share and discuss their own ideas and views (Lehesvuori et al. 2013). Pimentel and McNeill (2013) found that

teachers who used more dialogic student-centered interactions in their teaching encouraged the students to have more reflective thinking and meaningful discussions. In line with those studies, the Bio-Tech teacher who displayed a student-centered teaching strategy and dialogic/interactive communicative approach had greater success in teaching her students to ask research questions than the teacher who displayed a more teacher-centered teaching strategy and authoritative/non-interactive communicative approach. Teachers often shift their communicative approach during the lesson or teaching sequences (Lehesvuori et al. 2013; Scott et al. 2006). In the whole-class discussions that were examined in our study, the two teachers retained their communicative approach throughout the discussion. It is possible that examining other parts of the lessons or other Bio-Tech lessons given by the same teachers might reveal shifts in their communicative approach and teaching strategies, according to their goals and lesson plans.

Some studies suggest that the more experience teachers have in performing authentic scientific inquiry, the better their ability to teach inquiry becomes (Blanchard et al. 2009). Therefore, a possible explanation for the differences that were found between the two Bio-Tech classes could be attributed to the teachers' scientific research experience. Studies regarding the correlation between teachers' research experience and their students' learning during inquiry activities have yielded mixed results. For example, Windschitl (2003) found that among pre-service science teachers, those who implemented open inquiry in their classes were those with significant undergraduate or professional scientific research experience. However, other studies concluded that neither the academic degree nor the research experience of the teachers impacted their students' learning during the inquiry school activities (McNeill et al. 2011; Monk 1994). In the two Bio-Tech case studies analyzed here, the teachers' academic research experience was negatively correlated with the development of their students' ability to ask research questions. Namely, despite the fact that Sam is probably more experienced in conducting scientific research from his MSc studies (see Table 1), the students of Rebecca who holds a BSc degree (Table 1) performed better. This indicates that the academic level of the examined Bio-Tech teachers may have hindered the students' learning to ask appropriate research questions. Another possible explanation for this result is that there were other factors that may have affected the students' learning. Such factors might be Sam's students' low cognitive level prior to the lesson, as was seen in their limited ability to ask research questions in the pre-lesson questionnaire compared to Rebecca's students, or Sam's authoritative and non-interactive communicative approach during the discussed lesson. Another possible factor could be the size

class, since the number of students in Sam's class was larger than the number in Rebecca's class.

One of this study's limitations is that it examined only two Bio-Tech teachers and their classes and the teaching that was carried out in one classroom lesson. However, these teachers are believed to represent typical high-school biotechnology teachers. Other teachers and lessons should be investigated to further support our conclusions. Further research is required to gain a broader view of the teaching and learning of how to ask research questions.

This study's results indicate that students' ability to ask research questions may develop in student-centered, dialogic, and interactive lessons. Encouraging teachers to implement dialogic and interactive classroom discourse in authentic inquiry could be a meaningful tool to support the teaching and learning of scientific abilities such as asking research questions. In line with other studies that have recommended promoting student-centered teaching strategies in science classrooms and inquiry learning (Pimentel and McNeill 2013; Scott et al. 2006; van Zee and Minstrell 1997), we suggest that applying student-centered, dialogic, interactive teaching strategies during the teaching of how to ask research questions in inquiry-oriented programs may develop students' question-asking ability.

Conclusions

In the two examined case studies presented here, a connection was demonstrated between the more student-centered, dialogic, and interactive teaching strategy and the development of students' ability to ask research questions. In the student-centered class, most of the research questions that were investigated in the Bio-Tech program originated from the peer-critique activity during the lesson. This indicates that a student-centered, dialogic, and interactive teaching strategy may contribute to the development of students' ability to ask research questions in an inquiry-oriented high-school program.

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Authors' contributions

TB conducted the study as part of his research towards a PhD degree in Science Teaching at the Feinberg Graduate School of the Weizmann Institute of Science. He designed the study, carried out the experiments that are described in this manuscript, and wrote up the text. AY contributed to the conception of the study and its design, as she was the PhD supervisor of the first author. She partially participated in the acquisition of the data and helped in interpreting the collected data and in writing the manuscript for publication. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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References

- Abd-ElKhalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., & Tuan, H. L. (2004). Inquiry in science education: international perspectives. *Science Education*, 88, 397–419.
- Aharoni, A., Gaidukov, L., Yagur, S., Lilly Tokar, L., Silman, I., & Tawfik, D. (2003). Directed evolution of mammalian paraoxonases PON1 and PON3 for bacterial expression and catalytic specialization. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 101(2), 482–487.
- Australian Curriculum Assessment and Reporting Authority [ACARA]. (2012). The Australian Curriculum Science. Retrieved from http://www.acara.edu.au/_resources/20141219_ANR_2012_Parts_1-6_and_10.pdf
- Blanchard, M. R., Southerland, S. A., & Granger, E. M. (2009). No silver bullet for inquiry: making sense of teacher change following an inquiry-based research experience for teachers. *Science Education*, 93(2), 322–360.
- Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 20–62). Washington, DC: American Association for the Advancement of Science.
- Chin, C. (2002). Open investigations in science: posing problems and asking investigative questions. *Teaching and Learning*, 23(2), 156–166.
- Chin, C. (2007). Teacher questioning in science classrooms: approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, 44(6), 815–843.
- Chin, C., & Brown, D. E. (2002). Student-generated questions: a meaningful aspect of learning in science. *International Journal of Science Education*, 24(5), 521–549.
- Chin, C., & Kayalvizhi, G. (2002). Posing problems for open investigations: what questions do pupils ask? *Research in Science & Technological Education*, 20(2), 269–287.
- Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *Studies in Science Education*, 44(1), 1–39.
- Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: a theoretical framework for evaluating inquiry tasks. *Science Education*, 86, 175–218.
- Cox, J. S., & Walter, P. (1996). A novel mechanism for regulating activity of a transcription factor that controls the unfolded protein response. *Cell*, 87(3), 391–404. Retrieved from <http://linkinghub.elsevier.com/retrieve/pii/S0092867400813604>.
- Cuccio-Schirripa, S., & Steiner, H. E. (2000). Enhancement and analysis of science question level for middle school students. *Journal of Research in Science Teaching*, 37(2), 210–224.
- Dori, Y. J., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: analysis of an environmental case study. *Journal of Research in Science Teaching*, 36(4), 411–430.
- Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, 38, 39–72.
- European Commission. (2007). *Science education now: a renewed pedagogy for the future of Europe*. Retrieved from Brussels, Belgium
- Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: a meta-analysis. *Review of Educational Research*, 82(3), 300–329. doi:10.3102/0034654312457206.
- Gan Joo Seng, M., & Hill, M. (2014). Using a dialogical approach to examine peer feedback during chemistry investigative task discussion. *Research in Science Education*, 44(5), 727–749.
- Harlen, W. (2004). *Evaluating inquiry-based science developments* (Paper presented at the Status of Evaluation of Inquiry-Based Science at the National Research Council, Washington, DC).
- Harris, C., Phillips, R., & Penuel, W. (2012). Examining teachers' instructional moves aimed at developing students' ideas and questions in learner-centered science classrooms. *Journal of Science Teacher Education*, 23(7), 769–788.
- Hartford, F., & Good, R. (1982). Training chemistry students to ask research questions. *Journal of Research in Science Teaching*, 19(7), 559–570.
- Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond construction: five arguments for the role and value of critique in learning science. *International Journal of Science Education*, 37(10), 1668–1697. doi:10.1080/09500693.2015.1043598.
- Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: a response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99–107.
- Jimenez-Alexandre, M. P., Bugallo Rodriguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": argument in high school genetics. *Science Education*, 84, 757–792.
- Kawalkar, A., & Vijapurkar, J. (2011). Scaffolding science talk: the role of teachers' questions in the inquiry classroom. *International Journal of Science Education*, 35(12), 2004–2027.
- Keys, C. W. (1998). A study of grade six students generating questions and plans for open-ended science investigations. *Research in Science Education*, 28(3), 301–316.
- Lehesvuori, S., Viiri, J., Rasku-Puttonen, H., Moate, J., & Helaakoski, J. (2013). Visualizing communication structures in science classrooms: tracing cumulativity in teacher-led whole class discussions. *Journal of Research in Science Teaching*, 50(8), 912–939.
- Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood: Ablex.
- Lombard, F. E., & Schneider, D. K. (2013). Good student questions in inquiry learning. *Journal of Biological Education*, 47(3), 166–174.
- McNeill, K. L., Pimentel, D. S., & Strauss, E. G. (2011). The impact of high school science teachers' beliefs, curricular enactments and experience on student learning during an inquiry-based urban ecology curriculum. *International Journal of Science Education*, 35(15), 2608–2644.
- Mehan, H. (1979). *Learning lessons*. Cambridge: Harvard University Press.
- Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction: what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474–496.
- Monk, D. H. (1994). Subject area preparation of secondary mathematics and science teachers and student achievement. *Economics of Education Review*, 13(2), 125–145.
- Mortimer, E., & Scott, P. (2003). *Meaning Making In Secondary Science Classrooms*. McGraw-Hill Education (UK).
- National Research Council [NRC]. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
- National Research Council [NRC]. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academic Press.
- National Research Council [NRC]. (2007). *Taking science to school: learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.
- National Research Council [NRC]. (2012). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Retrieved from Washington, D.C.
- Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, 21(5), 553–576. doi:10.1080/095006999290570.
- Osborne, J. (2010). Arguing to learn in science: the role of collaborative, critical discourse. *Science*, 328(5977), 463–466. doi:10.1126/science.1183944.
- Pedrosa-de-Jesus, H., Silva Lopes, B., Moreira, A., & Watts, M. (2012). Contexts for questioning: two zones of teaching and learning in undergraduate science. *Higher Education*, 64(4), 557–571.
- Pimentel, D. S., & McNeill, K. L. (2013). Conducting talk in secondary science classrooms: investigating instructional moves and teachers' beliefs. *Science Education*, 97(3), 367–394.
- Roth, W. M., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. *Journal of Research in Science Teaching*, 30(2), 127–152.
- Scott, P. (1998). Teacher talk and meaning making in science classrooms: a Vygotskian analysis and review. *Studies in Science Education*, 32(1), 45–80.
- Scott, P. H., Mortimer, E. F., & Agular, O. G. (2006). The tension between authoritative and dialogic discourse: a fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, 90, 605–631.
- Tamir, P. (2006). Inquiry in science teaching and its reflection in biology teaching in Israel (in Hebrew). In A. Zohar (Ed.), *Learning by inquiry: an ongoing challenge* (pp. 15–56). Jerusalem: Magnes press.

- United Kingdom Department of Education. (2013). *National curriculum in England: science programmes of study*. Retrieved from <https://www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study/national-curriculum-in-england-science-programmes-of-study>.
- van Zee, E., & Minstrell, J. (1997). Using questioning to guide student thinking. *The Journal of the Learning Sciences*, 6(2), 227–269.
- Vygotsky, L. S. (1978). Interaction between learning and development. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society* (pp. 79–91). Cambridge: Harvard University Press.
- Wayne Allison, A., & Shrigley, R. L. (1986). Teaching children to ask operational questions in science. *Science Education*, 70(1), 73–80.
- Windschitl, M. (2003). Inquiry projects in science teacher education: what can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, 87(1), 112–143.
- Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, 92(5), 941–967.
- Yarden, A., Brill, G., & Falk, H. (2001). Primary literature as a basis for a high-school biology curriculum. *Journal of Biological Education*, 35(4), 190–195.

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