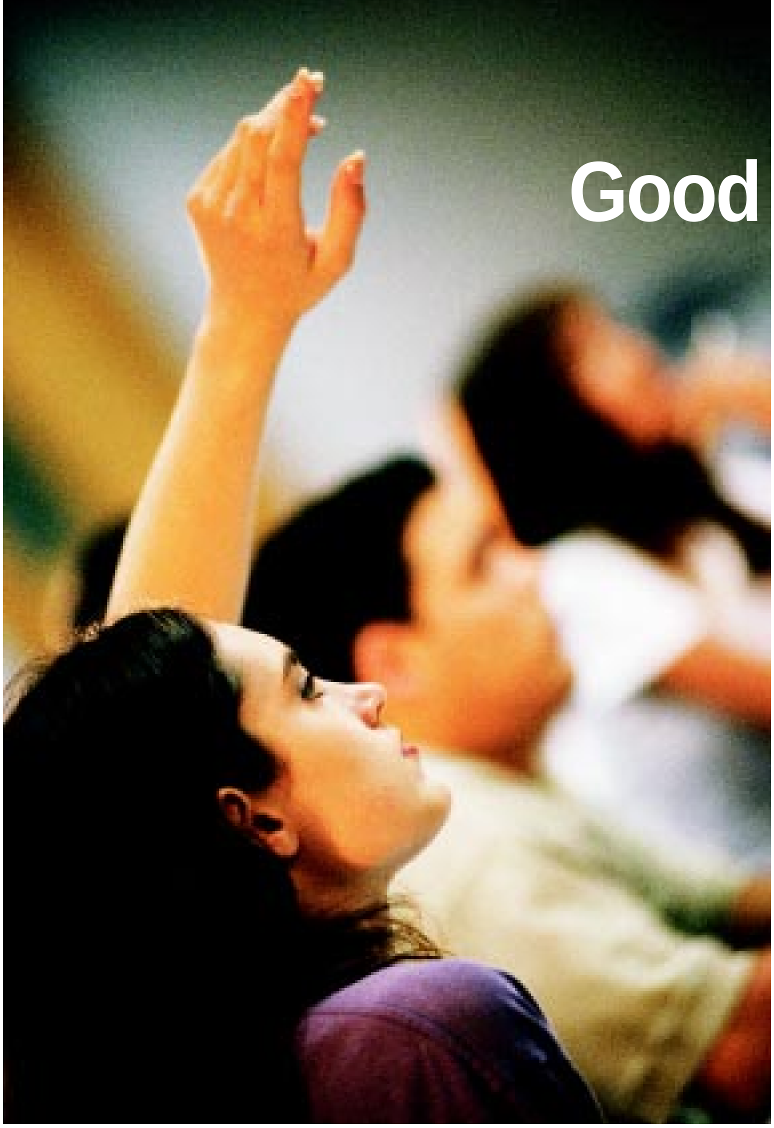

Good Science Begins With Good Questions

Answering the Need for High-Level Questions in Science

Gili Marbach-Ad and Phillip G. Sokolove

Students in a large, active-learning, freshman biology class learned to ask better questions with the aid of a new taxonomy for student questions. The taxonomy provided a tool that helped them (and the instructors) to evaluate the their questions and prompted the students to ask more high-level questions as the semester progressed.

"Those who ask questions—teachers, text, tests—are not seeking knowledge; those who would seek knowledge—students—do not ask questions."

—J.T. Dillon (1988, 197)

Over 30 years ago, Carner (1963) recommended that teachers focus their attention on the questions students ask in class. Studies show that "as grade level increases, students ask fewer on-task attention questions" (Good, Slavings, Hobson Harel, and Emerson 1987, 186). Good et al. suggest that this probably occurs because students do not want to call attention to themselves. It also seems that fewer questions are asked in class because teachers often "do not like" students to ask questions.

Wood and Wood (1988) have speculated about possible reasons that teachers do not "want" pupils to air their own views. First, they claim, many teachers feel they are paid to educate pupils, to transmit knowledge, and to prepare students for the future; such teachers are often afraid to lose control of the classroom. Second, it takes class time for students to contribute their own ideas—perhaps at the expense of other points a teacher wants to cover.

Although it appears over time that students ask fewer and fewer questions, this is true only in the classroom. As Dillon (1988) noted, children ask more questions as they get older, but they do so outside of the classroom. We see this happen in elementary and secondary schools (Dillon 1988; Good et al. 1987), and we see it happen at the college and university levels (West and Pearson 1994).

One of us (PGS) teaches an introductory biology course for majors in which an important goal is for students to learn to appreciate science. For that to happen, however, students must first relearn how to ask more effective in-class questions; initially inquiries such as those that curious young children make (why? how?) and later questions like those that scientists ask.

We believe that good science begins with good questions, and one of our objectives is to encourage students to recognize "good" questions (i.e., those that would be considered good in a scientific context because they are original and insightful ones about how the world works; cf., Heady 1993) and to ask more and better questions. However, to help students evaluate questions, we need to provide them with appropriate criteria together with examples of different types of questions. Only then can they begin to recognize which are high-level and which are low-level questions (fig.1).

In our study we asked for typewritten questions that students had to formulate outside of class after reading selected chapters in their textbook. We followed this procedure to obtain questions from all students (rather than just those willing to volunteer), and to give students time to think before they posed

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a question. In addition, we thought that it would be less intimidating for them to ask questions without having to confront the entire class.

When we searched the literature for criteria to classify students' questions, there was virtually nothing that allowed us to classify questions that students in science courses ask, or might be encouraged to ask. Many researchers have described the type of questions that teachers ask in an effort to elicit student responses and thereby to assess student understanding. They have found it helpful to develop various (and often comparable) categories of such questions. Several systems, such as Bloom's (1984), Carlsen's (1991), Carner's (1963), Gallagher's (1965), and Houston's (1938) consist of general categories that are based on thinking operations and the questions that stimulate them irrespective of content.

Other schemes do deal with students' questions (Watts, Gould, and Alsop 1997; West and Pearson 1994); however, the questions are usually student-initiated, verbal, in-class questions. These schemes generally fail to capture the full range of complex and high-level questions that one finds in written ones. Because we could not find an appropriate theoretical framework to categorize students' written questions, we decided to use the students' own questions to help us identify and develop a new and practical taxonomy for this purpose.

The New Taxonomy

The current study was conducted in one of two large sections of Biology 100 in the fall of 1998 with an enrollment of 267 students. The course was taught in an active-learning style employing student-centered, constructivist-based, and interactive instructional approaches (Sokolove 1998).

We examined a large sample of student questions from the homework assignments given in our class. Based on our reading of students' questions, we identified eight categories and arranged them in a semi-hierarchical order from low-level to high-level questions.

The eight categories listed in figure 1 seemed to fall into four major types:

- ***Type I*** (Category 0): Questions do not make logical or grammatical sense or are based on a basic misunderstanding or misconception. Such questions can be very useful to the instructor. In Biology 100 they helped the instructor to identify what sort of preconceptions or misconceptions students had after reading a chapter at home, and before they discussed the subject in class. We feel that these questions will enable instructors to understand what prior conceptions students had in mind, to identify students' misunderstandings, and to change their way of teaching. We agree with Watts et al. (1997) that "diagnosing pupils' existing understandings is important in order to understand the perspectives from which they see the world. . . ."
- ***Type II*** (Categories 1a and 1b): These are questions about a simple or complex definition, concept, or fact that a student could have looked up in the textbook. Most of the questions that fell into category 1a suggested to us that the students who wrote them did not read the chapter at all, or did not read it carefully. Most of the questions that fell into category 1b suggested that the students who prepared them did read the chapter carefully but did not understand what they read. Usually 1b questions dealt with definitions or concepts that were objectively complex.
- ***Type III*** (Categories 2, 3, and 4): These are questions in which the student seeks more information than is available in the textbook. Questions that fell in category 2 asked about "motives" or "intentions." Usually these questions dealt with ethical, moral, philosophical, or socio-political issues.

Figure 1. ***Categories of Students' Questions***

Category	Description of Questions
0	Question is not logical or grammatical, is based on a basic misunderstanding or misconception, or does not fit in any other category. ("Translation seems to be a process of trial and error. Noting this, how is it so efficient in its production of protein?")
1a	Question about a simple definition, concept, or fact that could be looked up in the textbook. ("What is the difference between diploid number and haploid number?")
1b	Question about a more complex definition, concept, or fact explained fully in the textbook. ("Could you please explain the steps of meiosis and [indicate] after each step how many chromosomes are present?")
2	Ethical, moral, philosophical, or sociopolitical question; often begins with "why." ("Why doesn't the FDA ban sunscreens with an SPF of less than 30?")
3	Question for which the answer is a functional or evolutionary explanation; often begins with "why." ("People wear clothes, so why do they still have body hair?")
4	Question in which the student seeks more information than is available in the textbook. ("Are all viruses necessarily detrimental to their host cells? If so why?")
5	Question resulting from extended thought and synthesis of prior knowledge and information; often preceded by a summary, a paradox, or something puzzling. ("I know that proteins are synthesized in the cytoplasm, but then how do ribosomal proteins get into the nucleus?")
6	Question that contains within it the kernel of a research hypothesis. ("Since it has been observed that certain blood types are predominant in people from different regions, was there a time in history when one blood type was more advantageous than the other?")

Generally there were only a few such questions, mainly concerning genetics. Questions that fell in category 3 sought information about why the world is the way it is. Many of these questions were "evolutionary questions", i.e., questions for which the answer is an evolutionary explanation. Category 4 questions were all the other ones that students asked to seek information not given in their textbook.

- ***Type IV*** (Categories 5 and 6): These are questions in which students must employ higher-level thinking skills such as integration of information acquired earlier in the semester. The distinguishing feature of a category 6 question is that it contains within it the kernel of a hypothesis. Such questions typically precede scientific research.

This taxonomy, once constructed, not only enabled us to evaluate students' questions, but also helped us to explain to students what type of questions we considered to be high-level.

Evaluating Studentsí Questions

Three times during the semester, students were asked to bring an original, typed question to class after reading a textbook chapter. The first homework exercise (Chapter 10; Starr and Taggart 1998) dealt with meiosis. The second homework exercise was based on two chapters (Chapters 13 and 14), one of which dealt with DNA structure and function, and the other with the relation between DNA and proteins. The third (Chapter 42) dealt with digestion.

The first homework exercise was given to the class at the beginning of the semester, the second in the middle, and the third toward the end of the semester. Homework questions were collected and categorized using our new taxonomy. After the second homework exercise the instructor presented the new taxonomy in class and provided an example question for each category.

Results

Table 1 and figure 2 present our results regarding the student questions we received in response to the three homework exercises. The distribution for Chapter 10 questions was similar to that for student questions based on Chapters 13 and14 except in categories 4 and 5. After reading Chapter 10, more students (23 percent) formulated questions that fell in category 5 (questions resulting from extended thought and synthesis) than they did after reading Chapters 13 and 14 (13 percent).

In contrast, after reading Chapters 13 and 14, more students (32 percent) formulated questions that fell in category 4 (questions requesting specific information not readily found in the textbook) than they did after reading Chapter 10 (20 percent). Nonparametric analysis showed no significant difference, however, between the overall distribution across question categories for the two sets of questions.

On the other hand, similar analysis showed that the difference between the set of questions generated after reading Chapter 10 (or Chapters 13 and 14) and the set of questions from Chapter 42 was highly significant ($p < 0.001$). Inspection of the data showed that the differences were due to the fact that fewer Chapter 42 questions were classified in categories 0-4 (Types I, II, and III) than questions from Chapters 10 or 13 and 14 (56 percent versus 70 and 80 percent, respectively), whereas more Chapter 42 questions fell into categories 5 and 6 (Type IV) than questions based on Chapter 10 or 13 and 14 (44 percent versus 30 and 20 percent, respectively).

Table 1: ***Percentage of students' questions in homework exercises***

Category	Chapter 10 N=182	Chapters 13/14 N=188	Chapter 42 N=173
0	15%	13%	8%
1a	12%	11%	5%
1b	12%	11%	9%
2	1%	3%	2%
3	10%	10%	2%
4	20%	32%	30%
5	23%	13%	30%
6	7%	7%	14%

Impact on Question-Asking Skills

The presentation of the new taxonomy in our class probably had a significant impact on students' questions. First, based on their responses it appeared that students began to understand what sort of questions we expected them to ask, and second, they become more discerning in their evaluation of questions. Only after students were given an early draft of the taxonomy did they begin to demonstrate significant improvement.

In addition to the presumed influence of our presentation of the taxonomy to the class (which was late in the semester), there were other variables that might well have influenced the type of question a student formulated for a given exercise. We can suggest three possibilities: content of the chapter, the student's background knowledge or understanding, and the level of biological organization.

First, it seems reasonable to us that subjects with which the students are more interested or more familiar will lead them to ask more thoughtful questions. Second, we feel that individuals will generally ask better questions when they have more knowledge about the subject. Thus, little or no knowledge should generally result in relatively naive questions, while more knowledge about a topic should enable one to ask questions that are insightful or sophisticated. Others have expressed similar thoughts. Olson, Duffy, and Mack (1985) suggest that, "Intuitively, there is a link between one's knowledge or understanding of a topic and the ability to ask a question about it (p. 219)."

Third, in many areas of biology (genetics, for example), one can distinguish between the macroscopic level (organisms or populations), the microscopic level (cells), or the submicroscopic level (molecules). Research on genetic conceptions has shown that students typically have more difficulty understanding processes and relationships at the microscopic and submicroscopic levels than they do at the macroscopic level

(Marbach-Ad and Stavy). This might explain why there were more questions that fell into category 5 after students read Chapter 10 on meiosis (a process that takes place at the cellular level) than after they read Chapters 13 and 14 on DNA (which deals with molecules and molecular processes).

Conclusion

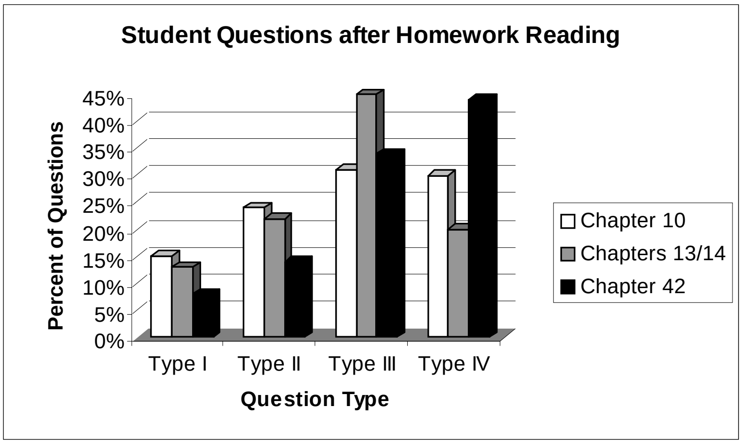
We have developed a new taxonomy that can be used to categorize and evaluate biology students' questions and determine whether students in an active learning, introductory biology class can learn to formulate high-level, written questions. The results suggest that the taxonomy also helped our students understand how to recognize and write better questions.

We also feel that there were positive side effects in asking students to formulate written questions after reading chapters at home. One of the major complaints of instructors is that "students do not read the book before they come to class." Focusing on question-posing forces students to read first in order to write their questions. We deliberately asked students to type their questions so that they would be more likely to complete the assignment at home and not during the first minute or two of class. The second side effect is one that we previously mentioned: the opportunity to understand what students have in mind and to uncover their misconceptions and/or preconceptions.

Our new taxonomy may not fit all courses or subjects even in science courses, but we hope that it will serve as a model that others can help us refine, or perhaps use to construct their own.

One might wonder if our efforts also increased the number and quality of verbal, voluntary, in-class student questions. Although we have not completed our analysis of in-class videotapes, preliminary observations suggest that students do ask more and better questions than in a comparable lecture class. More important, perhaps, is the fact that students in the active-learning class wrote many more questions about biology to the instructor on e-mail and handed the instructor many more written questions after the class period.

Figure 2: ***Distribution of student questions written after reading one or more textbook chapters***



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