Cell Biology Education
Vol. 2, 266–274, Winter 2003

Learning Biology through Research Papers: A Stimulus for Question-Asking by High-School Students

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Submitted December 19, 2002; Revised May 27, 2003 ; Accepted May 28, 2003
Monitoring Editor: James Gentile

Question-asking is a basic skill, required for the development of scientific thinking. However, the way in which science lessons are conducted does not usually stimulate question-asking by students. To make students more familiar with the scientific inquiry process, we developed a curriculum in developmental biology based on research papers suitable for high-school students. Since a scientific paper poses a research question, demonstrates the events that led to the answer, and poses new questions, we attempted to examine the effect of studying through research papers on students' ability to pose questions. Students were asked before, during, and after instruction what they found interesting to know about embryonic development. In addition, we monitored students' questions, which were asked orally during the lessons. Questions were scored according to three categories: properties, comparisons, and causal relationships. We found that before learning through research papers, students tend to ask only questions of the properties category. In contrast, students tend to pose questions that reveal a higher level of thinking and uniqueness during or following instruction with research papers. This change was not observed during or following instruction with a textbook. We suggest that learning through research papers may be one way to provide a stimulus for question-asking by high-school students and results in higher thinking levels and uniqueness.

Keywords: secondary, developmental biology, question-asking, primary literature, inquiry process.

INTRODUCTION AND RATIONALE OF THE STUDY

Scientific research may be conceived as a question-and-answer process (Dillon, 1988a). In this dynamic and ongoing process, questions are asked and answered, and presuppositions are accepted or abandoned (Dillon, 1988a). Rescher (1982) describes scientific inquiry as "a step-by-step exchange of query and response that produces sequences within which the answers to our questions ordinarily open up yet further questions." Thus, questions are an important part of the ongoing scientific research process. Asking research questions in the experimental sciences usually requires a combination of domain-specific declarative knowledge and procedural or strategic knowledge (Alexander and Judy, 1988; Farnham-Diggory, 1994), which together enable the performance of the required experiments in an attempt to answer the research question.

In addition to its fundamental role in scientific research, question-asking has an important educational role (Biddulph *et al.*, 1986; Scardamalia and Bereiter, 1992; White and Gunstone, 1992; Watts *et al.*, 1997; Chin *et al.*, 2002). Self-generated questions are thought to contribute to meaningful learning and to the construction of knowledge (Chin *et al.*, 2002). Question-asking by students can be considered a constructivist way of learning (Watts *et al.*, 1997), which serves to close gaps in the minds of the askers (Scardamalia and Bereiter, 1992). Question-asking may also create the motivation to find answers and, thus, contribute to higher cognitive achievements (White and Gunstone, 1992). In addition, question-asking can help teachers reveal the students' reasoning, alternative views and interest (Biddulph *et al.*, 1986).

Although question-asking is a basic requirement for the performance of scientific research, and for meaningful learning, the way in which science lessons are conducted does not usually stimulate question-asking by the students (Dillon, 1988b). Questions are posed mainly by teachers during lessons (Allison and Shrigley, 1986; Dillon, 1988b; Dori and Herscovitz, 1999) and not by the students. Many of the questions that are posed during lessons (Barden, 1995) or that are found in textbooks (Shepardson and Pizzini, 1991) require low levels of thinking (of the knowledge category, according to the taxonomy of Bloom *et al.* [1956]). In textbooks and in the classroom, students are required to learn techniques that will enable them to solve exercises that usually have one correct answer (Zoller, 1987). These kinds of questions only develop technical skills; they do not encourage high levels of thinking, and they create a learning environment that is far from

DOI: 10.1187/cbe.02-12-0062
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the environment that exists while conducting real scientific research.

As already mentioned, students do not usually tend to ask questions. Therefore, question-asking by students has to be encouraged by the environment created during the lesson (Dillon, 1988b; Scardamalia and Bereiter, 1992; Shodell, 1995). There is a variety of ways to conduct a question-stimulating lesson. Discussion is one of the ways in which, in addition to questions asked by the teacher, questions can also be posed by the students (King, 1994). Cognitive conflict (Allison and Shrigley, 1986), real-world problem-solving activities (Zoller, 1987; Chin *et al.*, 2002), or case studies (Dori and Herscovitz, 1999) have also been reported as catalysts to question-asking, provided the students are required to ask questions. Training students to ask questions and to improve their questioning skills can also serve to stimulate them to generate their own questions (Hartford and Good, 1982; Dillon, 1988b).

As with their answers to a teacher's questions, students' questions can reveal their level of understanding (Biddulph *et al.*, 1986; Dillon, 1988b). The skill of posing questions can be evaluated in several ways, most of which refer to the level of thinking required in order to answer the questions. One way is to evaluate questions according to Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation [Bloom *et al.*, 1956]). A simpler evaluation involves distinguishing among three categories of questions (Shepardson and Pizzini, 1991): input category—a question that requires recalling knowledge; processing category—a question that requires linking pieces of information; and output category—a question that requires hypothesizing, generalizing, criticizing, etc. Dori and Herscovitz (1999) suggested three different categories: the quantity of questions posed by the student; the orientation of the answer to the question—descriptive, consequences or effects, a solution to a problem or hypothesis; and the complexity of the answer—application, interdisciplinary, judgment, criticism, personal opinion. Scardamalia and Bereiter (1992) described another two categories of questions posed by students: text-based questions that are generated while reading texts, usually in response to specific requests to ask questions as part of the learning process; and wonderment questions that result from a deep interest of the student trying to make sense of the world.

In an attempt to specifically classify research questions, Dillon (1984) proposed five main categories: rhetorical, properties, comparisons, contingencies, and other. According to Dillon (1984), each category represents a different order of information that can be obtained by the research driven by this type of research question. The three categories—properties, comparisons, and contingencies—were classified by Dillon (1984) as first-, second-, and third-order categories, respectively, indicating their relative increase in contribution to scientific knowledge. In contrast, the rhetorical questions were classified by Dillon (1984) as zero order, since they will never contribute new knowledge. Dillon considered causal questions to be of the highest order of research questions since "they represent the kind of knowledge that scientific inquiry is conceived ultimately to aspire to and that it is hoped eventually to attain." Dillon (1984) further characterized each of the five categories of questions and specified all of the possibilities in each category.

To make high-school biology students more familiar with the process of scientific research, we developed learning material in developmental biology that is based on selected research papers (Yarden and Brill, 2000). In addition to processing research articles so they suit the cognitive level of high-school students, the curriculum includes an introduction expressing the main principles in developmental biology and major research questions in the field (Yarden *et al.*, 2001). Although scientists commonly report their research in research papers and continuously read research papers to learn about research performed by others, text-based learning through the use of scientific research papers in high schools is less common (Yarden *et al.*, 2001). As mentioned previously, the research question is an important component of research articles, as it combines procedural and declarative knowledge and can reveal the rationale of the research. The format of a research paper usually unfolds in an orderly way, describing the theoretical background that gave rise to the research question, the methods that were chosen according to the research question, and the nature of the results obtained in the research. Thus, we wondered whether learning through research papers could serve as a catalyst to asking research-type questions among high-school biology students.

METHODS

Research Sample

New learning material in developmental biology (Yarden and Brill, 2000) was initially introduced to high-school biology majors (17-year-old students in 11th grade [three classes; $n = 17$, $n = 12$, $n = 30$] and 18-year-old students in 12th grade [one class; $n = 10$]) at four urban high schools in Israel. The total number of student participants in the experimental group was 69. The group was composed of an approximately equal number of males (33) and females (36). In addition to this group of students, the same curriculum was introduced to an additional class (18-year-old students in 12th grade; $n = 18$) at another urban high school in Israel. From this additional class, qualitative data were collected and analyzed.

The control group consisted of an additional class of high-school biology majors from an urban high school in Israel (17-year-old students in 11th grade; $n = 38$). This class did not learn the developmental biology curriculum and was engaged in learning genetics, as an advanced topic of the syllabus for biology majors (see below).

In Israel, students choose to major during 11th and 12th grades in at least one scientific or nonscientific topic, which is evaluated in a national matriculation examination. The syllabus for biology-major studies in Israel (300 h of teaching [Israeli Ministry of Education, 1991, 2003]) includes, in addition to basic topics, advanced topics that are aimed to reflect the dynamics of biological research and discovery. Each of the advanced topics, including the curriculum in developmental biology, is designed for 30 h of teaching.

The Developmental Biology Curriculum

The curriculum unit in the area of developmental biology is described in detail by Yarden *et al.* (2001). Briefly, the program introduction describes principal stages in embryonic development and presents five key research questions in developmental biology. Each question is accompanied by a short discussion, which presents the rationale that led to posing the question. The main part of the program contains four research papers in developmental biology focusing on four different questions.

Apart from the translation of the original papers into Hebrew, each paper was modified as follows. (1) Essential information was added to the introduction of the article in order to help students understand the academic background of the research question. (2) The scientific methods used in the research and the discussion were simplified and adapted to the students' level. (3) Results that did not relate directly to the research questions were omitted. (4) A section about the contribution of the research to the understanding of processes occurring in humans, as well as in other organisms, was added to each paper.

Teachers were also provided with guiding questions for the introduction of the curriculum, as well as for the research articles. The main rationale behind these questions was to encourage a student-centered approach in which a discourse is created between the students and the text, leading the students to actively build their own knowledge structure while reading the article and the introduction of the curriculum. This is in contrast to a teacher-centered approach in which the teacher transfers the content of the text to the students.

The questions were variable and referred to different sections of the article (abstract, introduction, methods, results, and discussion) as well as to the introduction of the curriculum. The main aims of the questions were (1) to recruit prior knowledge; (2) to organize newly acquired knowledge; (3) to formulate the research questions of specific experiments; (4) to emphasize the difference between past experiments that are brought up in the introduction of the article, from which the research question emerged, and the experiments that were conducted in the currently reported research; (5) to help the students connect the terms they use in class with "real" research language; (6) to clarify the differences between the experiments that were conducted in the reported research; and (7) to connect relevant parts of the articles to the introduction of the curriculum.

The genetics curriculum introduces basic topics in classical genetics, as well as some molecular aspects. Briefly, the students of the control group learned about Mendelian heredity, multiple gene heredity, basic probability, linkage of genes, meiosis and mitosis, the chromosomal basis of heredity, and the process of gene transcription and mRNA translation. This topic was studied using a textbook (Atidya, 1990), which consisted of descriptive parts, followed by questions.

Acquisition of Quantitative Data

Quantitative data were collected using paper-and-pencil questionnaires, which were given to the students at the four high schools. The questionnaire included (among other questions) the following: "*What would it interest you to know about embryonic development?*" The questionnaire was handed out to the students at three time points during the 30-h teaching program: before starting the program (a pretest, T1), after learning the introduction and five research questions (T2), and following the study of one research article (T3). T2 served especially to monitor questions posed after the declarative part of the curriculum had been taught. Studying research papers, which followed immediately after T2, does not add a substantial amount of declarative knowledge (Yarden *et al.*, 2001). Indeed, the contribution of one of these articles to scientific declarative knowledge was summarized by one of the students in only one sentence (Yarden *et al.*, 2001). The contribution of the research papers seems, rather, to be to students' acquaintance with the rationale of the research, the research question, and scientific methods. It should be emphasized that during the implementation of the developmental biology curriculum there was no educational effort to elicit question-asking, and the students were not encouraged in any explicit way to ask questions.

The control group, which studied genetics, was asked to answer the question, "*What would it interest you to know about genetics?*" at two time points: the first was about 3 weeks after the beginning of the teaching period of the topic and was, therefore, parallel to T2 of the experimental group. The second time point was 3 weeks after T2, paralleling T3 of the experimental group. By T2, the control class had learned about Mendelian heredity, multiple gene heredity, and some basic probability. At T3, this class had learned most of the other subtopics of the subject (see The Developmental Biology Curriculum, above).

Acquisition of Qualitative Data

In addition to a quantitative approach, we used a qualitative approach to examine the way research articles influence the kind of questions students ask during actual lessons. In the past decade there has been a growing use of qualitative approaches in social science research, including research in science teaching. The need for qualitative research emerged from the difficulties encountered in trying to understand complex environments, in which many factors contribute to the observed phenomenon (Guba and Lincoln, 1998). In such environments, it is difficult to apply classical positivist research approaches, in which variables must be controlled or altered. Qualitative research may focus on a single event, or even a single research subject, but allows one to obtain rich and in-depth data as well as to analyze several variables at once (Guba and Lincoln, 1998). Qualitative research does not contradict quantitative research; rather the two can complement each other, as was our aim here.

Qualitative data were collected during the implementation of the developmental biology curriculum in one of the classrooms. Our analysis focused on the discourses that took place during two of the lessons: (1) a lesson in which part of the introduction to the curriculum was discussed and (2) lesson in which the methods and the results of one of the four research papers in the curriculum were discussed (this research article was modified from Riddle *et al.* [1993]). The first lesson spanned 45 min; the second, 70 min. The two lessons took place 3 weeks apart. They were videotaped and transcripts were prepared.

Categories of Questions According to the Order of Information

The questions, obtained either quantitatively or qualitatively, were evaluated using three categories following Dillon's (1984) classification of research questions. These categories refer to the thinking level required to provide the answers to those questions: (1) properties—answers to questions in this category describe the properties of the subject in question; (2) Comparisons—answering questions in this category requires a comparison between the subjects in question; and (3) causal relationships—answering questions in this category requires finding the relation, correlation, conditionality, or causality of the subjects in question. In most cases, an experiment is needed in order to answer questions in this category. Questions that raise some kind of criticism of the research were also included in this category, since they indicate contradictory relationships. Usually, questions from the properties category referred to one variable, while questions from the comparisons and causal relationships categories referred to at least two variables.

In the quantitative analysis of the students' questions, we referred to the class as a whole, and not to individual students, the main reason being that the number of students changed while the experiment was in progress (see Discussion). In addition, the change in the questions students asked is demonstrated by the number of questions in each category, rather than the change in the total number of questions. This is because the order of information that even one question seeks was considered the most important parameter, rather than the number of questions asked during a class session.

Analysis of Quantitative Data

All of the questions written by the students in the questionnaires, which were introduced in the four different schools at the three time points, were pooled to a single file, for a total of 224 questions. All the questions from the control group at the two time points were also pooled to a different file, for a total of 98 questions. Question categorization was carried out independently by the two researchers. The degree of agreement between the two independent categorizations was calculated by kappa analysis (Fleiss, 1981; Agresti, 1990).

Categories of Question Uniqueness

In addition to the categorization described previously, questions that were collected quantitatively were coded according to content. Questions that received the same code were either similar (for example, the question, "What are the stages in embryonic development?" and the question, "What develops when, and in what order?") or identical. Questions that received a different code were considered unique.

Table 1. The percentage of questions, classified according to their order of information, posed by students during the implementation of the developmental biology or genetics curricula

	Developmental biology[b] (learning using research papers)			Genetics[b] (learning using textbook)	
Category[a]	T1: $n = 91$, $\kappa = 1$ (100%)	T2: $n = 81$, $\kappa = 0.68$ (91%)	T3: $n = 52$, $\kappa = 0.83$ (92%)	T2: $n = 58$ (96%)	T3: $n = 40$ (100%)
Properties	94%	85%	73%	85%	100%
Comparisons	3%	11%	6%	15%	0%
Causal relationships	3%	4%	21%	0%	0%

[a]The categories used for classifying the questions, according to Dillon (1984).

[b]For the developmental biology curriculum, T1 to T3 represent the time points at which the questionnaire was introduced: T1—before starting the developmental biology program (a pretest); T2—after studying the introduction to the learning material; T3—following the study of one research article. For the genetics curriculum, T2—after studying three subtopics in genetics; T3—after studying additional subtopics in genetics. *n* represents the number of questions collected from the four schools at each time point; k represents the kappa value of the degree of agreement between the two independent categorizations of questions carried out by the two researchers. A κ of 0.75 or greater represents a high degree of interrater agreement among coders, while a κ of 0.4–0.75 represents good agreement among coders (Fleiss, 1981; Agresti, 1990). The κ value was not calculated for the group that studied genetics, since 0% of questions were asked in certain categories. The percentage agreement between the two independent categorizations of questions carried out by the two researchers is shown in parentheses.

The number of unique questions was then compared for each stage (T1, T2, and T3 for the experimental group, T2 and T3 for the control group), and a χ^2 test was applied to ensure statistical significance.

RESULTS

Quantitative Analysis of the Influence of Studying through Research Papers on the Type of Questions Posed by Students

Most of the questions (94%) posed by the students before the initiation of the learning using research papers were of the properties category (Table 1). Answering a question in this category requires only declarative knowledge. All questions of this kind that were posed by the students dealt with the different stages or course of events in the development of an embryo. The main characteristic of these questions was their generality: The students did not ask about specific stages or about specific embryos. The questions referred mainly to the whole-embryo level, for example, "In which order does the embryo develop?" and "What are the different stages of embryonic development?" Some of the questions did not have the structure of a question but, rather, were part of a phrase, for example, "stages of development" (see also Table 2). Only 3% of the students, at the initiation of the program, asked questions that were classified into the second or third categories (Table 1). Questions that were posed at this stage of the learning and were classified in the comparisons category were also general and dealt with stages of embryonic development (Table 2).

At the second time point at which the questionnaires were introduced, following a study of the introduction to the learning material in developmental biology, 85% of the students still posed questions that were in the properties category (Table 1). Some of these questions referred to some kind of manipulation of the embryo. An example of this kind of question is, "What are the reversible stages in the development of the embryo and what are the irreversible ones?" This student probably thought of some manipulation of the embryo (for example, replacing pieces of tissue) but did not express this in the question. Most of the questions in this category referred to the specific-organ level but were still general (for example, "How does the brain develop?"; see also Table 2). Eleven percent of the questions were of the second category, requiring some kind of comparison between embryos of different organisms, and 4% were of the third category, requiring some kind of manipulation of the embryo (Tables 1 and 2).

A substantial change was seen after reading one research paper (of the four research papers in the learning material). At this stage, 21% of the questions posed by the students were of the third category—causal relationships—while 6% of the questions were of the second category, and 73% were of the first category (Table 1). An example of a question from the third category after learning one research articles is, "If we take a primary muscle cell at a certain stage in the differentiation process, could we create a muscle cell that would help a person who has a problem with his muscles?" This question was posed after studying an article that focused on mechanisms that control muscle differentiation (following Hasty *et al.*, 1993). The student clearly combines procedural knowledge (taking an embryonic cell out of the embryo and into a new context—the patient) with declarative knowledge (differentiation of cells occurs gradually). In doing so, the student generates a typical if–then question, characteristic of hypothesis (additional examples appear in Table 2).

We noticed that none of the students' questions that were classified in the third category included questions of criticism. One possible reason for this is that the questionnaire presented a general request to ask questions about developmental biology, and therefore no questions of criticism were posed.

In contrast to the change observed in questions from the third category after learning through research articles, no such change was observed in the control group, which studied genetics using a textbook (Table 1). The type of questions asked by these students at T2 were similar to the type of questions asked by the students who learned developmental biology at T2 ($\chi^2 = 3.03$, df $= 2$, $p = .22$). At T3, students from the control group asked only questions from the first category (properties) and did not ask any other type of question. Thus, there was a significant difference between the type of

Table 2. Examples of questions from each category at three time points during implementation of the developmental biology curriculum

Category of questions	T1 (pretest)	T2 (following learning the introduction to the learning material)	T3 (following the study of one research article)
Properties	• The very first stages of development • Possible malformations • How does the embryo develop? • What are the malformations that might occur in embryonic development?	• What are the processes that begin gastrulation and the development of three layers? • How does the embryo breathe? • How does the heart develop? • To what extent can we control and change the characters of an embryo?	• Is it possible to create human body organs under laboratory conditions? • Which processes occur after the growth process [of the embryo] until the full development of the body, even after sexual maturation? • When do the senses of the embryo start to operate?
Comparisons	• Is embryonic development different in different species? • Is the development of all humans the same, or is there a variety like the variety in phenotypes?	• Which part of the embryo develops first? • How is it that certain animals give birth to several littermates, and humans usually give birth to only one child?	• Is the influence of the *myogenin* gene the same in different humans? • Is the pace of embryonic development different in different embryos?
Causal relationships	• Can enhanced physical activity, like going to the amusement park during pregnancy, hurt the embryo?	• Until which stage in differentiation is it possible to go back and switch their position [the cells of the embryo]? • What will happen if we take DNA from an animal and transplant it into a human embryo?	• If we take a certain cell in its first differentiation stage, could it become a new embryo? • Will the addition of the *myogenin* gene to the food of an embryo with a muscle defect save it?

questions asked by students in the control group and the type of questions asked by the students who learned using research papers at T3 ($\chi^2 = 12.702$, df = 2, $p = .002$). At both time points (T2 and T3), the main characteristic of the questions asked by students in the control group was their generality: They referred to general topics in genetics, such as genetic engineering and mutations. Most of the questions did not have question structure; rather they were part of a phrase, for example, "about cloning."

In addition to the increase in questions in the third category, which occurred after learning through a research article, an increase in the number of unique questions was also observed. Questions were coded according to their content, and the proportion of questions that were either similar or identical, as well as the proportion of unique questions at each stage, is shown in Table 3. As can be seen, the proportion of unique questions was significantly ($p = .001$) higher in T3 (73%) than the proportion in T1 (31%) or T2 (54%). While similar questions were only questions in the properties category, unique questions included those from all three information–order categories (properties, comparisons, and causal relationships). In contrast, questions asked in the control class, i.e., those who studied genetics using a textbook, revealed a decrease in unique questions (from 26% at T2 to 17% at T3; Table 3) and no significant difference was found in the proportion of unique questions between T2 and T3 ($p = .33$; Table 3). However, a significant difference ($\chi^2 = 27.947$, df = 1, $p = .001$) was found at T3, between the group that studied using a text book and the group that studied using research papers.

Qualitative Analysis of a Change in the Type of Questions Posed during Actual Lessons

The aforementioned changes in students' questions that were observed at the three time points during the learning process of the developmental biology curriculum were obtained from written questionnaires handed out to the students before or following instruction, and not during the actual learning process itself. To trace possible changes in the questions posed by students who are engaged in a learning process through research papers themselves, we followed students' questions that were asked orally during two lessons: One lesson dealt with a subject from the introduction to the curriculum in developmental biology, and the other, with one of the research articles from the curriculum. Although we refer to questions posed by all the students during the lesson, we focused on one student, M, who was particularly determined in her discussions with the teacher during the lesson that dealt with the research paper.

The First Lesson: Learning the Introduction to the Unit. This lesson was conducted as a typical Socratic dialogue. Questions were posed predominantly by the teacher, a phenomenon that has been described by Dillon (1988b). Nevertheless, students did ask questions ($n = 24$ during 35 min), although the purpose of many of these questions ($n = 14$) was to obtain information that did not concern the biological issue being discussed during the lesson, for example, "On which page is it?" and "What did you write there [on the blackboard]?" These types of questions have been reported as common in lessons that are based on Socratic

Table 3. The percentage of questions, classified according to their uniqueness, posed by students during the implementation of the curriculum

	Developmental biology[b] (learning using research papers): $\chi^2 = 15$, df = 1, $p = .001$[c]			Genetics[b] (learning using textbook): $\chi^2 = .95$, df = 1, $p = .33$[d]	
Category[a]	T1 ($n = 91$)	T2 ($n = 81$)	T3 ($n = 52$)	T2 ($n = 58$)	T3 ($n = 40$)
Similar or identical	69%	46%	27%	74%	83%
Unique	31%	54%	73%	26%	17%

[a]The questions were coded according to their content. Unique questions were separated from similar and identical questions.

[b]For the developmental biology curriculum, T1 to T3 represent the time points at which the questionnaire was introduced: T1—before starting the developmental biology program (a pretest); T2—after studying the introduction to the learning material; T3—following the study of one research article. For the genetics curriculum, T2—after studying three subtopics in genetics; T3—after studying additional subtopics in genetics. *n* represents the number of questions collected from the four schools at each time point.

[c]The chi-square tests the significance of the difference between the number of similar/unique questions asked at T3 and the number asked at T2 and T1.

[d]The chi-square tests the significance of the difference between the number of similar/unique questions asked at T3 and the number asked at T2.

dialogue and classified as conversational questions (Dillon, 1988b).

Students' questions that addressed the biological subject of the lesson were mostly of the properties category ($n = 7$; for example, "Is the ectoderm the inner tissue?"), and only one question that was asked during this lesson was of the comparisons category ("Is a cell that makes a growth factor itself affected by a growth factor?"). Most of these questions were short, as were the conversations with the teacher that followed them.

During this lesson, M was an active participant. She volunteered to read aloud when the teacher asked for volunteers. She gave correct answers to questions asked by the teacher. In addition, she was aware of differences between what the teacher said and what was described in the textbook, and commented on them. It was obvious that her peers considered her a very intelligent person. M also tried to explain a question to the teacher that another class member had asked and that the teacher had not understood. During this lesson, there is only one episode in which M asked the teacher questions:

> *M:* What does "alters the shape of the receptor" mean?
> *Teacher:* Yes, well, the receptor, when it receives a growth factor . . .
> *M:* OK.
> *Teacher:* . . . the shape that faces the internal part of the cell changes.
> *M:* Oh, as if to mark that it received it [the signal]?
> *Teacher:* It received it, something changed there, and as a result protein molecules inside the cell change.

In this episode, M's questions are characteristic properties-type questions. They deal with only one variable (the change in the shape of the receptor), and as soon as M receives the teacher's answer the lesson continues. This episode is similar to other episodes of questions posed by other students in the class during this lesson, in which the questions were of the properties category, and as soon as the answer was given by the teacher the lesson continued.

The Second Lesson: Learning through a Research Article. In this lesson, the teacher and the students went through the methods and the results of the research article they had just been reading (which was modified from Riddle *et al.*, 1993). The teacher conducted a lesson based on guiding questions meant to help the students make sense of what they had read: organize the knowledge they obtained from the article, monitor their understanding, help them connect the paper to other topics in biology, etc. The teacher usually asked the question and discussed it with the whole class. Sometimes she asked the students to answer the questions in groups, sometimes by themselves, but then she always conducted whole-class discussions of the answers. It should be emphasized that during the lesson, the teacher did not explicitly encourage the students to ask questions. At times her reactions even unconsciously discouraged students to ask questions (for example, ignoring students' questions).

The questions that students asked during this lesson ($n = 19$ during 70 min) were of two categories: either properties ($n = 10$) or causal relationships ($n = 9$). The students were interested in the methods used for the specific research and tried to understand the logic behind the method and the experiments (for example, "But doesn't the virus eventually ruin the cells?" "How do they make more of them [the viruses], if they do not overtake the [cell's mechanism of] translation with the disease?"). Their comments during the lesson, including their questions, were longer, delving into more detail ("We said that we use viruses that do not infect the . . . this chicken species, or something like that. That the . . . viruses . . . that the cells of the chicken are resistant to the viruses. So, it cannot influence the chicken. It cannot spread.").

A change was also evident in M's comments and questions during this lesson. M kept asking questions about the methods and the results described in the article. Some of her questions were of the properties category and involved one variable, for example, "Why do they implant the viruses if they cannot cause the illness?" "And then the virus injects its DNA into the cells and now they have the gene in them?" and "What does the virus do except for the fact that it has the gene?"

Other questions involved some kind of procedure, like proposing an experiment: "Why transplant it in the wing? Why not transplant it in the leg, or in the head? Every organ in the body has polarity!"

During this lesson, M continuously criticized the way in which the research had been done and offered her own ways to conduct the experiments. The following episode illustrates this.

> *M:* Can't you just infect cells that [already] have that gene, instead of like . . . transfer DNA into new cells?
> *Teacher:* What you would like is . . . you would like to control the way the gene is expressed. This means that in cells that normally have this gene, because all chick cells have that gene like you saw in the article, there is a certain stage in which the gene is expressed and certain stages in which it isn't.
> *M:* So, according to what you are saying, this gene also exists in fibroblasts . . .
> *Teacher:* That's right!
> *M:* So, what is the difference?
> *Teacher:* But it isn't expressed there.
> *M:* So, the fact that we transfer DNA . . .
> *Teacher:* So with genetic engineering methods we transfer the DNA in such a way that there will be a high quantity of the gene, and also that it will be expressed.
> *M:* How do you know that specifically the gene that you transferred will be expressed?
> *Teacher:* These are already details that you are not supposed to get into, but you transfer it with a very strong promoter to which the RNA polymerase binds strongly, so you will have transcription anyway.

This episode shows that M wants to understand the heart of the matter and she keeps asking until she does. Her questions indicate that she does not take things for granted, consistent with her learning behavior during the first lesson. She also offers other ways to conduct the experiment described in the research paper ("Can't you just infect cells that [already] have that gene, instead of like . . . transfer DNA into new cells?"), a phenomenon that was not observed during the first lesson, when students learned about other experiments in a textbook format. The episode is also much longer than the typical episodes from the first lesson.

During this lesson, there are four similar episodes (including the episode above) in which M expresses her skepticism and offers other ways to conduct the experiments. In these episodes, M's conversations with the teacher are long, and she poses questions of the third category, mainly questions expressing criticism, as well as questions of the properties category. These episodes lead M and the teacher to talk about the methods used in the experiments and the need to conduct manipulative research but, nevertheless, to conclude about normal development.

DISCUSSION

Question-asking is an important skill for both scientific research and meaningful learning. The acquisition of the question-asking skill is gradual: Students do not spontaneously pose questions reflecting a high level of thinking (Dillon, 1988b). In order to do so, they need either a stimulus or training (Dillon, 1988b). The new learning material that we developed may be one of the ways to stimulate question-asking at high thinking levels among high-school students. This is indicated by the data given here: During and after the reading of research papers, and without specific training, students (sometimes even spontaneously) started asking questions of high thinking levels, which dealt with causal relationships between variables and with criticism. In addition, students tended to ask more unique questions and fewer similar ones. This may indicate the more diverse directions of thinking that arise after reading research papers. A possible reason for these phenomena is the nature of research papers in which the reader, in our case high-school students, is exposed to the whole procedure of the research (the research question, the methods, the rationale of the experiments). In contrast, textbooks, which are the common learning material in high-school biology classrooms, usually either explain experiments without detailing the research methods or simply bring only the results of the research or even only the conclusions, without explaining how they were obtained. We believe that students who learn through textbooks do not usually question the data they obtain from those books or during the lessons. In contrast, students who are exposed to research papers start to grasp the way in which the research was conducted and how the conclusions were obtained. Since they are not familiar with the methods of the research, they tend to ask more about its details and, like M, may begin to criticize the way in which the research was conducted. After they understand better, students start to use the research methods they have learned to phrase new research questions, which deal with causal relationships. The combination of research methods (procedural knowledge) and theoretical background (declarative knowledge) allows a variety of possibilities and combinations in formulating research questions and, therefore, results in an increase in unique questions.

It may be postulated that the change in the type of questions posed by students that learn through research papers is simply due to the extra learning time that has elapsed between studying the introduction to the curriculum (T2) and studying the research papers (T3) and the acquisition of new knowledge during this period. In this view, the change in the questions generated by the students merely reflect different stages in their learning (Watts *et al.*, 1997). We believe this not to be the case for three main reasons. (1) The group that studied genetics using a standard textbook did not reveal such a change in the type of questions asked by the students, although a similar period of time had elapsed. It should be noted that the pattern of the type of questions in this group at T2 was similar to the pattern at T2 for the students who had learned through research articles. This may indicate that the ability to ask certain types of questions was similar in both groups. (2) It has previously been reported that students generate low–thinking level questions either during or following instruction due to the environment in the lessons, which discourages their asking (for review see Dillon 1988b), as well as to the examples of questions that students encounter in textbooks (Zoller, 1987; Shepardson and Pizzini, 1991) and that are posed to them by the teachers. (3) As already mentioned, the main declarative knowledge of the curriculum was taught during its introduction. Studying a research article does not add substantial declarative knowledge, as it can be summarized by the students in a single sentence (Yarden *et al.*, 2001). Its contribution seems, rather, to be to the development of the students' acquaintance with the rationale of the research, the research question, and the scientific methods.

It should be noted that the change we observed in the type of questions posed by students who learned through research articles from our curriculum was a nominally moderate change (from 3 questions in the causal relationships category at T1 and T2 to 11 at T3; see also Table 1). This moderate change could be due to the fact that asking questions requires not only a stimulating curriculum, but also a combination of factors that may contribute to a substantial increase in causal relationship-type questions. Those factors might be the teachers' reactions to students' questions (Dillon, 1988b), the students' reaction to peers' questions, or the students' knowledge about different levels of questions. Therefore, the teaching approach to learning through research articles should also contribute to the students' ability to ask causal relationship-type questions, but the teachers who participated in this research did not change any of their previous teaching approaches while using the research papers. In our current attempts to develop new methods of teaching through research articles, we try to create a supportive environment for students' questions during the lesson, and indeed in such an environment, we have noticed that students tend to ask higher–thinking level questions (data not shown). We therefore believe that the moderate change in the type of questions that we observed while students learned through research articles should be regarded as an initiation of developing the ability to ask higher level-questions and, together with the other factors mentioned above, can influence this thinking skill.

In contrast to the increase in the quality of the questions posed by students during the implementation of the developmental biology curriculum, there appeared to be a decrease in the total number of questions (T1, $n = 91$; T2, $n = 81$; T3, $n = 52$). A decrease was also observed in the class that learned genetics (T2, $n = 58$; T3, $n = 40$), and this was probably not due to the usage of either particular curriculum. This trend can be explained by the time that passed from T1 to T2 and then to T3, which was rather short (for some classes only a week; for other classes, 2 or 3 weeks). Repeating the task of asking questions in such a short time, especially when the students are not used to question-asking, can be quite tedious and may result in some reluctance to cooperate. Some of the teachers explicitly requested a certain number of questions on one occasion but not on others, and different teachers gave different times on task. In addition, for technical reasons, the composition of the students in a class changed from time to time. In classes that learned the developmental biology curriculum, the percentage of absent students changed from 16% at T1, to 58% at T2, to 36% at T3. The reasons were variable (for example, illness, special activities at school, matriculation examinations for some of the students). Therefore, the students that composed a class at T1 were not necessarily the same students at T2 and T3. These considerations, as well as others (see Categories of Questions According to the Order of Information, under Methods), led us to regard the students as a community of learners and to analyze the quality of the questions rather than their quantity.

The change we observed in the type of questions that students asked was not due to any intentional act of teaching. Teachers were provided with the same type of guiding questions for both the introduction to the curriculum and the research papers. In addition, teachers who taught the curriculum were not informed of our research question and were not instructed to teach any differently than they normally would. M's teacher, for example, did not use the questions asked by M as a stimulus for class discussion, resulting in a discourse between only the teacher and the student. Nevertheless, since teachers are not used to conducting text-based science lessons, we expected that using a curriculum based on research articles might in and of itself change their teaching approach and influence the type of questions the students asked. To our disappointment, this did not happen. We were present at all lessons that were conducted in all the classes that participated in this research, and although we did not perform a detailed follow-up of the lessons, as was done in student M's class, we did not observe any major changes in the teaching approaches of the teachers. Lessons were still conducted as a Socratic dialogue, with the teachers expecting the students to find the answers to the teachers' questions in the text. Therefore, we are now trying to implement the curriculum with appropriate teaching approaches, which will hopefully further allow and stimulate the question-asking abilities of the students and help them answer their own questions, if possible, using the text of the research article, as well as encourage active learning through the text (Yarden *et al.*, 2001).

In the course of studying the new learning material in developmental biology, we could discern three stages, which were accompanied by a typical level of questions posed by the students.

1. Information-gathering: At this stage, students lack basic knowledge of the subject matter. Therefore, their questions are of the lowest thinking level (of the knowledge category according to the taxonomy of Bloom *et al.* [1956]). Developmental biology is a topic in which high-school biology students in Israel have relatively low prior knowledge, and thus this level of questions was expected.
2. Knowledge organization: After, and sometimes also during, the gathering of basic knowledge on a topic, students raise questions that involve linking pieces of information. Descriptions of experiments in textbooks may stimulate general questions about the rationale of the research.
3. Participation in scientific research: At this stage, the students encounter the research papers, which provide them mainly with procedural knowledge and with examples of the rationale of a specific research work, and research questions. Therefore, they can integrate declarative knowledge, which they acquired through the introduction of the curriculum, and the procedural knowledge, in order to ask questions of a high thinking level, which may require actual experiments or manipulations. They can then also criticize the specific research study about which they are reading.

The first two stages occurred while students were engaged in learning the introduction to the curriculum. This part of the curriculum is not very different from other textbooks and, therefore, requires familiar ways of learning and offers mainly declarative knowledge. Students in high school readily reach stages 1 and 2. We propose that, if after reaching these stages students are exposed to scientific papers, they will gradually become involved in the research. They will be aware of the cascade of events that led to the answer, they will become familiar with the methods that enabled conducting the experiments that examined the research question, and they will read about the new questions raised by the paper. This opportunity can stimulate them to formulate questions of a high thinking level, which will result in meaningful learning.

Chin *et al*. (2002) reported that when sixth graders were engaged in laboratory activities and were not explicitly asked to generate questions, many of their attempts to construct meaning were not apparent to their teacher. During the lesson we described in this research, and in the questionnaire, students were not explicitly encouraged to ask questions. Nevertheless, during these lessons and also in the questionnaires, we could detect a change in their self-generated questions. We are currently attempting to apply students' generated questions to the process of learning through research articles. It would be interesting to determine whether the intrinsic ability of research papers to elicit high-level questions can be even stronger when students are explicitly encouraged to ask questions.

ACKNOWLEDGMENTS

We would like to thank the teachers Mrs. Masha Sheffi, Mrs. Tova Peri, Mr. Sagi Ben-Bassat, Mrs. Kiui Shpirer, Dr. Sima Grinberg-Levy, and Dr. Michal Zion for teaching the learning material in their classrooms. We are also thankful for the statistical analysis, which was conducted by Mrs. Yetti Varon, and for critical comments on the manuscript made by Professor Bat-Sheva Eylon and Professor Avi Hofstein. Gilat Brill's work was supported by the Sacta-Rashi Foundation.

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