מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Thesis for the degree
Doctor of Philosophy

חבור לשם קבלת התואר
דוקטור לפילוסופיה

By
Ayelet Baram-Tsabari

מאת
אילת ברעם-צברי

מה מעניין תלמידים לדעת על מדע?
זיהוי תחומי עניין במדע באמצעות שאלות תלמידים

What do students want to know about science?
Using students' questions to identify their scientific interests

Published papers format

Advisor
Dr. Anat Yarden

מנחה
ד"ר ענת ירדן

January 2008

שבט תשס"ח

Submitted to the Scientific Council of the
Weizmann Institute of Science
Rehovot, Israel

מוגש למועצה המדעית של
מכון ויצמן למדע
רחובות, ישראל

תודות

לד"ר **ענת ירדן**, ההשגחה הפרטית שלי,
שקרעה למעני את הים, והעבירה אותי בתוכו בחרבה, והובילה אותי אל הארץ המובטחת.
אוצר המילים שלי דל מכדי להודות לה כראוי

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אבל לא בגלל שהאחרים טיפשים
ל**הדס**, אחותי הבכורה, שלימדה אותי שטיפשות וחוכמה הם מושגים הרבה יותר מורכבים
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ולדקלה אלבז על החיוך התמידי והאמונה בי

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לועדה המלווה שלי פרופ' אבי הופשטיין ופרופ' בני גיגר
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ולאנשים שבלעדיהם שום דבר לא היה עובד:
לברק כהן, יטי ורון ותרצה קאודרס
על זה שהכל תקתק כמו שעון שוויצרי באמצע הלוונט
ולרקפת הלוי וברק צברי
שלולא הם יכולתי פשוט לסגור את הבאסטה וללכת הביתה

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Summary

Within the science-education community, much thought has been given to the question of "what students should know about science", but not to the question of "what students are interested in knowing about science". Indeed, many students find standard science curricula largely out of touch with their personal interests, a factor which contributes to the low number of students pursuing advanced science and mathematics courses in high school, and going on to choose scientific careers. Involving students in decisions about their life in school is not only a useful and pragmatic pedagogical strategy; it is also an important moral and educational principle. However, educators lack the necessary information and tools to guide modifications that could make use of the power of student-specific interests in improving those students' individualized learning and competency in scientific subjects.

A great number of studies have explored students' scientific interests by inviting them to respond to questionnaires. However, these questionnaire-based methods have traditionally relied on adult-centric views of what subjects should be meaningful for students. To overcome this inherent bias, during the course of this PhD a naturalistic approach to defining students' specific concerns by using students' self-generated questions, as an indication of their scientific interests, was developed. Over ninety thousand questions were collected from many different Ask-A-Scientist sites, television shows, and schools in order to use student's self-generated questions as an indication of their interests in science and technology.

Several age- and gender-related trends were identified using this method: an increase in the cognitive level of the questions with age, while the psychological distance of the object in question and its order of magnitude decrease; a developmental shift in interest in biology, accompanied by a decrease in interest in zoology and an increasing interest in human biology with age; the tendency of high school students to ask questions imposed by their teachers; the dominance of questions asked by females in web-based free-choice science learning environment; and the widening stereotypical gap between girls' and boys' science interests. Finally, six types of science questions were identified using cluster analysis. Implications for curriculum development, mainstreaming of science education and biology classroom practice are suggested.

Structure of the Thesis

The thesis consists of four parts:

Part I begins with rational and research goals for this study. They are followed by a general introduction to the fields of students' questions, the web as a free-choice science learning environment, students' interests, and the role of gender in students' scientific interests. This literature review is followed by the research approach, assumptions and limitations and a list of the research goals and main questions and the relevant papers answering them.

Part II consists of six papers – four of them published and two of them currently under review - and a chapter presenting unpublished data. Each of these components describes different form of analysis and different data sources. Together they form the main body of this study.

Part III is a general discussion followed by suggestions for future development and research in the field of student-interest focused learning materials, and implications for addressing students' interests in the science classroom.

An appendix which holds an additional published paper that was written during the Ph.D. but is not related to the main line of research of this thesis.

Part I: Introduction

Rationale

Teaching students what they want to know can be a very beneficial pedagogical strategy. Positive relationships have been reported between interest and a wide range of learning indicators (Pintrich & Schunk, 2002; Schiefele, 1998). When allowed to pursue their own interests, students participate more, stay involved for longer periods, and exhibit creative practices in doing science (Seiler, 2006). Interest has also been found to influence future educational training and career choices (Kahle, Parker, Rennie, & Riley, 1993). Beyond being a useful and pragmatic practice, involving students in decisions about their lives in school is an important moral and educational principle (Davie & Galloway, 1996). Regardless of the importance of interest, the current situation in science education was summarized by a Swedish student in the following manner: "The trouble with school science is that it provides uninteresting answers to questions we have never asked" (Osborne, 2006).

Students' scientific interests are traditionally identified by questionnaire-based methods which involve asking students to tick boxes in response to a series of prepared questions or topics (e.g. Dawson, 2000; Qualter, 1993; Sjoberg, 2000; Sjoberg & Schreiner, 2002; Stark & Gray, 1999). However, this methodology is inherently biased, since the listed topics are based on adult-centric views of what subjects should be meaningful to the students. To overcome this problem, a naturalistic method for using students' self-generated questions as a source of information about their interests was developed during this research (Baram-Tsabari, Sethi, Bry, & Yarden, 2006; Baram-Tsabari & Yarden, 2005; Baram-Tsabari & Yarden, 2007c; Baram-Tsabari & Yarden, 2008). By studying students' questions, we can learn about what students are interested in and what they want to know about a given topic (Biddulph, Symington, & Osborne, 1986; Chin & Chia, 2004).

Although questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph et al., 1986; Brill & Yarden, 2003; Scardamalia & Bereiter, 1992), it is hard to use children's questions in a classroom setting, since they are so rare. Researchers attribute this situation to a classroom atmosphere in which revealing a misunderstanding may render the student vulnerable, open to embarrassment, censure or ridicule (Pedrosa de Jesus, Teixeira-Dias, & Watts, 2003; Rop, 2003).

However, students do pose science questions in free-choice science-learning environments. Free-choice science learning is non-sequential, self-pacing and non-assessed (Dierking & Martin, 1997) and it occurs outside the traditional, formal school realm. This is the kind of learning that a person is engaged in throughout his or her life. It emerges during a whole range of human experiences and real world situations (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). One of the options which are open to children who are trying to find complex answers outside school, is to submit their questions to asynchrony human-mediated question-and-answer services, which are sometimes referred to as "Ask-A" services, such as "Ask-A-Scientist". Therefore, in the course of this study, over ninety thousand questions were collected from Ask-A-Scientist sites, television shows, and schools in order to use children's self-generated questions as an indication of their interests in science and technology.

Research goals

Goal 1. The first and main goal of this research was to characterize students' interests in science and technology. In order to attain this goal I addressed the following research questions:

1. What are the scientific interests of Israeli children?
2. What are their motivations for asking spontaneous questions?
3. What are the scientific interests of adolescents from various countries?
4. What are the differences between spontaneous and school related science interests?

Goal 2. The second goal of this research was to describe the way in which interest in biological topics develops with age. In order to attain this goal I addressed the following research questions:

1. What are children's interests in different biological topics?
2. How does interest in biology develops with age?

3. How does interest in biological topics differ between females and males?

Goal 3. The third goal of this research was to explore gender-related aspects of science question-asking in internet-based free-choice science learning environments. In order to attain this goal I addressed the following research questions:

1. Are internet based Ask-A-Scientist applications an attractive science learning environment for girls?
2. How does the female participation rate differ between countries?
3. Do females lose interest in asking scientific questions as they grow older?
4. Do the gender-related differences in interest in biology and physics exist in a free-choice science learning environments?
5. Do the stereotypic interest patterns change with age?
6. Are there gender-related differences in the type of information requested and in the motivation for asking science questions?

Goal 4. The forth goal of this research was to pinpoint additional patterns within the data. In order to attain this goal I addressed the following research question:

1. Can additional interactions between the characteristics of the question, the asker and the setting be identified using clustering techniques and contingency tables analysis?

Theoretical framework

Students' questions

Although question-asking is a basic requirement for the performance of scientific research and meaningful learning, the way in which science lessons are usually conducted does not stimulate question-asking by students, and questions are posed mainly by the teachers (Allison & Shrigley, 1986; Dillon, 1988; Dori & Herscovitz, 1999; Graesser, Person, & Huber, 1992; Marbach-Ad & Sokolove, 2000b). Requests for meaningful explanations are relatively infrequent in K-12 classrooms, and students at all grade levels (K-12) generally ask the same number of questions (Good, Slavings, Harel, & Emerson, 1987)—approximately 1% of the questions asked in class (Graesser et al., 1992).

Many researchers have recommended strategies to encourage question-asking by students, such as one-on-one tutoring sessions (Graesser & Person, 1994), discussion (King, 1994), cognitive conflict (Allison & Shrigley, 1986), real-world problem-solving activities (Chin, Brown, & Bruce, 2002; Zoller, 1987), case studies (Dori & Herscovitz, 1999), biotechnology-focused modules (Olsher & Dreyfus, 1999), use of written questions (Pedrosa de Jesus et al., 2003), and learning using adapted primary literature (Brill & Yarden, 2003).

In spite of the efforts to encourage question-asking by students, students are more often expected to answer questions than to ask them in a typical classroom setting (Chin, 2004), and the common situation in science classes is still the one described by Dillon (1988): "Children qua [= as] students do not ask questions. They may be raising questions in their own mind...but they do not ask questions aloud in the classroom." Researchers attribute this situation to a classroom atmosphere in which revealing a misunderstanding may render the student vulnerable, open to embarrassment, censure or ridicule (Pedrosa de Jesus et al., 2003). Students have described their teachers' responses to their questions as 'put-offish' or even annoyed, and their classmates' reaction as 'intolerant' (Rop, 2003).

The overall paucity of student question-asking has resulted in relatively few studies of pupils' questions, simply because researchers have not been able to find enough of them to examine (Maskill & Pedrosa de Jesus, 1997; Pedrosa de Jesus et al., 2003; Watts & Alsop, 1995). Good, Slavings, Harel, and Emerson (1987) specifically note the absence of comparative studies of student-generated questions across different grade levels using the same methodology.

Dim as the picture of student-generated questions may be, research, as well as life experience, tell us that students are capable of asking many questions when given the opportunity (Costa, Caldeira, Gallastegui, & Otero, 2000). Therefore, a better way to study children's questions might be to look for them where they are being asked fluently and voluntarily. Learners ask questions when they feel secure (Watts, Gould, & Alsop, 1997), and one place offering such security is free-choice science-learning settings on the internet.

The web as a free-choice science-learning environment

Examining free-choice science-learning environments can provide knowledge about the natural setting in which people learn in a self-directed, self-motivated, voluntary way, guided by individual needs and interests (Falk & Dierking, 2002). An example of such a free-choice setting is the World Wide Web, which is the primary source for news and information about science for 20% of Americans, second only to television (41%). Moreover, if people need information on a specific scientific topic, the internet is the primary source to which they turn (Horrigan, 2006). Two-thirds of internet users say they have come upon news and information about science when going online for other purposes, and half of all internet users have been to a web site which specializes in scientific content (Horrigan, 2006).

While access to the internet grows exponentially, American students are already wired: in fall 2005, nearly 100% of public schools in the US had access to the internet, and 94% of the instructional rooms in those schools had internet access (National Center for Education Statistics, 2006). In 2005, 87% of all youth between the ages of 12 and 17 had used the internet, and 68% of all teenagers had used the internet at school (Rainie & Hitlin, 2005). In general, youth hold positive attitudes and exhibit self-confidence with respect to internet use (Fidel et al., 1999; Watson, 2004). Their use of the web ranges from researching for school assignments to communicating with others and exploring their personal interests (Baram-Tsabari et al., 2006; Bilal, 2004; Hirsh, 1999; Levin, Arafeh, Lenhart, & Rainie, 2002; MaKinster, Beghetto, & Plucker, 2002; Weigold & Treise, 2004). Science web sites may influence young people's life-long interest in science and their appreciation of its beauty and importance (Weigold & Treise, 2004). However, a listing of the 15 sites most visited by teenagers did not include any sites related to science, technology or even education in general. Weigold & Treise concluded that teenagers usually go to the web to have fun and interact with others, but only occasionally use the web to learn.

There are mixed findings regarding the role of gender in using the web as a free-choice environment for science learning. Although boys have more formal and out-of-school experience using computers and the worldwide web (Kafai & Sutton, 1999; Shashaani, 1994), more girls prefer this type of lesson over traditional classroom-based science learning (Leong & Al-Hawamdeh, 1999). Ching, Kafai, and Marshall (2000) found that configuration of social, physical and cognitive gender-equitable spaces contributes to a positive change in girls' level of access to programming activities. The American Association of University Women (2004) describes girls and women as being attracted to the communicative aspects of online interactions, and therefore recommend online projects as a means of promoting gender-equitable participation.

At the interactive web site *Whyville*, which was designed to engage students in socially interactive, entertaining and educational activities that include inquiry science, most users were found to be girls (73% of the regular *Whyville* users who answered a survey), contrary to what might be expected from a science-oriented program (Aschbacher, 2003). The question of female usage of the web as a free-choice environment for science learning should be viewed in the context of females' general reluctance to use media that foster informal learning about science (National Science Foundation [NSF], 2004; Nisbet et al., 2002), and to take part in extracurricular science experiences (Greenfield, 1998).

Research on children's use of the World Wide Web for learning has generally been conducted in school settings (e.g. Bilal, 2001; e.g. Fidel et al., 1999; Guinee, 2004; Rogers & Swan, 2004; Slotta, 2004). The web is seen by educators as a site for student inquiry in science, which allows students to pursue questions of personal interest

(McCrory Wallace, Kupperman, Krajcik, & Soloway, 2000), since an effective search is also an exercise in inquiry and critical thinking (Brem & Boyes, 2000). However, most students have difficulty formulating and modifying search queries (Bilal, 2004; Hirsh, 1999; MaKinster et al., 2002; Wallace, Kupperman, Krajcik, & Soloway, 2000; Watson, 2004), and many of them fail to construct an accurate and broad understanding following an online inquiry (Hoffman & Krajcik, 1999).

Furthermore, children do not tend to question the accuracy of the information they find on the web (Hirsh, 1999; Russell, Weems, Brem, & Leonard, 2001; Schacter, Chung, & Dorr, 1998; Wallace et al., 2000). Such skepticism is sorely needed, as Keating, MaKinster, Mills, and Nowak (1999) found that as few as 30% of the search results for science concepts actually contain at least a short operational definition or graphic display of the concept, and many of the sites contain misconceptions. Another major problem is that students believe that they should be able to find answers to complex questions on specific web pages, instead of researching to form an answer (Soloway & Wallace, 1997). To sum up, although the internet has the potential to greatly facilitate positive changes in education, its use in school is sporadic, peripheral to the core curriculum, and simple and obvious in nature (Schofield, 2005).

Consequently, students report that there is a substantial disconnectedness between how they use the internet for school and how they use it during the school day and under the teacher's direction. For the most part, students' educational use of the internet occurs outside of the school day, outside of the school building, away from teacher direction (Levin et al., 2002). Steinkuehler (in press) suggests that in order to understand the current and potential capacities of technology for cognition, learning, literacy, and education, we must look at contexts outside the current formal educational system rather than those within. The reason for this is that what students do with online technologies outside the classroom is not only markedly different from what they do with them in schools but it is also more goal-driven, complex, sophisticated, and engaged. Hence, it might prove more fruitful to study children's use of the World Wide Web for learning in free-choice settings, rather than in school settings.

When children are using the internet to research their interests, some of their complex questions are better answered by experts than by a list of directories or sites.

England (Murphy & Whitelegg, 2006; Osborne & Collins, 2001; Spall, Barrett, Stanisstreet, Dickson, & Boyes, 2003), Israel (Friedler & Tamir, 1990; Trumper, 2006) and Germany (Hoffmann, 2002), and in international studies such as "Science and Scientists" [SAS] (Sjoberg, 2000) and ROSE (Sjoberg & Schreiner, 2002).

The ROSE studies conducted in Denmark (Busch, 2005), England (Jenkins & Nelson, 2005), Norway (Schreiner, 2006) and Finland (Lavonen, Juuti, Uitto, Meisalo, & Byman, 2005) found that girls' interests were focused on health, medicine, the body, the mind and well-being, whereas boys wished to learn more about the dramatic aspects of physics and chemistry, and how technology works. This gender gap in interest is also apparent among female students who are interested in science, as can be inferred from the polarized enrollment in elective biology and physics courses (Murphy & Whitelegg, 2006; Zohar, 2003) within the science-attentive student body. It is also evident in science-interest studies that use senior high-school science students as a sample. For example, Osborne and Collins (2001) surveyed students' views on school science using focus groups of 11th graders who intended to continue with their science studies, and those who did not. Girls in both groups made many more negative comments about physics than did boys. Thus, it seems that the increasing access of female students to the traditionally masculine science subjects is being accompanied by the emergence of biology as a feminine niche in science (Ayalon, 1995).

Some researchers have suggested that the basis of these stereotypically gendered interests is an inborn trait which hard-wires the average girl for empathy, while the average boy is predominantly hard-wired for understanding and building systems (Baron-Cohen, 2003). Other studies, however, did not find any such difference (Hyde & Linn, 2006). A landmark MRI study of normal brain development (Waber et al., 2007) found that mental performance differs very little with gender. In her review, Spelke (2005) states that "Thousands of studies of human infants, conducted over three decades, provide no evidence for a male advantage in perceiving, learning, or reasoning about objects, their motions, and their mechanical interactions. Instead, male and female infants perceive and learn about objects in highly convergent ways."

Additional explanations, which do not assume an inborn gender difference, were subsequently suggested to explain girls' lack of interest and under-representation in science; these are traditionally divided into the three, somewhat overlapping categories suggested by Kelly (1978):

(1) *Cultural* explanations, which may be referred to as 'socialization explanations', include the masculine image of science, which is seen years prior to the actual encounter with disciplinary school science (Farenga & Joyce, 1999), lack of female role models and their image in the media (Handelsman et al., 2005; Schibeci & Lee, 2003; Steinke, 1997), lack of out-of-school experiences (Kahle & Lakes, 1983; Shakeshaft, 1995), parental gendered-beliefs regarding science (Tenenbaum & Leaper, 2003), peers' views during puberty (Brownlow, Smith, & Ellis, 2002; Pettitt, 2004), girls' low self-efficacy (Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000), and issues concerning values and identity (Schreiner & Sjoberg, 2007).

(2) *Attitudinal* explanations refer to girls' negative attitudes towards science and pursuing a science-related career (Crettaz von Roten, 2004; Kahle & Lakes, 1983; Kelly, 1978; Miller et al., 2006; Simpson & Oliver, 1985; Weinburgh, 1995). Some factors, such as misuse, difficulty and masculine image, which were brought up to explain girls' less favorable attitudes toward science, apply more strongly to the physical sciences (Kelly, 1978).

(3) *Educational* explanations include school-related parameters, such as enrollment and achievement in mathematics classes, class atmosphere, teaching and assessment methods traditionally used in physics classes (Zohar & Bronshtein, 2005), gender-related differences in the notion of what it means to understand physics (Stadler, Duit, & Benke, 2000; Zohar, 2003), and science curricula which are heavily biased towards the interests, knowledge and abilities of boys (Hoffmann, 2002; Nair & Majetich, 1995). Haussler *et al.* (1998), for example, identified five domains of interest in physics; only one of them—physics as a scientific enterprise for its own sake—is overwhelmingly dominant in physics classrooms. Other domains, such as how science can serve humankind and explanations of natural phenomena, which are of more interest to girls, are almost nonexistent (Haussler, Hoffman, Langeheine, Rost, & Sievers, 1998). Despite international reports of educational success for girls, very little has in fact changed over the past few decades with respect to their science and mathematics subject choice (van Langen, Rekers-Mombarg, & Dekkers, 2006). For a comprehensive review

of recent research on girls' participation in school physics see Murphy and Whitelegg (2006).

The gender effect on science-related attitudes and beliefs is not homogeneous across measures, science-content areas, racial or socioeconomic groups (Kahle et al., 1993), or cultural or situational contexts (Linn & Hyde, 1989). However, stereotypical male and female interests seem to cross borders and cultures. The 'Science and Scientists' [SAS] project, for example, found strong similarities between the lists of Norwegian and Japanese science topics favored by boys and girls, despite the strong cultural differences between these two countries (Sjoberg, 2000).

This similarity is also valid for enrollment rates of women in science- and technology-related occupations. In Egypt, for example, a survey by the Supreme Council of Universities for 1995-96 reports that in disciplines such as pharmacy and dentistry, more than 40% of the faculty are women; in the sciences, 25% of the faculty are women, but this decreases to less than 10% in the engineering and technology departments. These statistics are very similar to those for US universities, where women constitute 50% of the health sciences faculty, 23.8% of the biological sciences faculty, and 6.1% of the engineering faculty (Hassan, 2000). In most OECD countries, the proportion of women choosing advanced science and technology studies remains below 40%, and the choice of discipline is highly gender-dependent (Organisation for Economic Co-operation and Development [OECD], 2006).

Contrary to expectation, gender differences are not smaller in technologically advanced countries, which foster mass education and equity legislation, or in advantaged socioeconomic groups (Steinkamp & Maehr, 1984). To list a few recent examples, in Latin America and the Caribbean, women account for 46% of the reported number of researchers, while their share falls to 15% in Asia and about 30% in Africa. In Europe, 32% of the researchers are women, with only five countries reaching gender parity (UNESCO Institute for Statistics, 2006). Among school students, gender differences in science achievements are higher for 4^{th} and 8^{th} grade students from the Netherlands, compared to students from Cyprus and Latvia (Martin, Mullis, Gonzalez, & Chrostowski, 2004; UNESCO Institute of Statistics, 2005).

Females, more than their male peers, tend to lose interest in science as they grow older, mainly during the middle-school and high-school years (George, 2006; Greenfield, 1998). American girls' attitude to science was found to become increasingly negative with age (Kahle & Lakes, 1983), a finding that was repeated among Israeli students (Friedler & Tamir, 1990; Shemesh, 1990). A study conducted in Germany also found a difference in the way interest in physics develops with age: girls, but not boys, find physics as a school subject less and less interesting as they grow older (Hoffmann, 2002; Hoffmann & Haussler, 1998).

Research approach, assumptions and limitations

Interest in science have been traditionally identified using written questionnaires that rely on adult-centric views of what subjects should be meaningful to students. I believe that relying on children's spontaneous ideas and questions is a better measure of their interests, and will enable progress towards incorporation of their views into the school curriculum, more than using their responses to an adult-written questionnaire. Responses to a questionnaire are externally regulated, while asking a question is a self-regulated action (Deci, Vallerand, Pelletier, & Ryan, 1991), and therefore should be a stronger measure of interest. Therefore, we recently suggested using children's self-generated science-related questions, submitted to Ask-A-Scientist sites as a tool to probe students' scientific interests (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005; Baram-Tsabari & Yarden, 2007c; Baram-Tsabari & Yarden, 2008).

This novel method relies on the assumption that the number of questions submitted to Ask-A-Scientist sites regarding a certain science topic reflects to some degree the interests of children from a similar age group and from the same gender in that topic. This assumption rests on two feet: one is the understanding that in natural setting people usually ask a question when they seek information that they lack, rather than raise rhetorical questions, suggestive questions, or questions asked to please someone (Flammer, 1981), which are usually the questions that students ask in class (Dillon, 1988). Therefore self-generated questions, asked in a free-choice science learning environment, can help reveal the asker's interests and needs. The second foot on which our assumption rests is the compatibility of our previous results that were obtained using this method with findings from independent studies, which used controlled samples in a school setting. Using an informal data source and a new methodology our results confirm and reinforce some of what was revealed using the traditional questionnaire methodology in formal settings. This agreement with findings described in the literature that were gathered using control samples, serves to bolster confidence also in our new findings, which were not described before. Therefore, we assume that the trends described using this method represent, to a certain degree, the interests of many children, and that posing questions represents a measure of student orientation of science interest.

The biggest threat to inferences from Web research is currently coverage error, at least to groups beyond those defined by access to or use of the web (Couper, 2000). Coverage error is a function of the mismatch between the target population (the set of people one wishes to study) and the frame population (the proportion of the target population that potentially can be reached via the web) (Couper, 2000). However, most western youth do have access to the web. The most recent Pew Internet Project survey found that 87% of all American youth between the ages of 12 and 17 use the internet (Rainie & Hitlin, 2005), and in the fall of 2003, nearly 100% of public schools in the US already had access to the internet (National Center for Education Statistics, 2005). This coverage theoretically allows all American students to send their questions via mail and be part of our sample. In Israel, above 60% of households and above 80% of businesses have an internet access (Ministry of Communication, 2006). However, access rate varies with socioeconomic status: 81% of the households in the highest tenth, versus 15.4% in the lowest tenth (Central Bureau of Statistics [CBS], 2006). We believe that with the exponential growth of access to the internet, using free-choice web-based science learning settings to study students' interest should become even a more representing and powerful tool in the near future than it is today.

The self-selecting sample used in this research does not represent all children in the US or in Israel. It represents a group of children who are probably more interested in science and have easier access to resources than the child population as a whole. Students who are not motivated to learn science are probably not represented in this self-selecting sample, regardless of their access to the internet. Other children that may be very interested in science but do not send questions are also not represented. Therefore, the opportunistic nature of the sample places some constrictions on the validity of the results. The validity of the study can be supported by the notion of using data that originate from the researched population itself, not as a response to a stimulus from a researcher, thus ensuring high ecological validity.

In these free-choice self-reported science learning environments some users do not bother to fill in all the required information, such as name and age. Therefore, another assumption of this research is that the data we were able to mine, is representative of the missing values as well, and that the number of repeated questions by the same person is similar in different grade levels.

Using the web as a data source results in other potential biases. For example, people on the net might be more interested in technology than the population as a whole, being more computer-savvy than their peers. If this is true, they might be more interested in technology than offline situations would measure, thus causing a selection bias. That said, it is important to reiterate that huge proportion of western youth is going online, and this activity is no more restricted to computer-geeks.

We can think of two scenarios for asking a question on an Ask-A-Scientist site. On the first, a child has a burning question, and is looking for a place he or she can find an answer. The other scenario of a "casual" participant who just happen to surf to the site with no formulated question in mind, and decided to ask something on the spot. We are unable to differentiate between the two scenarios using our current set of data. However, it is important to note that both types of questions are of value to us.

One should judge the advantages and shortcomings of our uncontrolled web-based approach relatively to the traditional methods, which are currently used to assess interest. The two scenarios for asking a question, for example, can not be distinguished in the traditional questionnaire based method, either. The researcher can not tell if a topic was marked as "interesting" since it is the long lasting hobby of the kid, or just a casual flick of the pen. Furthermore, people differ in the readiness with which they exhibit enthusiasm. "Very interested" for one student may signify no more enthusiasm than "interested" for another student (Thorndike & Hagen, 1969). It is also true that a surfer can fake his identity online, or ask a question he or she are not really interested in, but a respondent can fake his responses on an interest inventory as well. A key issue, then, is whether the subject would have a good reason to want to fake (Anderson, Ball, & Murphy, 1975).

A disadvantage of the questionnaire based method are measurement errors – the deviation of the answers of responders from their true values on the measure (Couper, 2000), a problem which does not exist using our data source. It is also important to note that in formal settings, as in free-choice settings, certain students are more likely to ask questions than others, with low-achieving students becoming less active participants with age (Good et al., 1987), and intelligent and creative students ask more and better questions than other groups (Lehman, 1972). Furthermore, many students who identify themselves as "uninterested in science" in formal setting are actually very interested in some areas of science in certain out-of-school contexts (Yang, 2007). Therefore observations in formal settings would not necessarily yield more representative findings than the ones presented herein.

Although web-based experiments of the kind used here are more difficult to control in some respects than are experiments conducted in a classroom setting, they present an important methodological advantage for studying students' self-guided science learning, taking into consideration that this kind and amount of data does not exist anywhere outside the web. Our study falls into the second and third categories of Skitka & Sargis (2006) classification of studies that use the web for data collection: It is a phenomenological research, in the sense that it compares interest in science in online and offline situations, and it is a novel methodological use of the internet, in the sense that it makes use of information freely available on the net. For these reasons, this methodology is better suited to studying the dynamic educational reality of the last decade, and may increase the affordances of interest research.

Methodology

Data Source

Science and technology questions were collected from different web-based, TV-based, magazine-based and school-based sources.

Classifying the questions

The questions were classified with reference to several coding schemes, such as subject and topic, thinking level, motivation for raising the question, the object of interest and its magnitude, and psychological distance of the object in question from the asker. Characteristics of the person who raised the question, such as gender, grade level, and country of origin were also considered.

Gender identification

Hebrew is a gender-identifying language. As a result, some of those submitting questions automatically revealed their sex through the use of verb gender indicators. Children's names provided a further indication of the sex of the questioner, although some names (e.g. 'Liron') could be associated with either a boy or a girl.

For questions in English gender identification was based on the asker's first name. In some cases initial classification was done semi-automatically using an English name gender finder[1], followed by manual classification using a baby name guesser,[2] which operates by analyzing popular usage on the Internet. In other cases only manual identification was carried out.

Statistical analysis

Unless otherwise indicated, a two-tailed Pearson chi-square test was used to calculate probabilities. Post-hoc multiple comparisons in sample proportions and Goodman's simultaneous confidence-interval procedure were used to find significant differences within proportions after the chi-square test. Clustering techniques and contingency tables analysis were used to pinpoint additional patterns within the data.

Reliability

Over 10% of the questions from each database were classified independently by two researchers, with a satisfactory level of agreement.

[1]Japan Online Directory: http://epublishing.nademoya.biz/japan/names_in_english.php?nid=A
[2] http://www.gpeters.com/names/baby-names.php

Table 1: Research goals, main research questions, sample, and the relevant papers

Research Goals	Main Research Questions	Sample	Paper
1. Characterize student's interests in science and technology	**1.** What are the scientific interests of Israeli children? **2.** What are their motivations for asking spontaneous questions?	1,676 science and technology questions submitted by Israeli children to a series of television programs of an enrichment cable channel.	Baram-Tsabari, A., & Yarden, A. (2005). Characterizing children's spontaneous interests in science and technology. International Journal of Science Education, 27(7), 803-826.
	3. What are the scientific interests of adolescence from various countries? **4.** What are the differences between spontaneous and school related science interests?	1,555 science-related questions submitted to an international Ask-A-Scientist Internet site.	Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (2006). Using questions sent to an Ask-A-Scientist site to identify children's interests in science. Science Education, 90(6), 1050-1072.
2. Describe the way in which interest in biological topics develops	**1.** What are children's interests in different biological topics? **2.** How does interest in biology develops with age? **3.** How does interest in biological topics differs between females and males?	1,751 self-generated biological questions raised by children, adolescents, and adults in three different free-choice science learning settings. Over 28,000 self-generated biological questions submitted by students from kindergarten through graduate school to an international Ask-A-Scientist Internet site.	Baram-Tsabari, A., & Yarden, A. (2007). Interest in biology: A developmental shift characterized using self-generated questions. The American Biology Teacher, 69(9), 546-554. Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (Submitted). Identifying students' interests in biology using a decade of self-generated questions.

3. Explore gender-related aspects of science question-asking in internet-based free-choice science learning environments	**1.** Are internet based Ask-A-Scientist applications an attractive science learning environment for girls? **2.** How does the female participation rate differ between countries? **3.** Do females lose interest in asking scientific questions as they grow older? **4.** Do the gender-related differences in interest in biology and physics exist in a free-choice science learning environment?	Nearly 79,000 questions sent to an international internet-based Ask-A-Scientist site during the last decade.	Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (Submitted). Asking scientists: a decade of questions analyzed by age, gender and country.
	5. Do the gender-related differences in interest in biology and physics exist in free-choice science learning settings? 6. Do the stereotypic interest patterns change with age? 7. Are there gender-related differences in the type of information requested and in the motivation for asking science questions?	1,088 spontaneous biology and physics questions raised by children, adolescents, and adults in three different free-choice science learning settings.	Baram-Tsabari, A., & Yarden, A. (2008). Girls' biology, boys' physics: evidence from free-choice science learning settings. Research in Science and Technological Education, 26(1).
4. Pinpoint additional	Can additional interactions between the	Nearly 6,000 science questions submitted by K-12 students to	Unpublished results chapter.

patterns within the data	characteristics of the question, the asker and the setting be identified using clustering techniques and contingency tables analysis?	five different free-choices and formal science learning environments.	

Part II: Papers

An overview

This section consists of six papers – four of them were already published and another two are currently under review - and a chapter presenting unpublished data.

- **Characterizing children's spontaneous interests in science and technology**

This published paper (Baram-Tsabari & Yarden, 2005) introduce the methodology of identifying children's science interests using their spontaneous questions. It reports the results of an analysis of 1676 science and technology questions submitted by Israeli children to a series of television programmes. The results point to the popularity of biology, technology, and astrophysics over other sciences, indicate a shift in interests and motivation with age, and reflect a variety of gender-related differences within the sample. The implications of the findings for some current trends in curriculum development and for informal science education are discussed with reference to the wider context of the pupils' voice in education.

- **Using questions sent to an Ask-A-Scientist site to identify children's interests in science**

This published paper (Baram-Tsabari et al., 2006) extends the same methodology to a different setting, age group and nationality. Adolescence's interests were measured by analyzing 1555 science-related questions submitted to an international Ask-A-Scientist Internet site. The analysis indicated that the popularity of certain topics varies with age and gender. Significant differences were found between children's spontaneous (intrinsically motivated) and school-related (extrinsically motivated) interests. Surprisingly, girls contributed most of the questions to the sample; however, the number of American girls dropped upon entering senior high school. We also found significant differences between girls' and boys' interests, with girls generally preferring biological topics. The two genders kept to their stereotypic fields of interest, in both their school-related and spontaneous questions.

This work was also presented at a talk at the European Science Education Research Association conference at Barcelona (2005).

- **Interest in biology: A developmental shift characterized using self-generated questions**

This published paper (Baram-Tsabari & Yarden, 2007c) suggests that identifying students' interests in biology can play an important role in improving existing curricula to meet their needs. An analysis of 1751 self-generated biological questions raised by children, adolescents, and adults yielded data regarding the different age groups' interests in biology. Applications for teaching biology are discussed in detail.

This work was also presented at the a talk at the Sixth Conference of European Researchers in Didactics of Biology in London (2006) and in a talk at the National Association for Research in Science Teaching conference at New Orleans (2007b).

- **Identifying students' interests in biology using a decade of self-generated questions**

This paper was submitted to the *Journal of Biological Education*, and is currently under review. It describes the findings from an analysis according to topic, age and gender of over 28,000 self-generated biological questions raised by students from kindergarten through graduate school. Topics popular among different age groups of males and females were identified, and ways in which students' interests can be incorporated into a standard-based curriculum are discussed, mainly as a trigger for the learning of less popular subjects which are required by the curricula.

- **Asking scientists: a decade of questions analyzed by age, gender and country**

This paper was submitted to the journal *Science Education*, it was revised to the request of the editor, and currently awaits his decision. This paper describes findings from the analysis of nearly 79,000 questions sent to an internet-based Ask-A-Scientist site during the last decade. The analysis was done according to the surfer's age, gender, country of origin and the year the question was sent. The sample demonstrated a surprising dominance of female contributions among K-12 students (although this dominance did not carry over to the full sample), where offline situations are commonly characterized by males' greater interest in science. This female enthusiasm was observed in different countries, and had no correlation to the level of gender equity in those countries. This suggests that the internet as a free-choice science-learning environment plays a potentially empowering and democratic role which is especially relevant to populations which are traditionally deprived of equal opportunities in learning formal science. However, worldwide, girls' interest in submitting questions to scientists dropped as they grew older relative to the boys' interest, and the stereotypically gendered science interests persisted in this environment as well. The strengths and limitations of using free-choice web-based data sources for studying youth interest in science are also discussed in this paper.

- **Girls' biology, boys' physics: evidence from free-choice science learning settings**

This published paper (Baram-Tsabari & Yarden, 2008) use evidence from free-choice science learning settings to study if female students' lack of interest in physics is also expressed in non-school settings. Three sets of self-generated questions raised by children, adolescents, and adults in the fields of biology and physics were used. The outcomes of this analysis show that the polar pattern previously described in school science settings, in which physics proves significantly less interesting to girls than to boys, while biology is of greater interest to girls than to boys, also appears in free-choice science learning settings. While boys develop an interest in physics with age, girls do not develop such an interest to the same degree. Thus, the initial gap in interest is probably not based on school-related causes, but its widening in later years probably is. A difference was also found between the genders in the type of information requested and in the motivation for raising the questions. We suggest that using topics that appeal to girls' interest as the context of science learning could prove beneficial in the process of mainstreaming science education, and that these topics can be identified using girls' spontaneous questions.

This work was also presented at a talk at the European Science Education Research Association conference at Malmo (2007a).

- **Unpublished results: additional pattern whithin the data**

In this chapter nearly 6,000 science questions collected from five different web-based, TV-based and school-based sources, were rigorously analyzed using cluster analysis and contingency tables analysis in order to identify K-12 students' interest in science. The questions were analyzed according to their subject, thinking level, motivation for raising the question, the object of interest and its magnitude, and psychological distance of the object in question from the asker. Characteristics of the asker, such as gender, grade level, and country of origin were also considered, alongside characteristics of the data source, such as language, setting (internet, school, TV), and the potential science-attentiveness of the users.

Baram-Tsabari, A., & Yarden, A. (2005). Characterizing children's spontaneous interests in science and technology. International Journal of Science Education, 27(7), 803-826.

International Journal of Science Education
Vol 27, No. 7, 3 June 2005, pp. 803–826

Routledge
Taylor & Francis Group

RESEARCH REPORT

Characterizing children's spontaneous interests in science and technology

Ayelet Baram-Tsabari and Anat Yarden*
Weizmann Institute of Science, Israel

This article reports the results of an analysis of 1676 science and technology questions submitted by Israeli children to a series of television programmes. It categorizes the children's questions with reference to five different coding schemes: field of interest, motivation for asking the question, type of information requested, country-specific aspects, and source of information. The results point to the popularity of biology, technology, and astrophysics over other sciences, indicate a shift in interests and motivation with age, and reflect a variety of gender-related differences within the sample. The implications of the findings for some current trends in curriculum development and for informal science education are discussed with reference to the wider context of the pupils' voice in education.

Introduction

The work presented here belongs in the context of the recently expanding research on the pupils' voice in education (Burke & Grosvenor, 2003, Economic and Social Research Council, 2004). Lloyd-Smith and Tarr (2000) called for the systems of education, as front-line providers for children, to model for other professionals a real process of acknowledging and valuing young people's views and opinions. Likewise, Rudduck and Flutter (2000) regard it as strange that, in a climate that privileges the consumer, pupils in school have not been considered as consumers worth consulting.

Within the science education literature, the principal reason for accommodating pupils' experiences and views seems to be far more immediate and direct; namely, the need to counter the declining interest that young people have in pursuing scientific careers. Osborne et al. (2003), for example, encourage researchers to identify those aspects of science teaching likely to make school science more attractive to pupils. Research into students' interests is also being conducted in the light of the relationship between students' interests and attitudes and the effective learning of

*Corresponding author. Department of Science Teaching, Weizmann Institute of Science, Rehorot, PO Box 26, Israel. Email: anat.yarden@weizmann.ac.il

ISSN 0950-0693 (print)/ISSN 1464-5289 (online)/05/070803–24

DOI 10.1080/09500690500038389

new scientific knowledge (Dawson, 2000). Such research is guided by the notion that an interested student will be prepared to expend the effort required to learn and understand new concepts (Osborne et al., 2002). Some limitations of this notion are discussed in the following.

A number of studies have previously explored students' scientific interests in the context of school curricula. Among high-school students in Northern Ireland, science subjects and mathematics were perceived as offering the least interest (Watson et al., 1994). Among the sciences, biology was well received in England (Murray & Reiss, 2003; Osborne & Collins, 2000; Qualter, 1993) and Australia (Dawson, 2000), even more so among girls. Spall et al. (2004) suggest that students enter secondary schooling with an equal liking to biology and physics, but over the course of their studies they feel less positive about physics than biology. Stark and Gray (1999) draw a different picture—in their study of Scottish students, boys' preferences for science topics shifted from biologically oriented topics to physics as the age of the pupils in the sample increased, while girls' preference for biological topics remained high through all age groups. In a multi-national study asking children what they wish to 'learn more about', the 'possibility of life outside earth' was the most popular topic among 13-year-old students from 21 countries (Sjøberg, 2000a, 2000b).

These attempts to identify pupils' preferences for topics in science have been conducted using tick boxes or Likert-type scales. This approach has been used with large numbers of students in Scotland (Stark & Gray, 1999), Australia (Dawson, 2000), Britain (Qualter, 1993; Taber, 1991) and in international studies such as ROSE (Sjøberg & Schreiner, 2002) and the Scientists and Society (SAS) project (Sjøberg, 2000b). Osborne and Collins (2001) have used focus groups to determine those aspects of science that pupils and parents value and use in their everyday life, whereas yet another methodology, involving an online response to questions, underpinned a student-led survey of the science curriculum in England (Murray & Reiss, 2003).

In contrast, the present study does not involve inviting students to respond to a series of prepared questions or topics. Instead, the approach is naturalistic. The data consist of science and technology-related questions submitted by Israeli children to a series of television programmes. Arguably, self-generated questions not only indicate the questioners' depth of thinking (Chin et al., 2002) and their reasoning, but also their misconceptions/alternative views and interests (Biddulph et al., 1986). Also, Dillon (1988) indicated that it is difficult for investigators to identify many student questions in the classroom or laboratory, even though the students might be raising them in their own minds or asking their friends.

Methodology

The sample

'*Lechu hapsu*' (roughly translated as 'Go and find out') is an Israeli television programme for children, broadcast 11 times weekly on 'Logi', a cable channel available upon subscription. Four of the 11 programmes are broadcast live. Each might be described as a hybrid of two formats; 'ask the experts' and a competition to find information. The introduction to the Internet site that accompanies the programme (www.logi.tv/ulpan_logi/logi-mika.asp) tells children that 'This is the place to ask any question in the world' and that 'We will help you find the answer, as well as the way to get it'. It also advises that the answers will be broadcast. Twenty-one categories of potential questions are identified, ranging from Relationships, Sport and Animals to Languages, Science and Nature, and Money. According to the programme editor, approximately 90% of the children send their questions via the specified Internet site, the remainder doing so via the telephone. Only the questions submitted via email are used in this study.

The programme was first broadcast in August 2003 and by early January 2004 over 3100 questions had been accumulated in an email database. Of these, 1535 questions fell in the following science and technology-related categories: Animals, Health & Medicine, How stuff works, Nature & Science, Earth & Space, Computers & Internet, and Inventors & Inventions. A total 17.6% of the questions in these categories were non-scientific; for example, historical questions like 'Who invented the ICQ?' (an instant messaging system) or legal questions such as 'Is the software Kazaa legal?' Questions of this kind were commonly associated with scientific and technological issues, and for this reason they were included in the analysis.

A total of 123 of these 1535 queries asked more than one question. The subquestions in each multiple query were separated and dealt with as discrete items. This resulted in a final sample size of 1676 science and technology-related questions, all of which were submitted in Hebrew.

Gender split. Hebrew is a gender-identifying language. As a result, some of those submitting questions automatically revealed their sex through the use of verb gender indicators; for example, 'I'm checking' translates as '*ani bodeket*' (feminine) or '*ani bodek*' (masculine). Children's names provided a further indication of the sex of the questioner, although some names (e.g. 'Liron') could be associated with either a boy or a girl. Thirty-two per cent of the 1676 questions could not be identified by either of these methods and the sex of these children therefore remains unknown. Among the 1140 gender-identifiable questions, 496 were asked by girls (43.5%) and 644 by boys (56.5%).

This gender split mirrors that found in an analysis of questions submitted to a scientific Internet site based in Rome (Falchetti et al., 2003), and a UK-based science line (K. Mathieson, personal communication, 2 April 2004), as well as results from the 1999 US Science and Engineering Indicators, which showed that women are less likely than men to use media that foster informal learning about science (National Science Foundation, 2000; Nisbet et al., 2002). It also resonates with the evidence that boys in general have more positive attitudes towards science than girls (Crettaz von Roten, 2004; Kelly, 1978; Weinburgh, 1995) and greater interest in it (Gardner, 1975).

Socio-economic split. The socio-economic status of the respondents was determined by their place of residence and characterization and ranking of local authorities of the Central Bureau of Statistics (2004). The latter uses a series of variables such as demography, education, standard of living, characteristics of the work force, and the level of financial allowances and support, in order to allocate local authorities to one of 10 groups on a scale of 1 (lowest socio-economic level) to 10 (highest). The number of people in each cluster is different, with most of the population falling in the mid-clusters.

The 1523 questions were analysed with reference to socio-economic status. Clusters 1, 2, and 3 were almost absent from the database (with zero, two, and seven questions, respectively). This is not surprising since most of the local authorities in those clusters are inhabited by Orthodox Jews or Israeli Arabs, two groups that tend not to watch Hebrew-speaking television. Clusters 4, 5, and 6 were well represented, with 208, 254, and 208 questions, respectively, whereas the dominant clusters were the more prosperous clusters 7 and 8, with 399 and 390 questions, respectively. The most prosperous (but much smaller), clusters 9 and 10, contributed 51 and four questions, respectively, to the database. These figures suggest that the population that submitted questions to the programme was more prosperous than the average population. This is not surprising since the sample was drawn from people who have an access to the cable service (60% of Israeli households; Israeli Ministry of Communication, 2003) as well as to the Internet (50% of Israelis according to the Computer Industry Almanac's estimation; ClickZ 2004), and who choose to subscribe to the children's enrichment channel.

Since the allocation of local authorities to a financial cluster depends upon a composite average figure, the bias towards the more prosperous socio-economic groups may be somewhat more marked than the figures in the previous paragraph indicate. Children from cluster 4 or cluster 5, for example, might belong to the most prosperous families in that town or city, and might be more appropriately associated with the average socio-economic state of cluster 8 or cluster 9.

Given these uncertainties, no attempt was made to establish a correlation between the types of question asked and the socio-economic status of the questioner. However, the data can be used to characterize the socio-economic level of the children in the research sample and to extrapolate the findings to comparable populations.

Age split. A total of 1461 of the questioners stated their age when asking their questions. The distribution obtained from these data is almost statistically normal, with a mean age of 10.6 years and a standard deviation of 2.3. All of the ages used in this analysis are expressed as whole numbers rounded to the nearest year. In broad terms, most questions in this research came from children in the later years of elementary school and in the early years of the Junior High School (ages 9–12).

Reliability. In order to test for internal consistency of the data, a split-half test was performed in the following manner: a chi-square test was performed between the odd and the even questions assembling the database. The split-half test showed no significant differences between the groups with regard to gender ($\chi^2_1 = 0.1, p = 0.75$), socio-economic split ($\chi^2_5 = 2.79, p = 0.73$), and age ($\chi^2_{10} = 6.13, p = 0.80$). It did not show significant differences for questions' characteristics as Field of interest ($\chi^2_5 = 1.45, p = 0.92$), Motivation ($\chi^2_8 = 3.55, p = 0.89$), Type of information requested ($\chi^2_5 = 5.9, p = 0.32$), Country-specific aspects ($\chi^2_1 = 0.08, p = 0.77$), and Source ($\chi^2_2 = 4.35, p = 0.11$).

Classifying the questions

One hundred of the questions were first translated into English and their classification and categorization carried out independently by two additional researchers in order to establish an acceptable level of reliability. For the first preliminary trial, 50 of the questions were coded independently. Problematic issues were discussed and refined. For the second trial, the remaining 50 questions were also coded. The agreement between the trials was: Field of interest, 89%; Motivation, 90%; Type of information requested, 85%; Country-specific aspects, 98%; Source, 98%. The remaining disagreements were then resolved by discussion between the researchers, with the coding system adjusted as necessary. The following five sets of coding schemes were eventually produced in order to provide a variety of perspectives regarding the children's interests in science and technology, as indicated by the questions they submitted to the programme. Each coding scheme was subdivided as necessary.

Field of interest

Questions in this coding scheme were placed in one of the following categories: 'Biology', 'Physics', 'Chemistry', 'Earth sciences', 'Astrophysics', 'Nature of science (NOS) inquiry', and 'Technology'.

'Earth Science' and 'Astrophysics' were kept as distinct categories since each accommodated a significant number of questions. 'NOS inquiries' were general questions about how scientists develop and use scientific knowledge (Ryder et al., 1999) without reference to a specific scientific context. 'Technology' questions were categorized by defining technology as the development, production, and maintenance of artefacts in a social context, as well as the artefacts themselves (Gardner et al., 1996). This enabled accommodating most of the questions from the original groups used by the television programme, namely the 'Computer & the Internet', 'How stuff works', and 'Inventors & inventions'. Each of the categories (except for the NOS inquiry) was further divided into subcategories, resulting in a total of 65 subcategories. Seven questions that did not fit any of these were classified as 'Undistinguished' (e.g. 'does god exist?'). For examples of the application of the categories and subcategories in this coding scheme, see Table 1.

Table 1. Some examples of classification according to field of interest

Category	Subcategory	Example (gender, age)[a]
Biology	Human physiology	How come we don't feel growing up? (nine years)
	Human nutrition	If you go on a diet, where does the fat go? Does it melt? (female)
	Zoology: Behaviour	When a cow goes 'Moo' is it speaking to its friends or keeping its territory? (male, eight years)
	Zoology: Extinct animals	Will the dinosaurs come back in 20 million years? (male, 18 years)
Physics	Light, heat, sound	Why is it that when you put the reverse of a CD in the light it becomes colourful? (male)
	Electricity & magnetism	Water does not conduct electricity, so why when I come out of the shower am I told not to put the lights on with wet feet? (male)
Chemistry	What things are made of	What are the capsules of medication made of? Is it plastic? Isn't dangerous to the digestive system? (male, 10 years)
	Elements	What does mercury look like in nature? (11 years)
Earth sciences	Meteorology	Why it doesn't snow at the seaside like in Jerusalem, and it doesn't rain all year like in England? (male, 15 years)
	Environment	What will happen in 50 years if we won't watch over the amount of toxic materials that are emitted into the atmosphere? (male, 12 years)
Astrophysics	Space missions	When Ilan Ramon and all the other astronauts on the Columbia had to pass through the atmosphere and didn't have enough power, why wasn't another spaceship sent to save them? ... And why didn't they pay attention to that little brick that was falling from the wing? (female, 13 years)
	The solar system	When we are looking from Earth to the sky we see the sun in the blue sky. So how can it be that the sun is in space, which is black? (male, nine years)
Nature of science inquiry Technology	Computers & the internet	If I want to conduct research and publish it, what should I do? (male, 13 years) I want to know how to build an internet site and if it is difficult. (female, 10 years)
	Electronics	Why is it forbidden to put iron in a microwave? (male, 12 years)
	Optics	How does the barcode in the supermarket work? (male)
	History of technology	Who invented the computer and how? (male, 10 years)

[a]Where data are available.

Motivation

An attempt was also made to identify and classify the questioners' motivation for asking their questions. Since it was not possible to ask the children why they sent their questions, it was necessary to interpret their possible motivation from the way in which their questions were worded and phrased. The two main categories chosen were 'Non-applicative' and 'Applicative'. The former was subdivided into 'Spectacular aspects', 'Philosophical and aesthetic aspects', 'General curiosity', 'Seeking an explanation for a direct observation' and 'Linguistics aspects'. For examples of the categories used in this coding scheme, see Table 2.

The subcategory of 'Spectacular aspects' emerged from the large number of children's enquiries about the 'biggest', 'fastest', 'oldest' or 'strongest thing ever'. There were very few 'Philosophical & aesthetic questions' but they were easy to identify. 'Linguistic' issues interested those children who wanted to know why things were named the way they were. 'Seeking an explanation for a direct observation' was a subcategory established to accommodate those science and technology-related questions that stemmed from children's personal observations. These direct observation questions were distinguished from 'General curiosity' items either by a specific reference in the question to the personal context of the observation or by the likelihood of the question being triggered by a personal observation.

The other main category of motivation was the 'Applicative' question, which was subdivided into 'Personal use' and 'Human health & lifestyle'.

Some questions classified as 'General curiosity' could have been alternatively classified as 'Personal use'. Examples include 'How are animals domesticated to make sure that they won't hurt you?' and 'How can you tell if dogs feel bad or sad or scared?' However, since these questions did not specify a personal use for the knowledge being sought, they were categorized under 'General curiosity'.

Table 2. Some examples of classification according to motivation

Category/subcategory	Example (gender, age)[a]
Non-applicative	
Spectacular aspects	What is the biggest lizard in the world? (male, 11 years)
Philosophical & aesthetic aspects	Why do people eat animals? (10 years)
General curiosity	Does a whale have a bellybutton? (female, 12 years)
Explanation for an observation	When I'm being hurt, what's in the plaster that helps the wound? (female, 10 years)
Linguistics	Why the dinosaurs' names are so long? In what language is the word 'dinosaur'? (male, 10 years)
Applicative	
Personal use	I want to add a chat application to my Internet site, what should I do? (male, 15 years)
Health & lifestyle	How can I lose weight in few days? (female, 12 years)

[a]Where data are available.

Type of requested information

Bybee has emphasized the importance of the ability to 'ask the right questions' for the development of higher levels of biological literacy (Biological Sciences Curriculum Study, 1993) and his question typology includes four types: description, investigation, prediction, and evidence. This typology mimics the scientific way of investigating phenomena as it is presented in school, thus proving to be unsuitable for the informal database used in the present research. In addition, the typology proved sensitive to age: a given question could be regarded as simple or complex, depending upon the age of the questioner.

As a result, a typology was developed that describes the nature of the question and the knowledge it generates. A category of requests for 'Factual' information included terminological (What is www?), historical (When was ...?), descriptive (What does a male mosquito eat?), and confirmatory (Is it true that ...?) items. Requests for 'Explanatory' information are basically 'Why' and 'How' questions. Requests for information regarding scientific research are divided into 'Methodological' and 'Evidential'. 'Methodological' information has to do with scientific ways of finding things out and with scientific and technological procedures. Requests for 'Evidential' information are concerned with how we know what we know. The 'Open-ended' type of information deals with opinions, controversial themes, and futuristic questions that science cannot answer for the time being. Requests for applicative information are concerned with the settings in which scientific and technological knowledge is being used to resolve problems and challenges. For examples of the allocation of questions to this coding scheme and its categories, see Table 3.

As with any typology, a few questions were difficult to classify; for example, 'How do you know that a dog has rabies?', which was asked by an 11-year-old boy. This

Table 3. Some examples of classification according to type of requested information

Category	Example (gender, age) [a]
Factual	Does a fly have a heart? (10 years); How many astronauts were sent into space? (female, eight years)
Explanatory	How come that from the electric wire that connects to our television we see a picture? (male); Why does the Earth turn around? (male)
Methodological	Why do the measurements always start at sea level? (female, 11 years); I read in the newspaper that scientists can multiply the average life span of certain creatures. How is it being done? (male, 13 years)
Evidential	What is evolution, and is there any evidence that it exists? (female); How do they know that there is a hole in the ozone layer? (11 years)
Open-ended	Why is it important to protect the environment? (eight years); Will there be flying cars in the future? (male)
Application	I'm 11 years old and I eat a lot and don't gain weight. I weigh 24 kilos and a half. My question is — is that bad? (female, 11 years); My dog is big and strong although it is not one year old yet, how should I tame it? (female, 11 years)

[a]Where data are available.

could be regarded simply as a request for 'Factual' information, asking what the symptoms of rabies are. It could also be categorized as a request for 'Methodological' information or as 'Evidential' information. In this case, the item was ultimately classified as 'Evidential'.

Another problem was posed by some of the questions submitted in the present tense when translation from Hebrew into English allowed two possible readings; for example, '*Ech bonim atar Internet*?' can be translated either as 'How is an Internet site built?' or as 'How do you build an Internet site?' 'How is an Internet site built?' is clearly a request for 'Explanatory' information—a 'how stuff works' type of question. However, a question of the form 'How do you build?' belongs in the category of 'Application'. In this case, the question was categorized as 'Applicative' and the motivation as 'General curiosity'. Fortunately, ambiguities of this type were few in number.

Country-specific aspects

Particular attention was given to questions with a local or national rather than international emphasis (e.g. 'Two years ago there was an attempt to hide a bomb in the Glilot gas distribution centre and they said the centre would be shut down, but until now nothing has been done. Why? It is very dangerous'.). The number and nature of such questions serves as an indication of the cultural dependence of the science and technology-related questions asked by the Israeli children responding to the television programme.

Source

Some questions indicated the sources of scientific and technological information that the children used and drew upon. The three sources mentioned in the questions were 'Hearsay' (e.g. 'I heard that' and 'People say that'), the broadcast and print 'Media' and 'School science'. These were therefore used as the categories for this class of question.

Results and discussion

In order to characterize children's spontaneous interests in science and technology, questions were collected from an Internet site that accompanies a children's television programme. The questions were analysed with reference to five different coding schemes: Field of interest, Motivation for asking the question, Type of information requested, Country-specific aspects, and Source of information, also considering the available background knowledge about the children who sent the questions.

Field of interest

A breakdown of the questions analysed by Field of interest is presented in Table 4.

The popularity of biological questions among Israeli children reflects findings from studies undertaken elsewhere (for example, Murray & Reiss, 2003; Qualter, 1993).

Table 4. Breakdown of the questions by field of interest

Field of interest	Frequency	Per cent
Biology	831	49.6
Technology	419	25.0
Astrophysics	204	12.2
Earth sciences	102	6.1
Physics	71	4.2
Chemistry	40	2.4
Undistinguished	7	0.4
Nature of science inquiry	2	0.1
Total	1676	100.0

Of the 831 biological questions in the present study, 72% were essentially zoological and one-quarter addressed issues in 'Human biology'. Botanical questions accounted for only 2.3% and the number of items concerned with the 'History of biology' was negligible. Table 5 provides details about the classification of the 'Zoology' and 'Human biology' questions by subcategory.

Among the 600 'Zoology' questions, there was a marked emphasis on the 'Physiology and anatomy' of a variety of animals. Such questions were mostly curiosity driven (e.g. 'How do dolphins sleep if they have to breathe?'). The second largest group of questions concerned relationships between animals and human beings (e.g. the taming of dogs and restoring sick pets to health). Animal behaviour and 'Taxonomy and biodiversity' (e.g. 'How many reptile species are there in the world?') were also popular themes. Under 'Other' were classified questions that did not fit any of

Table 5. Classification of 'Zoology' and 'Human biology' questions[a]

Subcategory	Human biology	Zoology
Sickness & medicine	33.3% (69)	3% (18)
Physiology & anatomy	32.9% (68)	33.7% (202)
Nutrition	12.6% (26)	5.7% (34)
Genetics & reproduction	9.2% (19)	5.2% (31)
Behaviour & neurobiology	7.2% (15)	13% (78)
Other	1.9% (4)	3.5% (21)
Evolution & creation	1.9% (4)	1.2% (7)
Biotechnology	1% (2)	0.3% (2)
Man & animals	–	17.7% (106)
Taxonomy & biodiversity	–	12.3% (74)
Extinct animals	–	4.5% (27)
Total	207	600

[a]Actual numbers in parentheses.

these subcategories (e.g. 'How many people are needed to pick up an elephant?', 'What is the most dangerous animal in the world?').

The 207 'Human biology' questions mainly focused on four subjects, with 'Sickness and medicine' and 'Physiology and anatomy' accounting for almost two-thirds of the items (see Table 5). 'Genetics and reproduction', 'Nutrition', and 'Behaviour and neurobiology' accounted for most of the remainder.

Whereas 'Physiology and anatomy', 'Evolution and creation', and 'Biotechnology' account for similar proportions of zoological and human biological questions, interest in 'Sickness and medicine' is much more marked among the latter (3% in 'Zoology', 33.3% in 'Human biology'). The most frequently mentioned diseases and illnesses are cancer, AIDS, influenza, rabies, and asthma, although rubella, smallpox, malaria, heart attacks and anorexia also prompted questions. Most of the items concerning 'Sickness and medicine' and 'Nutrition' are motivated by application, but most of the other biological questions seem to be 'Non-applicative'. Interestingly, although 'Human biology' is assumed to be the subject most directly relevant to children's lives, questions classified as 'Applicative' feature more prominently within 'Zoology' (21.7%) than in 'Human biology' (15.9%). However, the relative frequency of questions categorized as 'Zoology' decreases with age, whereas the interest in 'Human biology' increases ($\chi^2 = 8.35$, $p < 0.05$)[1] (see Figure 1).

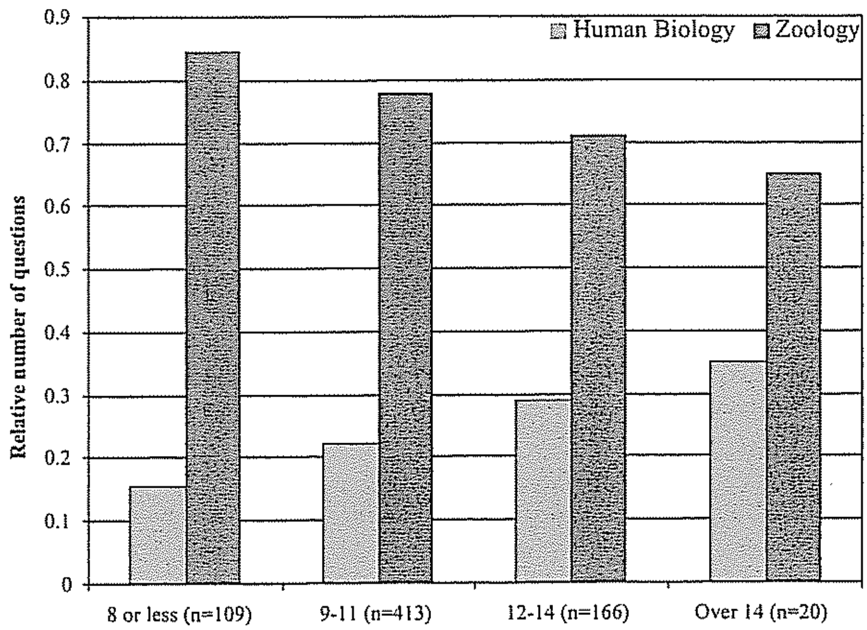

Figure 1. Relative frequency of 'Zoology' and 'Human biology' questions among four age groups

The interest of older pupils in human biology is well-attested by a number of studies. A focus-group study of 16-year-old students in England showed that aspects of human biology generated the largest number of comments and the lowest level of disagreement among girls and boys who were not planning to take post-compulsory science studies (Osborne & Collins, 2001). Likewise, Tamir and Gardner (1989) found that among 900 Israeli 10th-grade biology students, the highest levels of interest related to topics in human biology. Given the age distribution of the sample in the present study, it seems reasonable to assume that the change in focus of the questions revealed in Figure 1 is related to issues surrounding the onset of puberty.

The second largest group of questions (419), classified by field of interest, concerned technology and accounted for 25% of the database (see Table 4). Most of the questions concerned 'Computers and the Internet' (45%) and the 'History of technology' (31.5%). As might be anticipated, the motivation for asking questions here was dominated by application (especially 'Personal use') with a few items classifiable as 'Non-applicative'. Moreover, all the 'Applicative' questions related to the 'Computer and the Internet' and 'Inventions and patenting'. These are apparently the two fields in which the children were eager to do things by themselves and needed some information to help them with the task. Curiosity-driven technology questions are 'How stuff works' kind of questions, with many of the explanatory questions motivated by a direct observation (e.g. 'How does the barcode in the supermarket work?').

The third largest field of interest revealed by the questions is 'Astrophysics', the 204 questions accounting for 12.2% of the database. The main interest of the children here can be described as a type of 'space geography'; that is, how big and far away the planets are in the solar system (34.3%) and how far away are the stars and planets (26.5%). The 'Big Bang and star formation' comprise almost 10% of the database (e.g. 'Why did the Big Bang happen and what was exploded there?'). 'Space missions' make up 17.6% of the questions asking about the way spacecraft work, how they are named, their equipment, the number of astronauts sent into space, and the reasons for going to the moon. The possibility of 'Extraterrestrial life' and of any ill intention towards Earth account for another 9.3% of the 'Astrophysics' items. Again, this interest in space science among Israeli students mirrors that found among students elsewhere (for example, Osborne & Collins, 2001; Sjøberg, 2000b), as well as among Spanish scientific television programme viewers, where the biggest audience share was recorded for episodes concerning cosmology and physics (Estupinya et al., 2004).

The 102 'Earth sciences' questions made up 6.1% of the database. In decreasing order of popularity, questions dealt with 'Meteorology', 'Environment', 'Geography', 'Earth atmosphere', 'Geology', 'Oceanography', together with a small but determined group of 'The end of the world' items (2.9%). The 'Earth sciences' category is characterized by an above-average percentage of 'Explanatory', 'Methodology' and 'Open-ended' type of requests for information and by a relatively few 'Factual' and 'Applicative' requests.

Most of the 71 (4.2% of the database) 'Physics' questions related to classical physics—'Light, heat and sound' (34%), 'Electricity and magnetism' (22.5%), and 'Mechanics' (11%). Another 11% of the 'Physics' questions addressed topics in 'Modern physics' (e.g. 'What happens while moving at the speed of light?') whereas a surprisingly large proportion asked about the history of the discipline (21.2%).

There were only 40 'Chemistry' questions (2.4% of the database) and many asked about the composition of everyday objects such as erasers, toilet paper, and glasses. Others addressed the more visually appealing dimensions of the subject such as the making of fireworks, blue gas flames, and diamonds. A few questions related to such chemical topics as the states of matter (e.g. 'Is there a substance that is not in any of the three states of matter?') or sublimation (e.g. 'What do you call it when a substance goes directly from solid to gas?').

The fields of interest in science and technology show a number of changes with age, as can be seen in Figure 2. The significant differences between the age groups ($\chi^2 = 33.03$, $p < 0.05$) is mainly owing to a decrease in the interest in 'Biology' and an increase in interest in 'Technology' among the two older age groups. The decrease in interest in 'Biology' is accompanied by the shift in interest within the discipline from 'Zoology' to 'Human biology' referred to earlier.

Another notable feature of Figure 2 is the relative popularity of 'Physics' among the youngest age group. This group generated 7% of the 'Physics' questions compared with 3.2–3.8% of those from older children. No age-related shift in children's interest in 'Earth sciences' ($p = 0.77$) or 'Astrophysics' ($p = 0.87$) is indicated by the data.

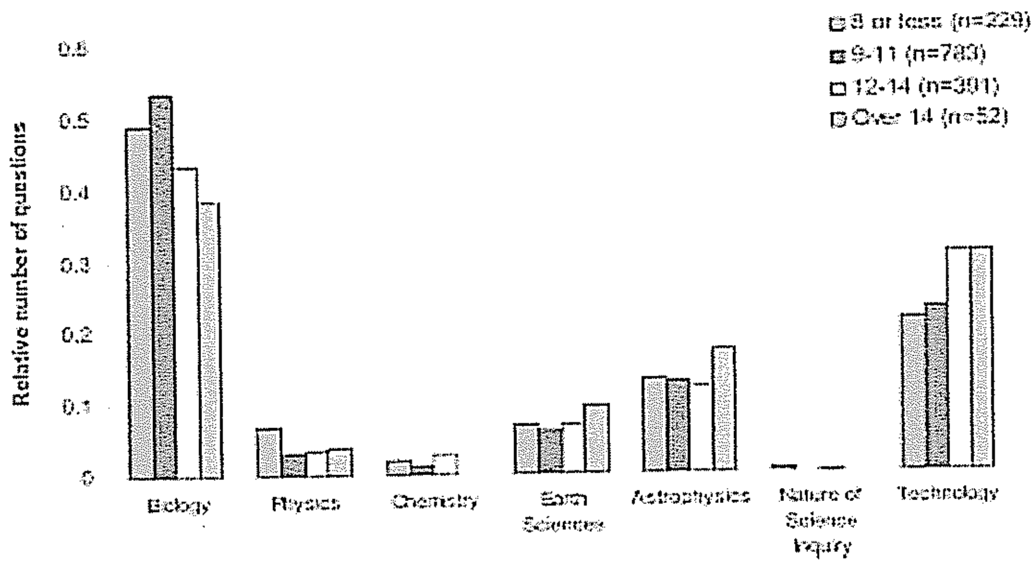

Figure 2. Interest in science and technology issues among four age groups

Motivation

The children's motivation for asking their questions was for the most part 'Non-applicative'. Only 20% of the questions explicitly related to an application, and almost all of these were associated with 'Biology' (e.g. 'My cat eats grass, is it harmful? What can I do about it?') or 'Technology' (e.g. 'How can I build my own Internet site?').

There are some shifts with age in the motivation for asking the questions. The proportion of questions asked for applicative reasons rises steadily with age between ages 6 and 16 ($\chi^2 = 51.21, p < 0.001$), as can be seen in Figure 3.

The fall in the proportion of 'Applicative' questions among the 16-year-old group is not significant—there is no statistical difference between the 15 year olds and the 16 year olds ($\chi^2 = 0.331, p = 0.57$). Since the 16 year olds are rather a small group, it is impossible to determine whether the trend evident in the earlier years is actually reversed or whether the sample of 16 year olds is not large enough to reflect an ongoing applicative trend. If attention is confined to groups of $n > 50$, 'Applicative' questions increase from 10.3% at age 7 to almost one-third of the questions at the age of 14. Such a shift is redolent of the early-twentieth-century developmental ideas of T.P. Nunn, who identified three motives in the minds of pupils at different stages of their conceptual development: wonder, utility, and systematization (Jenkins, 1979; Nunn, 1925). If wonder is equated with 'Non-applicative' questions and 'Applicative' with utility, then the shift between these two stages lends some empirical support to Nunn's notion of progression.

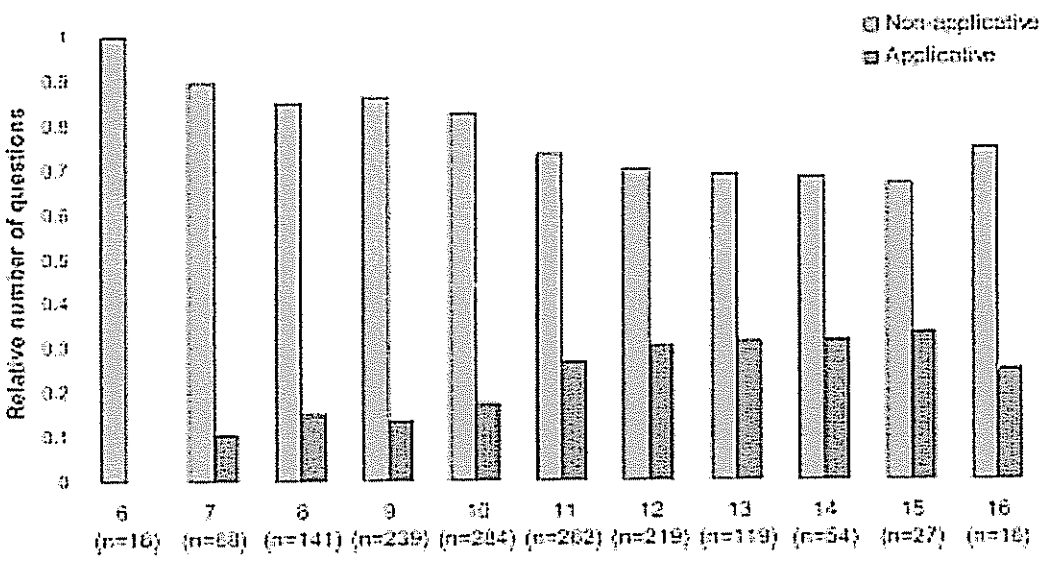

Figure 3. Motivation for asking the questions among four age groups

Type of requested information

More than one-half of the questions asked by the children were 'Factual', a little more than one-quarter were 'Explanatory', and 13.5% were 'Applicative'. Together, those three types account for 96% of all the questions. 'Methodology', 'Evidential', and 'Open-ended' questions make up the remaining 4%. This picture of children's questions is far more encouraging than that portrayed by studies conducted within science classes. Monitoring the type of questions asked by six eighth-grade students during hands-on activities in chemistry, for example, showed that a majority (86%) of the questions sought basic factual or procedural information, with only 14% of them reflecting curiosity, puzzlement, scepticism or speculation (Chin et al., 2002), a finding consistent with Dillon's study of non-science high-school classrooms (Dillon, 1988).

While most of the questions in the present sample are unique, and appear only once, there are a few questions that seem to interest a significant proportion of the children. Examples of these are presented in Table 6. Although non-scientific questions and 'Open-ended' questions constituted only a small proportion of the overall sample, such questions were among the most frequently asked.

Country-specific aspects

Only 50 questions (3%) in the entire sample were 'Country-specific' (e.g. 'Can you see Venus from Israel?'), and over one-third of those were non-scientific (e.g. 'When is the F-16I (Fighting Falcon) scheduled to be brought to Israel?'). Twenty-two per cent of the questions that refer to an Israeli context related to 'Earth sciences' (e.g. 'How come the minerals in the Dead Sea don't run out?').

Sources of information

Only 44 out of the 1676 questions included a specific reference to a source of information. The main sources were 'Hearsay' and the 'Media', with only five children in the sample indicating that they were asking something related to their school science education. Questions about the height and composition of the atmosphere were very

Table 6. Frequently asked questions

Question	*n*
Which is the biggest/fastest/strongest/smallest animal?	46
Who invented the computer?	26
Untill what age does a dog/cat/hamster/turtle live?	22
Is there life in space/on other stars?	15
How do I build an Internet site?	13
Who invented television?	11
How to convince mom to let me have a pet?	11

common, perhaps because of the publicity associated with the first Israeli astronaut travelling aboard the spaceship Columbia early in 2003.

Gender and social background

Reference has already been made to the different numbers of boys and girls who submitted questions to the television programme. As far as the social background of the questioners is concerned, the percentages of boys to girls from the lower (3–4) and average (5–6) communities were very similar (48.5–51.5% and 48.4–51.6%, respectively). It is the more prosperous communities (7–8) that principally accounted for the masculine bias in the overall database (59.5% boys, 40.5% girls) ($\chi^2 = 14.6, p < 0.05$). The gender differential was more marked in the most prosperous clusters (9–10), (75.9% boys, 24.1% girls), although it should be noted that this group is relatively small ($n = 55$, 29 of those with gender known).

An analysis of the questions reveals a significant difference in the field of interest of questions asked by the two genders. Questions from girls are predominantly biological (75.0% of the total), with boys dominating in all the remaining categories ($\chi^2 = 23.08, p < 0.001$). Girls' preference for biology ($\chi^2 = 9.5, p < 0.01$) was matched only by their lack of enthusiasm to submit physics questions ($\chi^2 = 7.2, p < 0.01$), a finding consistent with that of the recent ROSE study involving nineth-grade Israeli students (Trumper, 2004) and with the number of Israeli female students choosing to take post-16 biology and physics courses in high school (only 33% of the post-16 physics students are female versus 65% of the biology students; Coordinating Supervisor of Physics, personal communication, 29 July 2004; Coordinating Supervisor of Biology, personal communication, 8 September 2003). No gender-related differences in interest were found in the case of 'Astrophysics' ($p = 0.39$) and 'Earth sciences' ($p = 0.43$). The numbers in the 'Chemistry' and 'NOS' categories were too small to permit a meaningful quantitative analysis. 'Technology' might be described as a borderline case.

Statistically, it cannot be argued from the present study that interest in 'Technology' is gender dependent ($\chi^2 = 3.1, p = 0.078$). However, there is a significant difference between girls and boys within the 'Technology' subcategories ($\chi^2 = 14.3, p < 0.05$). Boys focused their questions on 'Computers and the Internet' and on the 'History of technology', whereas the girls were more diverse in their interests.

These findings are consistent with work performed elsewhere, including Scotland (Stark & Gray, 1999), Australia (Dawson, 2000), USA (Jones et al., 2000), England (Osborne & Collins, 2001) and the international study SAS (Sjøberg, 2000b). The SAS study is noteworthy for the inclusion of a free response item that invited the 13-year-old respondents to write about 'Me as a scientist'. Biological themes were by far the most popular in responses to this question, by both boys and girls, but with the latter being more marked. The present study does not, however, reflect the gender differences found in 'Technology' and 'Earth sciences' recorded in the SAS study among students from countries in the developed world.

Although the emphasis on 'Biology' is very different between girls and boys, there was no gender difference in the questions relating to 'Human biology', 'Zoology', and 'Botany'. It seems that within biology boys and girls share the same fields of interest. Within 'Astrophysics' the boys were more interested in the physical aspects of the discipline, whereas the girls asked more about space missions. Both genders were equally interested in the possibility of 'Extraterrestrial life', another finding consistent with that of the SAS study (Sjøberg, 2000b).

Boys and girls also tended to ask for different types of information ($\chi^2 = 17.8$, $p = 0.01$), with the boys favouring 'Factual' and 'Methodological' types of information whereas girls asked for more 'Explanatory' and 'Applicative' types of information. The same pattern is mirrored with respect to motivation ($\chi^2 = 31.3$, $p < 0.001$). Boys tended to pose 'Spectacular' and 'General curiosity' questions, whereas girls sought straightforward explanations for their own direct observations. Girls also asked more 'Applicative' questions, with reference to 'Personal use' and 'Health and lifestyle'.

History of science

The children's questions indicate an interest in the history of some scientific disciplines. While 31.5% of the 'Technology' questions were historical, only five questions in 'Biology' (0.6% of the 'Biology' questions) revealed a similar historical concern. In 'Physics' 21.1% of the questions were due to interest in the history of the discipline, whereas 'Chemistry', 'Astrophysics', and the 'Earth sciences' did not have enough historical questions to be accounted for separately.

Within the 'History of technology', children seemed very interested to know who invented the technologies they used. For example, they asked about the inventors of computers and the internet, television, various computer games, air conditioning, escalators, plastic, the compass, cars, airplanes, and other useful objects and developments. Notably, many of the historical questions seemed to imply that a technological innovation, such as a computer, could be attributed to a single inventor or circumstance. There was also no indication that children understood that a given technology evolved over time. For the most part, questions simply asked 'Who invented X?', with 'Who was the first to invent X?' a relatively common variant. Some children were interested to know where and when a particular technology was invented. There were similarities with the 15 questions regarding the 'History of physics'. Eight of them asked who invented or discovered electricity, where, when, and how. Other topics of interest were the inventors of the LASER and the magnet. Occasionally, the children's interest in the human aspect was so great that it eclipsed the science itself, as demonstrated by the question asked by a 13-year-old boy: 'Who discovered aerodynamics, and what is it anyway?'

Among the five questions concerned with the 'History of biology', the emphasis was once again on the date and/or priority of the discovery or the identity of the discoverer. Examples include 'Who was the first to discover the dinosaurs?' (nine year old), 'Who were the scientists who discovered bacteria?' (13-year-old boy), and 'Who discovered the vitamins?'

The reasons for these apparent differences in interest among the children regarding the historical aspects of the different scientific disciplines are not clear. They may reflect different historical emphases in the teaching of the sciences in school and/or suggest that the historical bases of the disciplines are more evident in some cases than others.

Implications

Although the study described sheds some light on what interests Israeli students, caution is needed in identifying any implications the pupils' voice may have for school science education, as discussed in the following. The self-selecting sample used in this research does not represent all Israeli children, let alone children in general. It is a group of children that might be more interested in science and have more access to resources than the entire children population. Therefore, the opportunistic nature of the sample places some limitations on the validity of our results.

Although our study does not use a controlled sample, the criterion validity of the results is agreeable—there is sufficient similarity with key findings from other research based upon selected and controlled samples to suggest that the outcomes of the present study can command a degree of confidence.

There are three aspects of the findings that are relevant to current debates about school science curriculum reform. These relate to the incorporation of the history and philosophy of science and technology within school science courses, the teaching of contemporary socio-scientific issues, and the accommodation of science and technology as an integrated programme. Each of these will now be considered in turn.

First, the results reported suggest that many children are interested in at least some of the human dimensions of science and technology, a finding that might be seen as offering some support to advocates of the history and philosophy of science and technology in the school curriculum (Galili, 2001; Jenkins, 1989; Matthews, 1994; Solomon, 1989). However, it is clear that any such interest is differentiated by discipline (as discussed earlier). Whatever the reasons for this apparent difference may be, it seems that the case for including the history of science in the school curriculum may need to take more account of the differences between the scientific disciplines than is presently the case. It perhaps also needs to take account of the finding in England that 16-year-old pupils regarded the school science curriculum as more concerned with the past than with contemporary science (Osborne & Collins, 2000). In addition, it may be appropriate to distinguish different aspects and periods of the history of science and technology. To cite an obvious example, the development of the modern computer as a historical event seems likely to interest more children than, say, Mendeleef's periodic table.

Second, at a time when curriculum developers are promoting school science courses that address contemporary issues in science and society, the relative lack of interest among the Israeli students responding to the television programme with questions addressing such issues is of some interest. The preponderance of younger children in the sample may be significant here since contemporary science and technology-related issues seem more likely to interest those who are somewhat older. However, while the age distribution of the sample may be significant, a similar analysis of questions sent by audience from all ages to an Italian 'Expert on line' application yielded very few requests for opinions on controversial issues (Falchetti et al., 2003). It may of course be the case that the 'Ask the expert' format does not encourage questions that are likely to require discursive and/or contentious answers.

Using local issues in the science classroom is also considered to be a mean of making school science more relevant to the student. The assumption is that teaching should be built on the interests and experiences of the student. Sjøberg (2000b) argues that the content of school science needs to be adapted to culture and context, since national culture and current conditions affect students' attitudes about science (Hofstein et al., 1986). However, for the most part, the children's questions to 'Lechu Hapso' reflected no local emphasis. The overwhelming majority made no reference to Israel, its distinctive geography or unique fauna. Rather, they reflected what might be termed a global or international view.

Third, the findings of this study underscore the need for caution in discussing science and technology as a homogeneous field. Findings relating to, for example, gender differences that apply to school science may not necessarily apply to school technology and vice versa. Similarly, it is sometimes important to differentiate between the sciences and different types of technology when commenting upon such issues as students' interests and motivation.

Whereas some countries have developed separate school courses in science and technology (e.g. England, New Zealand), others have preferred a more integrated or coordinated approach. The STS approach was officially adopted in Israel as a leading model for elementary (Israeli Ministry of Education, 1999) and junior high-schools (Israeli Ministry of Education, 1996) in the form of science and technology studies (Barak & Arely, 2003). Each subject in the syllabus contains three strands: scientific, technological, and social. The children in the sample studied here have all been taught in accordance with this new syllabus.

The pupils' voice

What role may the 'pupils' voice' assume in constructing or reforming school science courses? It is evident that most of the children's questions in their present form are unlikely to be answered by the Israeli science and technology curriculum. It is unreasonable to expect a curriculum to answer directly a question such as 'Did the cave men have cats?', asked by an eight year old, even if the relevant section of the curriculum includes a unit about living creatures.

A further difficulty stems from the problems associated with relating abstract and general scientific knowledge to highly specific, and often practical and everyday, contexts (Jenkins, 2000). Studying food chains in class is unlikely to satisfy the curiosity of a boy who wonders why he cannot raise a lion at home and turn it into a vegetarian. However, Gallas (1995) has shown that it is possible to respond creatively to the issues surrounding knowledge transfer by developing a curriculum designed to promote children's sense of wonder. Her strategy enabled children to ask questions and offer theories about the human body that went well beyond the developmental expectations for their chronological age. She claims that a curriculum that emerges from children's questions becomes part of the process of building a community of learners whose interests, questions, and theories emerge from the inside-out, rather than the outside-in (Gallas, 1995). But even this luxurious solution answered just few of the children's questions, and then in a very specific area. It is by no means obvious that it can be generalized to other areas of science education or indeed used to construct a national science curriculum.

The results also raise an interesting issue about the broad fields of interest of the children and the time devoted to them in the school curriculum. For example, the interest of younger children in zoological topics sits somewhat uncomfortably with the amount of time spent studying other biological topics in Israeli elementary and junior high schools. Another contrast is the emphasis put on human biology at an age when pupils' questions suggest that they are more likely to be interested, for example, in the pregnancy of their guinea pig than in their own blood system. If the outcome is that school science delays gratification of pupils' genuine curiosity and interest, then this is likely to have a negative effect on pupils' interest in science (Osborne & Collins, 2000). Engendering positive enquiring attitudes to science and scientific issues during primary school might well pay off in the longer term (Stark & Gray, 1999), since the elementary grades are pivotal years for the development of an interest in science (Shapiro, 1994). Cognitive gains may also depend on ensuring that the affective aspects are considered.

It is not, of course, being argued that topics such as photosynthesis, the cell, energy conservation and the particle model should not be taught just because they do not appear in the children's self-generated questions. Nor is it being assumed that interest in a topic is the same as being willing to make the intellectual commitment required to understand it scientifically, although it is obvious that children's questions can be used by a skilful teacher to promote a wider scientific understanding than that required simply to answer the question. However, a fundamental issue remains. In what sense or senses is a curriculum 'relevant' if there is a marked difference between what school science offers and the topics that seem to interest children? According to Rudduck and Flutter (2000), the concept of 'relevance' has traditionally been defined in reference to an adult's, rather than a pupil's, view. If relevance is refocused in response to this pupil-centred view, then it becomes possible to inject a hitherto ignored element into debates about the form and content of school science education, to respond more explicitly to gender or other significant differences (Osborne & Collins, 2001) and to identify contexts in which scientific concepts are more, rather than less, likely to be presented successfully. For example, the current data present a gloomy, if not unfamiliar, picture of children's spontaneous interest in chemistry and physics as expressed by their self-generated questions, especially among girls. The same data suggest that it may be worth exploring the teaching of a number of topics drawn from physics and chemistry in the context of space science or with reference to their technological applications. Likewise, while questions about the nature of science and epistemological questions (classified as evidence and methodology type of requested information) were fairly rare, the relevant issues may be more successfully addressed in the context of inventions and patents, a field of interest that drew mainly applicative questions from the children.

Informal science education

Finally, it is important to acknowledge that school science does not hold a monopoly on the dissemination of scientific knowledge. When non-scientists are looking for scientific information, they usually turn to the mass media (Friedman, 1986). Seven out of 10 French students stated that they gained most of their scientific knowledge from watching television (Delacote, 1987). Also, on the other side of the Atlantic, most American adults learn about the latest developments in science and technology primarily from watching television (National Science Foundation, 2002). When formal education in science ends, the media are the most readily available and sometimes the only source of information about science (Nisbet et al., 2002). Too often, however, programmes reflect a lack of interest in the audience and its needs. 'What questions would most people really like to have answered about science?' asks LaFollette, adding that 'We know little about which facts the audience is interested in' (LaFollette, 1992). Crane (1992) similarly points to the need to examine the public's understanding of science from the perspective of the audience. The results of the present study might be used, therefore, to inform the producers and editors of popular science and educational programmes.

Acknowledgements

Much of the work on this paper was carried out by Ayelet Baram-Tsabari as a Marie Curie Fellow at the University of Leeds, UK. The authors wish to express their gratitude to Professor Edgar Jenkins and Dr Jim Ryder (CSSME, School of Education, Leeds University) for their priceless reviews and valuable comments upon the early drafts of this paper.

Note

1. Unless otherwise indicated, a two-tailed Pearson chi-square test was used to calculate probabilities. Very small groups with expected counts of less than 5 were removed from the analysis. Because of the high number of subcategories, the results represent many times an aggregation of small and similar subcategories. When several series containing a different number of questions are presented on the same scale, the relative number of questions is used in the interest of clarity and comparison. Not all the inquirers provided their full details; therefore, sample sizes differ from graph to graph and are indicated by the '*n*' values.

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Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (2006). Using questions sent to an Ask-A-Scientist site to identify children's interests in science. Science Education, 90(6), 1050-1072.

Using Questions Sent to an Ask-A-Scientist Site to Identify Children's Interests in Science

AYELET BARAM-TSABARI
Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel

RICKY J. SETHI
Department of Computer Science and Engineering, University of California, Riverside, CA 91801, USA

LYNN BRY
Department of Pathology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02115, USA

ANAT YARDEN
Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel

Received 5 December 2005; revised 26 March 2006; accepted 28 April 2006

DOI 10.1002/sce.20163
Published online 20 July 2006 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Interest is a powerful motivator; nonetheless, science educators often lack the necessary information to make use of the power of student-specific interests in the reform process of science curricula. This study suggests a novel methodology, which might be helpful in identifying such interests—using children's self-generated questions as an indication of their scientific interests. In this research, children's interests were measured by analyzing 1555 science-related questions submitted to an international Ask-A-Scientist Internet site. The analysis indicated that the popularity of certain topics varies with age and gender. Significant differences were found between children's spontaneous (intrinsically motivated) and school-related (extrinsically motivated) interests. Surprisingly, girls contributed most of the questions to the sample; however, the number of American girls dropped upon entering senior high school. We also found significant differences between girls' and boys' interests, with girls generally preferring biological topics. The two genders kept to their stereotypic fields of interest, in both their school-related and spontaneous questions. Children's science interests, as inferred from questions to Web sites, could ultimately inform classroom science teaching. This methodology extends the context in which children's interests can be investigated. © 2006 Wiley Periodicals, Inc. *Sci Ed* 90:1050–1072, 2006

Correspondence to: Anat Yarden; e-mail: anat.yarden@weizmann.ac.il

THEORETICAL FRAMEWORK

The Glenn report *Before It's Too Late* (The National Commission on Mathematics and Science Teaching for the 21st Century, 2000) states that "we are failing to capture the interest of youth for scientific and mathematical ideas." Indeed, many students find standard science curricula largely out of touch with their personal interests, a factor which contributes to the low number of students pursuing advanced science and mathematics courses in high school, and going on to choose scientific careers (Millar & Osborne, 1998). Adolescents' decisions about the contents and directions of their educational training have been found to be influenced to a high degree by the topic-related interests they developed in the preceding years (Krapp, 2000).

Organizations, including the National Research Council (1996) and the American Association for the Advancement of Science (1993), have proposed that science curricula taught at a secondary-school level should provide a common basis of knowledge while addressing the particular needs and interests of students. However, educators lack the necessary information and tools to guide modifications that could make use of the power of student-specific interests in improving those students' individualized learning and competency in scientific subjects.

The issue of students' interests may also be viewed in the context of the pupil's voice in the education movement (Burke & Grosvenor, 2003; Economic and Social Research Council, 2004; Mirta, 2004; Whitehead & Clough, 2004). Until recently, the pupil's voice had been marginalized or neglected by educational researchers. The student was regarded as an object of study but not as someone who could make an informed judgment on what should be taught in school science courses (Jenkins & Nelson, 2005). Lloyd-Smith and Tarr (2000) have called for the educational system, as frontline providers for children, to model, for other professionals, a real process of acknowledging and valuing young people's views and opinions. Similarly, Rudduck and Flutter (2000) regard it as strange that, in a climate that privileges the consumer, pupils in school have not been considered consumers worth consulting.

Interest is a powerful motivator (Deci, 1992), which differs from most other motivational concepts by its content specificity (Krapp, 2002). Interest refers to a differential likelihood of investing energy in one set of stimuli rather than another (Csikszentmihalyi & Hermanson, 1995). Research indicates positive relationships between individual interest and a wide range of indicators of learning (Pintrich & Schunk, 2002; Schiefele, 1998). However, the potential benefits of interest have been largely ignored in school reform: students rarely learn out of interest, and they usually lose interest during learning (Prenzel, 1998), with the consequence that bored and unengaged students are also less likely to learn (Blumenfeld et al., 1991).

A number of studies have explored students' scientific interests by inviting them to respond to questionnaires (Dawson, 2000; Qualter, 1993; Sjøberg, 2000; Sjøberg & Schreiner, 2002; Stark & Gray, 1999), participate in focus groups (Osborne & Collins, 2000, 2001), or respond to a student-led review of the science curriculum (Murray & Reiss, 2005). These techniques have identified age-, gender-, and subject-specific issues impacting students' general interests in specific subjects, including a significant decline in interest in physics, chemistry, and mathematics that occurs as the students' progress in grade level. This decline is particularly evident as students enter high school, and is especially pronounced for girls (Krapp, 2002).

The gender-related aspects of the interest theory for science education are that boys in general have greater interest in science than girls (Gardner, 1975 1998), and while physics proves significantly less interesting to girls than to boys, biology is of greater interest to girls (Dawson, 2000; Friedler & Tamir, 1990; Jones, Howe, & Rua, 2000; Sjøberg, 2000; Stark & Gray, 1999; Zohar, 2003). Within the field of biology, high school girls were shown to display greater interest in human biology than boys, in both Israel (Tamir & Gardner, 1989) and England (Taber, 1991). The relevance of science education (ROSE) studies conducted in England and Denmark found that girls' interest was focused on health, medicine, and the body, whereas boys wished to learn more about the dramatic aspects of physics and chemistry, and how technology works (Busch, 2005; Jenkins & Nelson, 2005). Moreover, subject-matter related interests have a greater influence on boys' grades than girls' (Schiefele, Krapp, & Winteler, 1992).

The questionnaire-based methods usually used to explore students' scientific interests have traditionally relied on adult-centric views of what subjects should be meaningful for students. To overcome this inherent bias, we developed a naturalistic approach to defining students' specific concerns by using children's self-generated questions as an indication of their scientific interests.

Posing questions is an important part of scientific inquiry (National Research Council, 1996). Self-generated questions can help reveal the asker's reasoning, alternative views, and interests (Biddulph, Symington, & Osborne, 1986). Studying students' questions can give teachers an awareness of what students are interested in and what they want to know about a given topic (Chin & Chia, 2004).

The best known and most often used way of classifying students' questions according to their cognitive level is the hierarchical Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956), which suggests classifying questions into low-order (knowledge, comprehension, application) and high-order (analysis, synthesis, evaluation) questions. A simpler evaluation involves distinguishing among input questions—those which require recalling knowledge, processing questions—which require linking pieces of information, and output questions—which require hypothesizing, generalizing, and criticizing (Shepardson & Pizzini, 1991). Graesser, Person, and Huber (1992) proposed analyzing a question according to the hierarchical content of the information requested, with deep-reasoning questions being highly correlated with the deeper levels of cognition in Bloom's taxonomy. Marbach-Ad and Sokolove (2000) classified students' questions into eight categories, the highest one being a research hypothesis. Another taxonomy of questions distinguishes between "confirmation questions," and the higher quality "transformation questions," which signal the restructuring or reorganization of students' understanding (Pedrosa de Jesus, Teixeira-Dias, & Watts, 2003).

Students rarely ask questions in the classroom, and when they do, only a very small subset of their questions evidence genuine intellectual curiosity (Dillon, 1988; Graesser & Person, 1994; Marbach-Ad & Sokolove, 2000; Pedrosa de Jesus et al., 2003; Rop, 2003; White & Gunstone, 1992). The overall paucity of student questioning is attributed to the classroom atmosphere, where revealing a misunderstanding renders the student vulnerable, open to embarrassment, censure or ridicule (Pedrosa de Jesus et al., 2003). Students described their teachers' response to their questions as "put-offish" or even annoyed, and their classmates' reactions as intolerant (Rop, 2003).

Learners usually ask questions where they feel secure (Watts, Gould, & Alsop, 1997). We therefore looked for self-generated questions in free-choice science-learning environments. Examining free-choice science-learning environments can provide knowledge about the natural setting in which people learn in a self-directed, self-motivated, voluntary way, guided by individual needs and interests (Falk & Dierking, 2002), and has much to offer to formal education (Walter & Westbrook, 2001). An example of such a free-choice setting is the Web, which can be seen as a site for student inquiry in science, which allows students to pursue questions of personal interest (Wallace, Kupperman, Krajcik, & Soloway, 2000).

Research on children's use of the World Wide Web for learning has generally been conducted in school settings. In the fall of 2003, nearly all of the public schools in the

United States had access to the Internet (National Center for Education Statistics, 2005). Students reported regularly accessing science sites to get help with school assignments (Weigold & Treise, 2004). Nevertheless, although they exhibit positive attitudes and self-confidence (Fidel et al., 1999; Lumpe & Bulter, 2002; Watson, 2004), children have difficulty formulating and modifying search queries (Bilal, 2004; Hirsh, 1999; MaKinster, Beghetto, & Plucker, 2002; Wallace et al., 2000). Furthermore, children do not tend to question the accuracy of the information they find on the Web (Hirsh, 1999; Schacter, Chung, & Dorr, 1998; Wallace et al., 2000).

Students using the Web are often overwhelmed by the amount of information available (MaKinster et al., 2002). An effective search is also an exercise in inquiry and critical thinking (Brem & Boyes, 2000). Most students fail to construct an accurate and broad understanding following an online inquiry (Hoffman & Krajcik, 1999). However, a deficiency in students' skills is not always to blame: Keating, MaKinster, Mills, and Nowak (1999) found that only 30% of the search results they received actually contained at least a short operational definition or graphic display of the science concept they were searching for, and many of the sites contained misconceptions.

Sometimes, when children are trying to find complex answers on the Web, they need people who have the answers, rather than a list of directories or sites. These human-mediated question-and-answer services are sometimes referred to as "Ask-A" services, such as "Ask a Scientist" (Lankes, 1999) or "Expert Services" (Janes, Hill, & Rolfe, 2001). These digital reference services allow one to send questions that interrogate a collective cranium of experts versed in a variety of disciplines (Parslow & Wood, 1998). They are oriented to matching the asker with people having the expertise to answer his/her questions, not just to matching an information need to a textual source with the information (White, 1999). The mode of communication is asynchronous electronic communication. Usually, such sites maintain searchable public archives in which previously answered questions are returned as search results, thus making this archive a resource for their users (Pomerantz, Nicholson, Belanger, & Lankes, 2004).

In this research, we used children's questions asked under free-choice conditions to identify their scientific interests. Using a similar methodology, we were previously able to characterize Israeli students' interests in science and technology (Baram-Tsabari & Yarden, 2005). The ability to identify students' interests in science may play an important role in improving existing curricula to meet their needs. This study aims to assist science educators, teachers, and curriculum developers in identifying such student interests using a novel methodology.

METHODOLOGY

Data Source

MadSci Network is an independent, award-winning, nonprofit organization operating from a server in Boston (http://www.madsci.org). Unlike most Ask-A-Scientist services (see further on), MadSci Network covers all branches of science, and does not focus on a specific subject area. It collects as much, and potentially more information than most Ask-A-Scientist services, and stores key demographic information as meta-data, making it easier to mine the information from the archives. The MadSci Network receives 90–150 questions daily, which are answered by nearly 800 scientists.

Many other English-language Ask-A-Scientist services are available on the Net, but none were found suitable for our research. The services run by Scientific American[1] and

[1] http://www.sciam.com/page.cfm?section=expertform

the Internet Public Library,[2] for instance, do not ask for the age of the questioner. The paid service Google Answer[3] does not have any information about the askers. The Argonne National Labs[4] Ask-A-Scientist service records geographical information only about Americans, while Ask Dr. Universe[5] is aimed mostly at elementary-school children. Many other services only answer questions on a specific topic. The service run by Howard Hughes Medical Institute,[6] for example, receives only biology questions, while Ask Dr. Math,[7] obviously, deals with math questions.

The Sample

Questions submitted to the MadSci Network by 4th- through 12th-grade students from August to October 2004 were collected, resulting in a sample number of 1555. For each entry, information was recorded about the question, age group, first name, and country of origin of the asker. Questions automatically answered by the archives search engine were not included, since the system did not record them. Questions asked by populations other than 4th- through 12th-grade students were also excluded.

More than 94% of the contributors originated from English-speaking countries, most of them from the United States (71.7%), Australia and New Zealand (7.2%), Canada (6.1%), and the United Kingdom (4.6%). We assume that this bias reflects the number of people with Internet access and fluency in English, as well as the English-based nature of the MadSci Network, rather than a more pronounced interest in science. Half of the contributors were high school students, 39% were in junior high school, and the remaining 11% were 4th- to 6th-graders. The first name was used to determine the asker's gender, using an English name gender finder (Na-Demo-Ya, 2002). In this manner, we were able to identify 1167 of the contributors, who were divided into 56.4% female and 43.6% male. The age and gender split differed between countries, with the United States being characterized by more young and more female contributors relative to other countries.

Classifying the Questions

The questions were classified with reference to several coding schemes.

Field of Interest. The most straightforward classification was field of interest. In this coding scheme, questions were placed in one of the following categories: "biology," "physics," "chemistry," "earth sciences," "astrophysics," "technology," "nature of science inquiry (NOS)," and "mathematics." "Technology" questions were categorized by defining technology as the development, production, and maintenance of objects in a social context, as well as the objects themselves (Gardner, Penna, & Brass, 1996). NOS questions asked about how scientists develop and use scientific knowledge (Ryder, Leach, & Driver, 1999) without reference to a specific scientific context.

The categories were further divided into 58 subcategories (for the full list, see Appendix). Using this scheme, only 22 questions failed to fit any category, and were designated "undistinguished" (e.g., "What is astrology and how do horoscopes influence people's lives?").

[2] http://www.ipl.org/div/askus/
[3] http://www.answer.google.com/answers/
[4] http://www.newton.dep.anl.gov/archive.htm
[5] http://www.wsu.edu/DrUniverse/
[6] http://www.hhmi.org/askascientist/
[7] http://mathforum.org/dr.math/ask/submit.html

For examples of the application of the categories and subcategories in this coding scheme, see Table 1.

Many of the questions in the field of biology were embedded in the context of human biology or the zoology of nonhumans, e.g., "Is our inability to synthesize vitamin C an inborn error of metabolism?" (10th–12th grade, female, UK), "Do dogs have a dominant paw that they prefer to use?" (7th–9th grade, female, US). These questions were classified as portraying a "human" and "zoology" interest, respectively.

Spontaneous Versus School-Related Motivation for Raising the Question. Gross (2001) makes a distinction between questions that are self-generated (internally motivated by personal context) and those that are imposed (thought up by one person, such as a teacher, and then given to someone else, such as a student, to resolve). Intrinsic motivation refers to doing something because it is inherently interesting or enjoyable. Extrinsic motivation refers to doing something because it leads to a separable outcome (Ryan & Deci, 2000) as a means to an end (such as praise or avoiding punishment) (Vallerand et al., 1992). In school, intrinsic motivation becomes weaker with each advancing grade (Ryan & Deci, 2000). Most learning in school is extrinsically motivated, and the acquisition of knowledge is rarely enjoyed for its own sake (Csikszentmihalyi & Hermanson, 1995).

Although all of the questions in our sample were generated by students, not all of them were the outcome of an intrinsic motivation to know. Many of the questions were required for school assignments and were originally raised by teachers or textbooks. To differentiate between the two types of motivation for raising the question, we classified the questions as either "spontaneous," which can serve as an indication of intrinsic motivation to know, or "school related," which can serve as an indication of an extrinsic motivation for seeking an answer.

Questions were classified as school related only if it was explicitly stated in the question that the information is required for a school assignment, such as a science fair project, report, and homework. All other questions were classified as spontaneous. For examples of the application of the categories in this coding scheme, see Table 1.

Cognitive Level of the Question. Two classification methods to hierarchically describe the cognitive level of the questions were used here: order of information requested and type of information requested (see further on).

Many schemes were suggested for classifying the cognitive level of students' questions, but they did not fit the nontraditional sample used in this research, because they are only suitable for questions asked in the context of a textbook (Shepardson & Pizzini, 1991), a discourse (Graesser et al., 1992), or a classroom setting where questions are categorized with respect to the task at hand (Marbach-Ad & Sokolove, 2000; Pedrosa de Jesus et al., 2003). This was also the reason that we could not use Bloom's taxonomy (Bloom et al., 1956)—if a student has previously encountered a question similar to the one he or she is asking, then a higher order question may turn into a lower order question (Dori & Herscovitz, 1999). Our sample includes specific, stand-alone questions generated by knowledge-deficient mechanisms. This was also the reason we could not use the Scardamalia and Bereiter (1992) classification of basic information or wonderment questions. In our case, all of the spontaneous questions were wonderment questions.

Order of the Requested Information. A modified typology, based on one defined by Dillon (1984), was used to classify questions according to a gradual increase in the cognitive level required to answer them (Brill & Yarden, 2003): (1) "Properties"—answers to

TABLE 1
Examples of Questions Classified According to Spontaneous vs. School-Related Motivation for Raising the Question and to Field of Interest

Motivation[a]	Field of Interest[b]	Example (Class, Gender, Country of Origin)[c]
Spontaneous	Physics: Modern physics	Hand-held dynamo particle accelerator: could an accelerator like this be built easily? I think I would like to play with my own electron beam. (10–12, m, US)
Spontaneous	Chemistry: Thermodynamics	When you boil water and you put in macaroni, why does it stop boiling? (4–6, US)
Spontaneous	Nature of science	Is biology an actual science? Why? (10–12, f, UK)
Spontaneous	Earth sciences: Environment	What makes dust in the air? I'm just curious because I see so much dust in my room, I was wondering where it came from. (10–12)
Spontaneous	Astrophysics	Does a black hole lead to another galaxy? (7–9, US)
School related	Biology: Botany	I need help on a science fair. I need to know if talking to your plant has an effect on its growth.
School related	Physics: Mechanics	Will an egg float higher in Salt Water, Sugar Water or, Normal Water? This is an experiment I am performing for school. Please email me ASAP (4–6, m, US)

[a]Questions were assigned to the "school-related" category only if they explicitly referred to a school assignment, such as a science fair project, report, homework. All other questions were classified as spontaneous. Note that some school-related questions may have been mistakenly assigned to the spontaneous category.
[b]The first word represents the category (out of eight total) and the second, the subcategory (out of 58 total).
[c]Numbers represent grade level, f = female, m = male, US = United States, UK = United Kingdom. Some questions do not contain all the background variables.

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 outlined in the question; and (3) "causal relationships"—answering questions in this category requires finding the relation, correlation, conditionality, or causality of the subjects in question. Usually, questions from the properties category refer to one variable, whereas questions from the comparisons and causal relationships categories refer to at least two variables. For examples of the application of the categories in this coding scheme, see Table 2.

Type of Information Requested. A typology influenced by Bloom's taxonomy (Bloom et al., 1956) and Bybee's classification for research questions (Biological Sciences Curriculum Study, 1993) was developed. The typology describes the nature of the question, and the knowledge it generates, along a gradually increasing cognitive-level continuum. The lowest category, "general request for information," includes questions that did not ask for specific answers but for information in general. The second category consists of requests for "factual" information. The third category consists of requests for "explanatory" information, with basically "why" and "how" questions. The fourth category, consisting of questions asking for "methodological" information, has to do with scientific ways of finding things out and with scientific and technological procedures. The highest categories were "predictions"—cases in which the asker described an experiment and asked what the results would be, and requests for "open-ended" type of information dealt with opinions, controversial themes, and futuristic questions that science cannot answer for the time being. For examples of the application of the categories in this coding scheme, see Table 2.

Reliability

Classification and categorization of 150 of the questions used in this study were performed independently by two researchers. The concordance of classification between researchers ranged from 84% to 98% for the different coding schemes. To test for internal consistency of the data, a modified split-half test was performed: random halves of the data (odd and even observations) were compared. A consistency was found in the distribution of all variables between the two halves.

Statistical Analysis

Unless otherwise indicated, a two-tailed Pearson chi-square test was used to calculate probabilities. Not all the inquirers provided their full details; therefore, sample sizes differ from graph to graph and are indicated by n values. Post-hoc multiple comparisons in sample proportions and Goodman's simultaneous confidence-interval procedure (Marascuilo & McSweeney, 1977) were used to find significant differences within proportions after the chi-square test.

RESULTS

To characterize children's interests in science, their self-generated questions were collected from a Web-based Ask-A-Scientist service.[8] The questions were analyzed with reference to four different coding schemes: field of interest, spontaneous versus school-related motivation for raising the question, and type and order of information requested. We also

[8] http://www.madsci.org

TABLE 2 Examples of Questions Classified According to Order and Type of Information Requested

Order[a]	Type[b]	Example[c]
Properties	Factual	How much, approximately, does an ant weigh? (4–6, f, US)
Properties	Open ended	What is mind? Does every living being have a mind? (4–6, Oman)
Properties	General request for information	Have there been any new discoveries on Mars recently? I'm just interested in Mars and I just wanted to know what is going on that planet!! (10–12, US)
Comparisons	Factual	What is the difference between Shooting stars and regular stars? (4–6, f, US)
Comparisons	Methodological	The way I know, I think there are relations between blood types to personalities of people. I would like to know more about this subject, but since most of the people do not know their blood types, how could I tell the relation? (10–12, m, US)
Causal relationships	Prediction	Will my moving of things outside the tank (i.e. furniture) have as great of an effect on the fish as rearranging gravel? (7–9, f, US)
Causal relationships	Factual	If a girl straightens her hair every day what will happen to her hair? Will it affect hair follicles? (7–9)
Causal relationships	Explanatory	How does the size of a balloon affect how loud it pops? (7–9)

[a]Order of information requested was classified into properties, comparisons, or causal relationships, as detailed in the Methodology section.
[b]Type of information requested was classified into requests for information, "factual," "explanatory," "methodological," "predictions," and "open ended," as detailed in the Methodology section.
[c]Numbers represent grade level, f = female, m = male, US = United States, UK = United Kingdom. Some questions do not contain all the background variables.

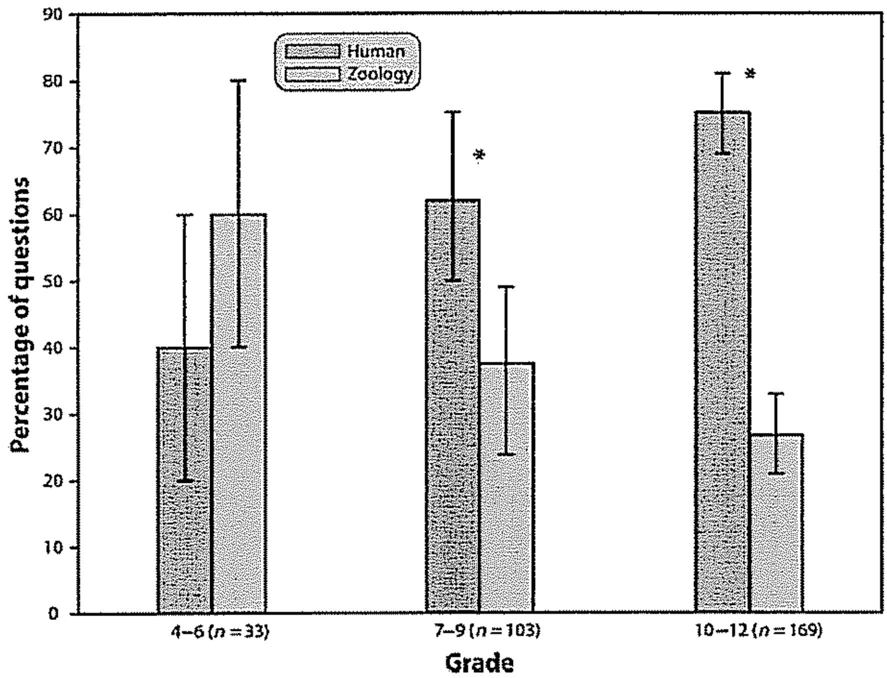

Figure 1. Percentage of zoology and human biology questions among three age groups. Overall differences were found to be significant at $p < 0.0005$. Significant differences of $p < 0.05$ between the relative number of zoology and human biology questions are marked with an asterisk.

considered the relationship between the four different schemes and the available background knowledge about the children who sent the questions.

Field of Interest

In a basic breakdown of the questions ($n = 1555$) analyzed by field of interest, biology proved more popular than the other sciences, and was the focus of 44% of the questions. This popularity reflects findings from previous studies (Murray & Reiss, 2005; Qualter, 1993). Biology was followed by chemistry (21.9%), physics (12.9%), technology (7.5%), earth sciences (5.9%), astrophysics (5%), NOS (1.1%), and mathematics[9] (0.5%), while 1.4% of the questions could not be classified into a scientific field of interest. The subcategories of each field of interest are detailed in the Appendix, in their order of popularity.

Many of the questions in the field of biology were embedded in the context of either human biology or zoology. Our analysis indicated that the relative frequency of zoology questions decreased with age, as the proportion of questions relating to human biology increased ($\chi^2 = 15.4$, $p < 0.0005$) (Figure 1). The interest of high school students in human biology is well attested to by a number of studies, including research done in England (Osborne & Collins, 2001) and Israel (Tamir & Gardner, 1989). The increased interest in human biology with age might be explained by the approach of puberty in this age group. A similar increase in interest with age has been noted among the spontaneous questions of Israeli elementary and junior high school students (Baram-Tsabari & Yarden, 2005).

[9] MadSci Network is an educational science site, and does not encourage math questions.

Spontaneous Versus School-Related Motivation for Raising the Question

Children asked more school-related questions as they got older: 10%, 33%, and 57% of the questions were school related for elementary, junior high and senior high schools, respectively. The same trend was found in school libraries, where students placed less spontaneous queries with age (Gross, 2001).

The spontaneous scientific interests of children were found to be different from their school-related questions (Figures 2 and 3). In all age groups, astrophysics was more prevalent among children's spontaneous questions ($p < 0.01$) (Figure 2). This interest in space science mirrors existing literature about students' interests (Osborne & Collins, 2001; Sjøberg, 2000). Chemistry, on the other hand, was far more prevalent among children's school-related questions than spontaneous ones ($p < 0.01$) (Figure 2). Biology was the most popular subject, among both spontaneous and school-related questions.

The major fields of interest do not reveal the whole picture. When studying interest, the devil is in the little details. Therefore, we compared students' spontaneous versus school-related interest in the different subcategories (Figure 3). Biology, which dominated the same percentage of questions in both groups, revealed much more diversity when broken down into topics. When analyzing biological questions in topics that appeared more frequently (as detailed above), we realized that "anatomy and physiology," "sickness and medicine," and "genetics and reproduction" were all characterized by relatively more spontaneous than school-related questions. At the other end of the spectrum, "botany and mycology," "microbiology and virology," and "cell biology" yielded many more teacher- and textbook-generated questions than spontaneous ones. "Ecology" and "neurology and the mind" were almost equally distributed among both types of questions and generated a relatively high number of them.

A similar analysis conducted on the chemistry questions revealed that the most popular subcategories (e.g., "bonding and structure") were all school related. All of the astrophysics topics, on the other hand, were mostly spontaneous. Among earth science and technology topics, there were no major gaps between the number of school-related and spontaneous questions. Physics subcategories, however, appeared at both ends of the scale. "Mechanics" provoked more school-related questions than spontaneous ones, whereas "electricity and magnetism," "modern physics," and "light–heat–sound" were the source of authentic childish interest, yielding spontaneous questions.

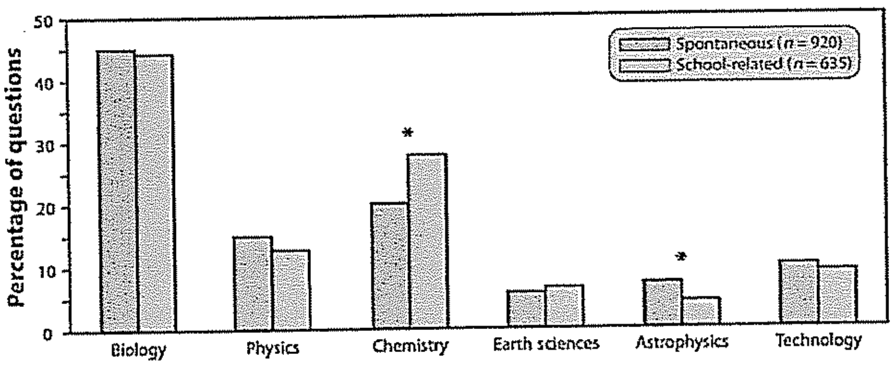

Figure 2. Students' spontaneous vs. school-related scientific interests: an overview. Students' questions were classified according to their field of interest. Percentage is calculated out of the total spontaneous ($n = 920$) or school-related ($n = 635$) questions. Undistinguished ($n = 22$), nature of science ($n = 17$), and math ($n = 7$) questions are not shown due to their relatively small number. A significance of $p < 0.01$ is marked with an asterisk.

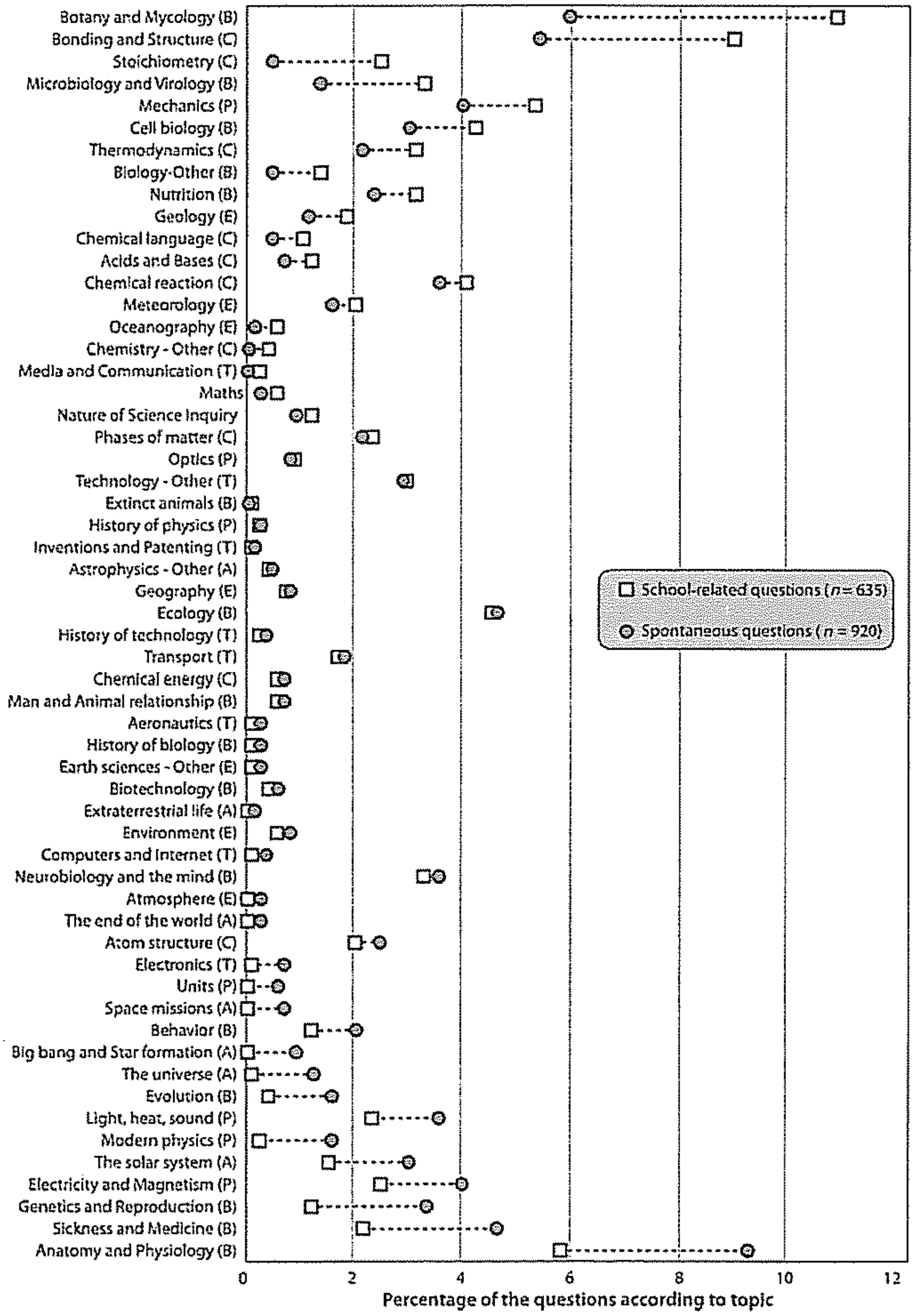

Figure 3. Students' spontaneous vs. school-related scientific interests in specific topics. Students' questions were classified into one of 58 subcategories, according to their field of interest (see Appendix). Percentage is calculated out of the total spontaneous ($n = 920$) or school-related ($n = 635$) questions. Undistinguished ($n = 22$) questions are not included. The subcategories are listed according to the gap between the number of spontaneous and school-related questions. B: biology; C: chemistry; P: physics; E: earth sciences; A: astrophysics; T: technology.

Cognitive Level of the Questions

We subsequently analyzed the cognitive level of the questions submitted to the MadSci Network. The questions studied here were found to present higher order of requests for information than reported in the literature, using two separate classification schemes. Among the 920 spontaneous questions, 77% asked properties type of questions that mentioned only a single variable, whereas the remainder asked for comparisons or causal relationships between two variables, i.e., inquiries of a higher cognitive level. The order of information requested increased with age, as students in secondary school raised more comparison and causal relationship questions (25.3% among 7th–9th graders, 23.6% among 10th–12th graders) compared to elementary school students (13.8%). In contrast, studies in high school biology classes have found that fewer than 6% of the students' questions deal with more than one variable (Brill & Yarden, 2003).

Moreover, among the 920 spontaneous questions, only 54% were general requests for information and questions of the factual type, 35.6% were explanatory, and 5.3% were methodological. Predictions and open-ended questions made up the remaining 5.1%. This picture of children's questions is far more encouraging than the one portrayed by studies conducted within science classes, which report that only 14% of the questions reflect curiosity, puzzlement, skepticism, or speculation, while all the rest are simple factual or procedural questions (Chin, Brown, & Bruce, 2002). These desirable traits characterized all of the spontaneous questions studied here.

Gender-Related Findings

Gender Split. Surprisingly, girls asked most of the questions in this study (56.4% overall). This female dominance was apparent in questions sent from the United States, Canada, and the United Kingdom, but not in those from other countries surveyed in this research. This female majority contradicts previous female-to-male ratios obtained from a scientific Internet site based in Italy (Falchetti, Caravita, & Sperduti, 2003), a UK-based science line (K. Mathieson, personal communication, April 2, 2004), and science and technology questions at an Israeli Web site (Baram-Tsabari & Yarden, 2005). Furthermore, females were previously shown to be less likely than males to use media that foster informal learning about science (National Science Foundation, 2000; Nisbet et al., 2002), and to take part in extracurricular science experiences (Greenfield, 1998). It was found that although boys have more formal and out-of-school experience using computers and the World Wide Web (Kafai & Sutton, 1999; Shashaani, 1994), more girls preferred this type of learning over traditional classroom-based science learning (Leong & Al-Hawamdeh, 1999).

Nevertheless, a significant decrease ($p < 0.05$) in the number of American girls submitting science questions occurred during the transition from junior to senior high school (Figure 4). This finding mirrors previous research in which American girls' attitude to science was found to become increasingly negative with age (Kahle & Lakes, 1983), as well as studies carried out in Israel (Friedler & Tamir, 1990; Shemesh, 1990).

Fields of Interest. Consistent with previous studies (Dawson, 2000; Friedler & Tamir, 1990; Jones et al., 2000; Sjøberg, 2000; Stark & Gray, 1999; Zohar, 2003), the girls in our sample found physics to be significantly less interesting than the boys ($p < 0.05$), whereas biology was of greater interest to girls than boys ($p < 0.025$). This polarized trend was apparent in both school-related and spontaneous questions, suggesting that girls and boys follow certain content-related stereotypic interests in both school and self-guided activities with respect to science education.

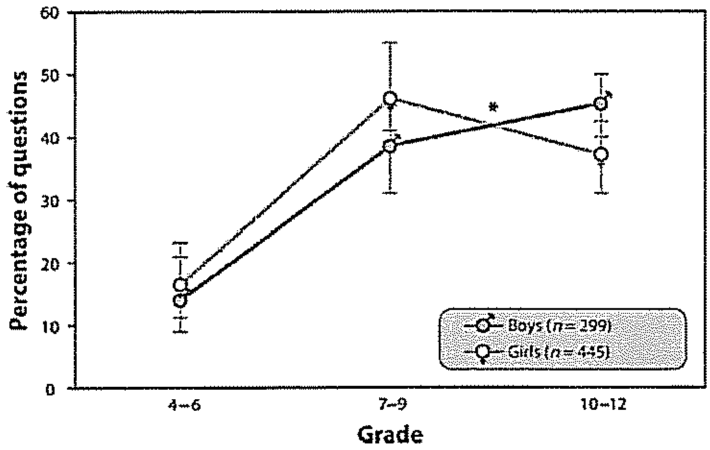

Figure 4. Percentage of American boys' and girls' questions among three age groups. The overall differences between the proportions of boys and girls in the different age groups are significant at $p < 0.05$. The different trends of girls' and boys' questioning behavior among the 7–9th and 10–12th grade groups are the reason for this significance according to a post-hoc test. The relative drop in the girls' number from the 7–9th to 10–12th grade groups was found to be significant at $p < 0.05$ and is marked with an asterisk.

To refine our analysis, we compared girls' and boys' interests in the various subcategories of the fields of interest (Figure 5). The girls' preference for a biological context was apparent: among their top ten topics, eight belonged to the biological field of interest, one to chemistry, and one to astrophysics. Boys, on the other hand, had more diverse interests, with their top ten made up of four physics, two technology, two biology, one chemistry, and one astrophysics topic. This list of gender-related learning interests fits well with known stereotypic preferences for specific topics (Busch, 2005; Jenkins & Nelson, 2005; Jones et al., 2000; Sjøberg, 2000; Stark & Gray, 1999; Taber, 1991).

Spontaneous Versus School-Related Motivation for Raising a Question. Girls asked many more school-related questions than boys: 45.7% of the girls' questions were school related, compared with 36.5% of the boys. This trend might be explained by Simpson and Oliver's (1985) findings that American 6th- to 10th-grade females are significantly more motivated than boys to attain high achievements in science, although exhibiting less positive attitudes toward it.

We found no gender-related difference in the type or order of information requested.

DISCUSSION

The purpose of this study was to investigate students' interests in science using their self-generated questions. We argue that there is considerable promise in using students' self-generated and primarily spontaneous questions to enhance the attractiveness and relevance of science curricula. The methodology used here may provide a rapid and consistently up-to-date way of assessing children's interests while avoiding adult-generated views. Some limitations of this methodology are discussed further on.

Some of our results confirmed and reinforced what is already known about children's interests, using a different data source and methodology. However, this study provides new insights into topic-specific differences between spontaneous and school-related interests in science; the higher cognitive level of children's questions in this sample compared to

Figure 5. Boys' and girls' interest in various scientific topics. Students' questions were classified into one of 58 subcategories, according to their field of interest (see Appendix). Percentage is calculated out of the total girls' ($n = 635$) or boys' ($n = 509$) questions. Undistinguished ($n = 22$) questions are not included. The subcategories are listed according to the gap between the number of girls' and boys' generated questions. B: biology; C: chemistry; P: physics; E: earth sciences; A: astrophysics; T: technology.

classroom settings; the dominance of female participants in a free-choice science-learning setting, and the females' tendency to ask more school-related questions than boys; and finally, the persistence of girls' and boys' stereotypic interests among both the spontaneous and school-related questions. The significance of these new insights is discussed further on.

An important observation of this study is the recurring inconsistency between students' spontaneous (intrinsically motivated) and school-related (extrinsically motivated) interests. There is evidence that intrinsic motivation can promote learning and achievement better than extrinsic motivation (Pintrich & Schunk, 2002). Therefore, it might prove pedagogically beneficial to respond to children's interests by incorporating into school science, topics which are of spontaneous interest to children, such as "the solar system," "modern physics," "evolution," and "the universe," which are currently underrepresented in many science curricula.

Our findings suggest that students can raise questions reflecting a high cognitive level on their own, but may feel less comfortable or encouraged to do so during science class. Another interpretation is that students may have more time to reflect and compose their questions in an online setting than during science class. It should be borne in mind, however, that the student population submitting questions to the MadSci Network may have a higher level of motivation to seek sources outside the classroom for science learning, thus providing a potential bias in our analyses.

The female dominance found among the MadSci responders suggests that online science education Web sites provide an attractive science-learning environment for girls. It is possible that the varying data between different countries highlight a dynamically changing landscape as girls gradually gain more access to the Internet and acquire the skills needed to use it to satisfy their scientific curiosity and obtain assistance with their science schoolwork. We anticipate that further investigation in this area will elucidate the benefits of online forums for science education in bringing equality to previously gender-biased areas of scientific interest. We cannot ignore, however, the sad fact that even in this seemingly attractive setting, the number of questions posed by American girls dropped upon their entering senior high school.

When basing new material on children's interests, it is important to pay attention to gender differences in preferences (Daiute, 1997). We found significant differences between girls' and boys' interests, with girls generally preferring biological topics. The two genders kept to their stereotypic fields of interest in both their school-related and spontaneous questions, hinting that the differences in interest described in the literature relating to school-science settings may also be relevant to free-choice settings.

However, there are also topics which appeal to both sexes, and arouse spontaneous interest as well. Therefore, it seems possible to teach scientific concepts and ideas in the context of topics which are not profoundly preferred by boys, but rather preferred by girls or equally attractive to both genders (Hoffmann & Haussler, 1998; Krapp, 2000; Sjøberg, 2000). Our study identified a few equally attractive topics, such as health issues, atom structure, and chemical bonding and structure, and a few science subjects which are very popular among girls, such as ecology, anatomy, botany, nutrition, and neurology. Using these topics as the context for science learning could prove beneficial in the process of mainstreaming science education.

Research Limitations

Although the study described here sheds some light on what interest children, caution is needed in identifying implications for school science education. The self-selecting sample used in this research does not represent all children. It represents a group of children that might be more interested in science and have more access to resources than the child population as a whole. Students who are not motivated to learn science are not represented in this self-selecting sample at all. Other children that may be very interested in science but do not send questions are also not represented. Therefore, the opportunistic nature of the sample places some limitations on the validity of our results.

Another setback of this research lies within the criteria for coding school-related questions. Since only questions that explicitly stated a school-related motivation for seeking an answer were coded as "school related," it is very likely that some school-related questions were mistakenly coded as spontaneous ones. As a consequence, the difference between school-related and spontaneous interests might be somewhat different than what is reported here. Furthermore, all of our findings are based on observations and their interpretation. For ethical reasons, we could not ask our subjects to explain their true intention in raising the question, their aim or their motivation. All of these were inferred from the wording of the written text generated by the child. We might have misunderstood the askers' meaning in some cases, a problem that might be partially addressed in the future by interviewing children who send science questions to Ask-A-Scientist sites.

Other problems are independent of our specific research design, but are intrinsic to the agenda of the pupil's voice movement. What role should the pupil's voice play in determining curriculum content? Should we teach children what they wish to know now, or what they ought to know in order to become scientifically oriented citizens in the future? And even if we pay attention to children's interests, how can one be interested in something one does not know exists? It is evident from examining Figure 3 that most popular school-related topics yielded a relatively high number of spontaneous questions as well. Some of these questions were probably school-related questions in disguise, but surely not all of them. These children's intrinsic motivation to know might have been evoked by their formal or informal science education.

Finally, we are faced with the big question of trying to implement results gathered in a free-choice science-learning setting into formal schooling. Once those topics become compulsory in the classroom, will not they lose their free-choice appeal? All of these setbacks need to be addressed in the process of using students' individual interests in science education.

Implications for Teachers

Although individual interests have a significant effect on learning, their use in educational settings may be problematic. Catering to the personal interests of individuals in the classroom might be an extremely time- and effort-consuming task, especially if the classes are large (Hidi & Anderson, 1992). However, a few steps have already been taken down the path of incorporating students' interests into the science classroom. Gallas (1995) used her students' questions to construct a curriculum which emerged from children's questions. But even this luxurious solution answered just a few of the children's questions, and in a very specific area. It is by no means obvious that it can be generalized to other areas of science education or indeed used to construct a national science curriculum.

Students' interests can provide a positive instruction tool within the standard science curriculum as well, since topics that fascinate children can be related to subject matter to provide a base for new knowledge. Daiute (1997, p. 329) instructs teachers on how to recognize and use those topics in the classroom:

> Children tend to explore such [fascinating] issues through the details of specific events rather than to state explicitly that they are interested in "justice," "life and death," or "identity," so we need to be astute listeners to the underlying themes of children's talk. When such topics

emerge as recurrent themes underlying children's conversations, it is the optimal time to explore such issues in relation to subject matter in your curriculum.

An expert teacher can use students' individual interests as opening points or triggers for the study of less popular subjects which are required by the curricula. There are also existing pedagogical tools that take into account student's interests, such as science fairs and project-based learning, which allow students to create their own research questions within a given topic (Ching, Kafai, & Marshall, 2000; Fallik, Eylon, & Rosenfeld, submitted).

Many of the Ask-A-Scientist sites have an archive, which usually presents a frequently asked questions (FAQs) section. Teachers may consider these repeated questions to be of general interest to children, and they can search the archive for children's questions on the subject they wish to teach, at the appropriate age level.

Another implication of this research would be to prompt science teachers to make more room for students' questions. Questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph et al., 1986; Scardamalia & Bereiter, 1992). Our results indicate that students are able to pose science questions in informal settings, and it would be educationally beneficial if they would use this ability in classrooms as well.

Implications for Curriculum Developers

Adults construct the curriculum based on their notions of what appeals and is important to children, but Seiler (2001) argues that standards-based curricula will continue to fail in urban settings of poverty because they have not included the voice of the students. We believe that not only students from low social classes can benefit from a more student-centered type of curriculum. If curriculum relevance is to have any meaning, it cannot exclude the views of the students themselves (Jenkins & Nelson, 2005). Therefore, more emphasis should be placed on what students wish and ask to know while constructing the curriculum which serves them.

This might be achieved by choosing preferable contexts for teaching scientific concepts and ideas. School level "cell biology," for example, can be taught using examples of organisms from all kingdoms. Our results indicate that using a human context may prove to be less of a turn off.

Implications for Interest Researchers

The methodology presented here may extend the context in which children's interests can be investigated. Children's science interests, as inferred from their questions to Web sites, could ultimately inform classroom science teaching. However, it seems that classifying the questions into 58 topics is not sufficient if we wish to use the power of students' interests in curriculum development. Subcategories such as "sickness and medicine" or "anatomy and physiology" might be too broad. We need to focus at a higher resolution, learning about students' interests in specific issues, species, illnesses, and technological breakthroughs in order to use them as "hooks" within the curriculum. This goal can only be achieved by using samples of tens of thousands, rather than thousands of questions. These data exist in the archives of many Ask-A-Scientist sites and can be used for such analyses, with the cooperation of the sites' operators. Such future cooperation between researchers and Ask-A-Scientist site operators could make the data gathered in them more valuable for interest research. For example, upon question submission, some questions might be added regarding the scientific basis for the question, its relation to school, and the motivation for raising it. These types of questions might also help the scientists who answer the questions.

This methodology can also be used to track the development and shift in interest in a specific field or topic, by using a few sites which cater to different age levels. Another option is to compare the science interests of children from different cultures, by using non-English language Ask-A-Scientist sites or by comparing questions from different countries in English-based sites, when this kind of data is available. Once a very large corpus of data is gathered from various databases, we believe that the power of clustering analysis can be used to unearth unexpected patterns of age, gender, and country-of-origin effects on the scientific interests, motivations, and cognitive levels of the questions. Finally, it is important to emphasize that all of the information regarding children's science interests can be used by informal science educators to make free-choice science-learning opportunities more engaging and attractive to children.

APPENDIX

Biology
- Botany and mycology
- Anatomy and physiology
- Ecology
- Sickness and medicine
- Cell biology
- Neurobiology and the mind
- Nutrition
- Genetics and reproduction
- Microbiology and virology
- Behavior
- Evolution
- Other
- Man and animal relationship
- Biotechnology
- History of biology
- Extinct animals

Physics
- Mechanics
- Electricity and magnetisms
- Light–heat–sound
- Modern physics
- Units
- History of physics

Chemistry
- Bonding and structure
- Chemical reaction
- Thermodynamics
- Atom structure
- Phases of matter
- Stoichiometry
- Acids and bases
- Chemical language
- Chemical energy
- Other

Earth Sciences
- Meteorology
- Geology
- Geography
- Environment
- Oceanography
- Other
- The end of the world
- Atmosphere

Astrophysics
- The solar system
- The universe
- Big bang and star formation
- Other
- Space missions
- Extra-terrestrial life

Nature of science inquiry

Technology
- Other technologies (low-tech)
- Transportation
- Optics
- Electronics
- History of technology
- Computers and Internet
- Aeronautics
- Inventions and patenting
- Media and communication

Math

Undistinguished

The authors would like to thank Mrs. Yetty Varon for her expert statistical advice, Mrs. Rakefet Halevi for her valuable help in the coding of the questions, Professor Edgar Jenkins, Dr. Gilat Brill, Mrs. Hadas Gelbart, the editor, and the three anonymous reviewers for their helpful comments on an earlier version of this manuscript.

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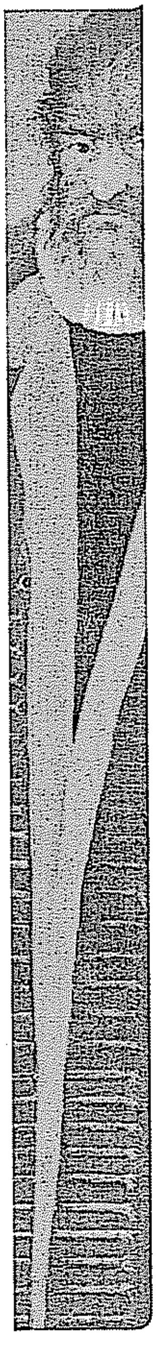
Baram-Tsabari, A., & Yarden, A. (2007). Interest in biology: A developmental shift characterized using self-generated questions. The American Biology Teacher, 69(9), 546-554.

ARTICLE

INTEREST IN BIOLOGY: A Developmental Shift Characterized Using Self-Generated Questions

Ayelet Baram-Tsabari Anat Yarden



Why Are We Interested in Interest?

Within the science-education community, much thought has been given to the question of "what people should know about science." In contrast, the question of "what people are interested in knowing about science" is rarely considered. Interest refers to a differential likelihood of investing energy in one set of stimuli rather than another (Csikszentmihalyi & Hermanson, 1995). It is a form of intrinsic motivation, which refers to doing something because it is inherently interesting or enjoyable (Ryan & Deci, 2000), in contrast to extrinsic motivation, which refers to doing something because it leads to a separable outcome such as praise or avoiding punishment (Vallerand et al., 1992). Interest is a powerful motivator (Deci, 1992), which differs from most other motivational concepts by its content specificity (Krapp, 2002). Although positive relationships have been reported between individual interest and a wide range of indicators of learning (Schiefele, 1998), the potential benefits of motivation for school reform have been largely ignored (Anderman, 1997).

The issue of students' interests may also be viewed in the context of the "pupil's voice in education" movement. Involving students in decisions about their life in school is viewed as a useful and pragmatic practice, as well as an important moral and educational principle (Davie & Galloway, 1996). However, until recently, the pupil's voice was marginalized or neglected by educational researchers. The student was regarded as an object of study but not as someone who could make an informed judgment on what should be taught in school science courses (Jenkins & Nelson, 2005). This is not only true for formal K-12 science education. Too often television science programs reflect a lack of interest in the audience and its needs. "What questions would most people really like to have answered about science?" asks LaFollette (1992), adding that "We know little about which facts the audience is interested in."

Jenkins (1999) examined the implications of "citizen science," i.e., science which relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday lives, for the form and content of school science education. He suggested constructing science curricula that enable young people to engage in science-related issues that are likely to be of interest and concern to them (Jenkins, 1999). This idea has also been present in the recommendations of several organizations, including the National Research Council (1996) and the American Association for the Advancement of Science (1993), which proposed that science curricula provide a common basis of knowledge while addressing the particular needs and interests of students. Therefore, the ability to identify students' interests in science plays an important role in improving existing curricula to meet their needs.

Compared to other science subjects, biology enjoys the most popularity among students (Qualter, 1993; Dawson, 2000; Osborne & Collins, 2000; Baram-Tsabari & Yarden, 2005; Murray & Reiss, 2005; Baram-Tsabari et al., 2006) and adults (Falchetti et al., 2003), especially among females. According to results from the ROSE project in Denmark (Busch, 2005) and England (Jenkins & Nelson, 2005), girls are most interested in biological topics regarding health, mind and well-being. Results from the ROSE project in Finland indicated that boys are more interested than girls in basic processes in biology (such as ecology and cell biology), whilst girls find human biology and health education more interesting than boys (Uitto et al., 2005).

Interest in biology is not a constant trait—it changes with age. Stawinski (1984) found that among 13- to 16-year-old students, human biology becomes important while interest in plants and animals decreases. Older pupils' interest in human biology is well-attested to by a number of studies, including one conducted in England (Osborne & Collins, 2000), and another in Israel (Tamir & Gardner, 1989). Among Israeli high-school students, 86% preferred studying about the human body, 14% preferred animals and none preferred studying about plants (Tamir, 1984).

More detailed knowledge of students' interests in biological topics at various ages may be used to contextualize and personalize some of the formal curricula. Adults' interests in biology can be used to learn about the possible future interests and concerns of today's students. In addition, this type of data regarding students and adults may be used to inform the producers and editors of popular science and educational programs in the process of improving the quality of scientific-information dissemination.

How Can We Measure Interest?

Most of the attempts to identify pupils' preferences for topics in science have been conducted using tick boxes or Likert-type scales. These questionnaire-based methods have traditionally relied on adult-centric views of what subjects should be meaningful to students. To overcome this inherent bias, we developed a naturalistic approach to defining specific interests by using self-generated questions. Using this methodology, we were previously able to characterize children's interests in science (Baram-Tsabari & Yarden, 2005; Baram-Tsabari et al., 2006).

Ayelet Baram-Tsabari (ayelet.baram@weizmann.ac.il) is a Ph.D. Student, and Anat Yarden (anat.yarden@weizmann.ac.il) is Head of the Biology Group, both in the Department of Science Teaching, Weizmann Institute of Science, Israel. Anat Yarden is the corresponding author.

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Self-generated questions can help reveal the askers' reasoning, alternative views and interests (Biddulph et al., 1986). However, in a classroom setting, it is hard to use children's questions, since they are so rare. As Dillon (1988) plainly states "Children qua (=as) students do not ask questions. They may be raising questions in their own mind ... but they do not ask questions aloud in the classroom." However, research, as well as life experience, tells us that students are capable of asking many questions when given the opportunity (Costa et al., 2000), for example, during one-on-one tutoring sessions (Graesser & Person, 1994). It seems that they just do not feel comfortable doing so in the classroom. Therefore, to identify interests in the field of biology among different age groups and between genders, we collected questions for this analysis from informal science-learning sources.

The Sample

Three sets of self-generated questions were used in this research. Those were raised by children, adolescents, and adults.

Children

One thousand six hundred and seventy six science questions submitted by Israeli children to an Internet site (www.logi.tv) which accompanies a series of television programs were collected. The program might be described as a hybrid of two formats: "Ask the Experts" and a competition to find information. The introduction to the Internet site that accompanies the program told children that "This is the place to ask any question in the world." The program did not encourage the children to ask about content that was already broadcasted, but to submit their own spontaneous questions. In this sample, 49.6% of the questions (n = 831) were biological in nature (Baram-Tsabari & Yarden, 2005). Among the 1,140 gender-identifiable questions,[1] 43.5% were asked by girls and 56.5% by boys. Most questions were submitted by children in the later years of elementary school and in the early years of junior high school (ages nine to twelve years). This sample is described in detail in Baram-Tsabari and Yarden (2005).

Adolescents

One thousand five hundred and fifty five science questions submitted by fourth through twelfth grade students to an "Ask a Scientist" service on an international Internet site (www.madsci.org) were collected. In this sample, 44% of the questions (n = 684) were about biology (Baram-Tsabari et al., 2006). Over 94% of the contributors originated from English-speaking countries. Among the 1,167 gender-identifiable questions,[2] 56.4% were asked by females and 43.6% by males. Most of the questions were asked by junior and senior high-school students. This sample is described in detail in Baram-Tsabari et al. (2006).

Adults

Six hundred and twenty two science questions submitted by Israeli television viewers to a popular-science television series (news.shmone.co.il) were collected. In this sample, 37.9% of the questions (n = 236) were about biology. Among the 538 gender-identifiable questions,[1] only 30.5% were asked by females and 69.5% by males. Most of the questions (65%) were sent by young adults under the age of 30.

Since there is a partial overlap between the age of the audience responding to the three databases (e.g., fourth through sixth graders are represented both in the **children** and **adolescents** sources of questions), all the biological questions from the three different sources were pooled, resulting in a sample of 1,751 biology questions. They were then re-divided into four age groups: elementary school (up to 12 years of age), junior high school (13-15 years of age), senior high school (16-18 years of age), and adults (over 18).

Classifying the Questions

Classification was performed on the basis of coding schemes that had been developed and used in previous research (Baram-Tsabari & Yarden, 2005; Baram-Tsabari et al., 2006). The coding schemes used here were as follows:

- **Interest in biological topics.** All the questions were classified into one of 16 topics. For examples of this coding scheme, see Table 1.
- **Human interest.** Many questions were embedded in the context of human biology or the zoology of non-humans (e.g., "Is our inability to synthesize Vitamin C an inborn error of metabolism?" "Do dogs have a dominant paw that they prefer to use?"). These questions were classified as portraying either a "human" or "zoology" interest, respectively.
- **Motivation for raising the question.** The two main categories chosen were non-applicative and applicative. The former was subdivided into general curiosity, spectacular aspects of the field, and seeking an explanation for a direct observation. Applicative questions were subdivided into personal use, health and lifestyle, and school- and job-related questions. For examples of this coding scheme, see Table 2.
- **Type of requested information.** A typology was developed that describes the nature of the question and the knowledge it generates. A category of requests for "Factual" information included terminological, historical, descriptive, and confirmatory items. It also included requests for further information on a topic. Requests for "Explanatory" information were basically "How" and "Why" questions. "Methodological" information had to do with scientific ways of finding things out and with scientific and technological procedures. The "Open-Ended" type of information deals with opinions, controversial themes, and futuristic questions that science cannot answer for the time being. For examples of this coding scheme, see Table 3.

Classification and categorization of questions in each database were performed independently by two researchers, with a satisfactory level of agreement between the coders.[3] A two-tailed Pearson's chi-square test was used to calculate probabilities. Not all the inquirers provided their full details; therefore, sample sizes differ between tests.

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[1] Hebrew is a gender-identifying language. As a result, some of those submitting questions automatically revealed their sex through the use of verb gender indicators, e.g., "I'm checking" translates as *ani bodeket* (feminine) or *ani bodek* (masculine).

[2] The first name was used to determine the asker's gender, using an English name gender finder.

[3] Reliability between coders: 100 children's questions = 85%-90% agreement for the various schemes; 150 adolescents' questions = 84%-98% agreement for the various schemes; 50 adults' questions = 82%-90% agreement for the various schemes.

Table 1. Some examples of questions in biological topics and their frequency within various age groups.

Topic[a]	Age group	% of questions[b]	Example[c] (gender, age, country of origin)[d]
Anatomy and Physiology	Elementary school	31.12	How come we don't feel growing up? (9, IL)
	Junior high school	20.72	Why is it that when you put salt on your hand then put ice on top of it and press down for a while, it leaves a mark on your hand? What is really happening? (m, Canada)
	Senior high school	20.06	Why do men have nipples? (m, US)
	Adults	18.5	A short while ago me and my wife drove to Eilat. All the way south the sun was shining on us. We could not agree: do the sun rays pass through the car glass and can make us tan and burn? (m, 30, IL)
Sickness and Medicine	Elementary school	10.52	My grandfather underwent heart operation and he was given artificial heart during the operation. How does an artificial heart work? Can it replace a real heart that a person can live with like with a real heart? (m, 10, IL)
	Junior high school	5.8	How do human hearts stop from beating? When you have a heart attack what causes that to happen? (f)
	Senior high school	12.26	How likely is it that if body fluids which contain high concentrations of HIV (Semen, vaginal fluids, blood) contact a 5 to 6 day old finger cut, infects the person? . . . What if the cut was 5 to 6 days old never bleed after it was initially cut, but had some pinkish or reddish tissue?... (m)
	Adults	48.9	In your show there was a professor who talked about curing autoimmune diseases using camel milk. Can I have his contact details? (f, 31, IL)
Genetics and Reproduction	Elementary school	4.18	How long is a dog's pregnancy? (f, 8, IL)
	Junior high school	6.91	Me, my sister and brother are similar in everything (looks and character) to my father, and no one is similar to my mother in nothing! How can it be? (13, IL)
	Senior high school	6.41	What age is sex appropriate? (f, US)
	Adults	5.73	Is their a difference between the pheromones secreted by a gay person and a straight? (m, IL)
Behavior	Elementary school	10.37	When a cow goes 'Moo' is it speaking to its friends or keeping its territory? (m, 8, IL)
	Junior high school	4.97	Does a goldfish react to changes occurring out of the tank the same as in? (f, US)
	Senior high school	3.62	Are human beings wild or domesticated? (m, US)
	Adults	2.64	Why do dogs raise their leg when they urinate? (f, IL)
Neurobiology and the Mind	Elementary school	2.02	What is the percentage of the brain that we use? Why can't we use 100% of it? (f, 12, IL)
	Junior high school	7.18	Which gender has a better memory? (f, US)
	Senior high school	6.41	Does a deaf person's audio part of the brain work for the visual part?... (m, US)
	Adults	7.05	How does the brain interpret smell? (IL)
Man and Animal Relationships	Elementary school	12.82	Did the cavemen have cats? (8, IL)
	Junior high school	4.7	Is the female anopheles mosquito the animal that kills the most people (with malaria) annually?
	Senior high school	1.39	Can baby field mice survive in my care? (US)
	Adults	0	NA
Biotechnology	Elementary school	0.29	Is there any possibility of bringing a Poke'mon to actual life? (m, US)
	Junior high school	1.1	I read in the paper that scientists can make creatures live many times over their average life span. How is it possible to do it? (m, 13, IL)
	Senior high school	1.67	What's up with cloning, why are we doing it, and what have we cloned?? For a scientific paper. (m, US)
	Adults	1.76	My question is about DNA tests. Many times I see on TV doctors drip a dark substance into a tank containing transparent liquid, and the result of all this is some kind of sequence of dark and light segments . . . What is the meaning of this "map" with segments? (m, 23, IL)

a The topics are listed in order of popularity within the whole sample.
b The percentage is calculated out of the questions of each age group. The percentages do not add up to 100 since questions classified as "Other" are not presented.
c These are verbatim quotes, or translations of verbatim quotes. In some cases only a part of the question is shown.
d Where data is available. m = male; f = female; IL = Israel; US = United States; NA = not available.

Table 2. Some examples of motivations for asking biological questions and their frequencies at various age groups.

Motivation	Age group	% of questions[a]	Example (gender, age, country of origin)[b]
NON-APPLICATIVE			
Spectacular Aspects	Elementary school	10.66	What is the biggest lizard in the world? (m, 11, IL)
	Junior high school	1.66	What is the longest snake in the world? (14, IL)
	Senior high school	0.28	What's the largest cell in men, and what is the smallest cell in women? (Malaysia)
	Adults	0	NA
General Curiosity	Elementary school	56.77	Does a whale have a bellybutton? (f, 12, IL)
	Junior high school	41.72	How come horse and donkey can reproduce, if two species (dog and cat) can not reproduce? (m, 14, IL)
	Senior high school	43.73	Why does a mosquito bite itch? I have always been wondering why? Are they putting poison in our body? If yes, still why would that make us want to itch it? (m)
	Adults	36.56	Why do the Chinese, Japanese, Mongolians, and Asians in general have slanted eyes? (or why we don't have them) (m, 24, IL)
Direct Observation	Elementary school	9.51	When I'm being hurt, what's in the plaster that helps the wound? (f, 10, IL)
	Junior high school	6.63	Why do our fingers and toes shrivel when in water for a long period of time, but the rest of our body doesn't seem to change? (f, US)
	Senior high school	4.46	Why if I go to sleep at 9 pm, I feel the same tiredness as if I go to sleep at 10pm? ... I experimented with this on myself many times, but the same results have always occurred. (m, US)
	Adults	11.89	When the nails in the fingers of the hands grow, do they grow on the upper part or from the root? Is the nail that I see is a new nail that grew, or an old nail that climbed from beneath? (m, 22, IL)
APPLICATIVE			
Personal Use	Elementary school	16.57	What kind of food should I give a turtle? (m, 7, IL)
	Junior high school	8.84	I want to add a chat application to my internet site, what should I do? (m, 15, IL)
	Senior high school	5.01	Can you identify animal type by reflected colour from tapetum? When I go out at night and shine a flashlight across a field, the light is reflected back by the tapetum of the animals' eyes. Dogs seem to have orange "eyes". Where can I find a list of animals to reflected eye colour? (m, US)
	Adults	3.52	I have patina on my glasses, at the points that hold the glasses on my nose. What can I do to prevent it? (m, 36, IL)
Health and Lifestyle	Elementary school	3.31	How can I lose weight in few days? (f, 12, IL)
	Junior high school	3.87	What can I eat to get a better memory? Do you suggest eggs?
	Senior high school	12.26	What is the ideal weight from what to what for a five foot 3 and a half person? How do you figure it out; Is there any chart you have?
	Adults	44.93	I wanted to ask whether it's true that people who wear glasses are more likely to suffer from radiation from cellular, since their glasses transfers the radiation. I read about it in some newspapers, but I don't know whether to take that too seriously. (IL)
School and Job	Elementary school	3.17	I know cancer starts by smoking. But how does it form? My teacher in health told us to get an answer. (f, US)
	Junior high school	37.3	Do ants prefer sugar or cheese better? I hope you answer my question - it's for a science report. (US)
	Senior high school	34.22	Can I become a heart surgeon in less than 7 years? (m)
	Adults	3.08	A few days ago you broadcast a program about trauma and malfunction in the production of RNA... I wish to read the research... since it is connected to my job, which deals many times with emotional and physical trauma (f, 53, IL)

a The percentage is calculated out of the questions of each age group.
b Where data is available. m = male; f = female; IL = Israel; US = United states; NA = not available

Findings

The analysis of 1,751 self-generated biological questions yielded data concerning typical questions in each of the four age groups with regard to interest in biology, specifically human biology, motivation, and type of information requested.

Interest in Biological Topics

All the biology questions were classified into one of 16 topics. The topics in decreasing order of popularity were: *Anatomy and Physiology*, *Sickness and Medicine*, *Ecology*, *Botany and Mycology*, *Nutrition*, *Genetics and Reproduction*, *Behavior*, *Neurobiology and the Mind, Man and Animal Relationships, Cell Biology, Microbiology and Virology, Evolution, Extinct Animals, Biotechnology*, and *History of Biology*. Questions that did not fit any of these topics were classified as *Other*.

Significant differences ($p < 0.0001$) were found between the biology interests of the different age groups. Some examples of the breakdown of the questions analyzed by topic and age group are given in Table 1. The youngest age group was significantly more interested than the others in *Anatomy and Physiology, Behavior*, and *Man and Animal Relationships*. The oldest age group, on the other hand, was significantly more interested than the others in *Sickness and Medicine*. *Neurology and the Mind* was a constant focus of interest among people over 12 years of age, while elementary-school children did not find this topic very attractive.

Significant differences ($p = 0.0001$) were also found between the biology interests of males and females. The following topics were of greater interest to boys than girls: *Anatomy and Physiology, Extinct Animals, Cell Biology, Ecology*, and *Genetics and Reproduction*, while the following topics were of greater interest to girls than boys: *Man and Animal Relationships, Behavior, Nutrition, Botany and Mycology*, and *Neurobiology and the Mind*. The difference was significant only for *Anatomy and Physiology*. Interestingly, results from the ROSE project in Denmark indicated that the greatest mean differences between boys and girls were found in topics concerning the mind and nutrition (Busch, 2005). Despite the differences, both genders were most interested in *Anatomy and Physiology* (28.8% of boys' questions, 20.4% of girls' questions), and *Sickness and Medicine* (15.7% for boys, 15.4% for girls). Both genders were least interested in *History of Biology* and *Biotechnology*.

Human Interest

According to our analysis, the relative frequency of zoology questions decreased with age, as the proportion of questions relating to human biology increased ($p < 0.0001$) (Figure 1). We had previously seen this trend among young (<14-year-old) Israeli children (Baram-Tsabari & Yarden, 2005) and adolescents from various countries (Baram-Tsabari et al., 2006), and here we saw the trend continue among adults as well. This combination of questions from different sources indicates that the shift in interest from zoology to human biology with age might be cross-cultural. We assume that the increased interest in human biology among adolescents is due to the approach of puberty and the related increasing interest in one's body. Adults seem to be more interested than the rest in human biology because they are more concerned with health issues.

Table 3. Some examples of types of information requested and their frequencies at various age groups.

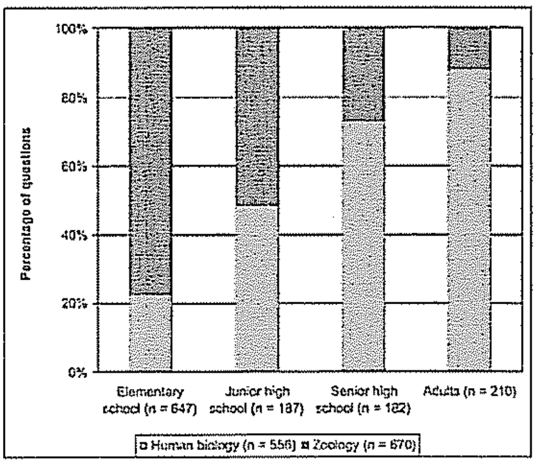
Type[a]	Age group	% of questions[b]	Example (gender, age, country of origin)[c]
Factual	Elementary school	59.51	Does a fly have a heart? (10, IL)
	Junior high school	56.63	If a girl straightens her hair every day what will happen to her hair? will it affect hair follicles?
	Senior high school	57.38	Do our eyelids naturally block UVA & UVB rays? (f, US)
	Adults	70.48	Can someone who suffers from complete loss of memory recognize words but not remember their meaning? (m, IL)
Explanatory	Elementary school	36.74	Why does the Earth turn around? (m, IL)
	Junior high school	30.94	It is said that sugar isn't very healthy and you shouldn't eat a lot of it. On the other hand they say that fruits are healthy. But fruits have sugar in them, so why isn't it preferable to eat chocolate, and it's better to eat a fruit instead? (13, IL)
	Senior high school	28.41	Why do people yawn? (m, 15, IL)
	Adults	26.43	Why do people with an extra chromosome suffer from down's syndrome? (f, IL)
Methodological	Elementary school	3.02	Why do the measurements always start at sea level? (f, 11, IL)
	Junior high school	10.5	I am doing a science fair project on who has a cleaner mouth (human vs. dogs). What I need to know is would mould grow from saliva? And if it does would I grow in gelatine or is there some other alternative substance? (m, US)
	Senior high school	10.58	I think there are relations between blood types to personalities of people. I would like to know more about this subject, but since most of the people do not know their blood types, how could I tell the relation? (m, US)
	Adults	2.2	Please explain how findings' age (like bones and stones) is being determined (m, IL)
Open-ended	Elementary school	0.72	What is mind? Does every living being have mind? (Oman)
	Junior high school	1.93	Do you think it is alright to clone?
	Senior high school	3.62	I would like to know how the growth and evolution of trees would be effected by them growing in 1/6 the earths gravity and how they might look once they had become well adapted to the low gravity? (m, US)
	Adults	0.88	Will it be possible in the future to implement any organ, or are their organs that we can be sure that will never be implemented artificially? (f, IL)

a The percentage is calculated out of the questions of each age group.
b Where data is available. m = male; f = female; IL = Israel; US = United states; NA = not available

Motivation for Raising Questions in Biology

Significant differences ($p < 0.0001$) were found between the motivations of different age groups. Elementary-school students asked less applicative questions (23.1%) than all the other age groups (50-54.6%). They asked significantly more questions about spectacle dimensions of biology and more general curiosity and personal-use questions than older participants. Junior and senior high-school students asked significantly more school- and job-related questions, such as requests for help in school assignments (e.g., "Do ants prefer sugar or cheese better? I hope you answer my question–it's for a science report"). We do not attribute this to the age of the responders but to the nature of the Web application, because the elementary-school children were sending their questions to a site that accompanies a television show, which was not helping with school work. Adults asked significantly more questions having to do with health and lifestyle, compared to the other age groups.

Figure 1. Developmental shift in interest in human biology and zoology of non-humans across four age groups.



Significant differences ($p < 0.0001$) were also found between the motivations of males and females in asking biological questions. Females had more practical motivations than males in raising their questions: 47.4% of the females' questions were applicative, compared to 33.2% of the males' questions. Within the non-applicative questions, males asked more questions about spectacle aspects of biology and out of general curiosity, while females were more concerned with direct observations.

Type of Information Requested

Most of the questions in our sample were factual (60%), followed by explanatory (32%), methodological (6%) and the very rare open-ended ones (2%). Significant differences ($p < 0.0001$) were found between the types of information requested by the different age groups. Elementary-school students asked more explanatory questions, while adults asked more factual ones. Junior and senior high-school students asked more methodological questions. We attribute this trend to the common questions dealing with school-related science fairs.

Research Limitations

The use of self-generated questions as a method of identifying interest in biology is a relatively new approach. For that reason, here we discuss some issues concerning this specific methodology and the role of pupils' voice in education in general.

Can These Results Be Generalized?

This research made use of a self-selected, non-control sample. There is a positive correlation between knowing about science and being interested in it (Ziman, 1991). Therefore, people who watch science news on television or surf science Web sites are probably more interested in and more knowledgeable about science than the general population. We chose to work with an uncontrolled sample, although results from controlled studies already exist, for several reasons:

- We believe that relying on children's self-generated ideas and questions is more valuable for identifying their interests than using their responses to an adult-written questionnaire, which is the traditional way to collect information regarding students' interest today.
- Using an informal data source and a new methodology, our results confirm and reinforce what was revealed using the traditional questionnaire methodology. This agreement, with findings described in the literature gathered using control samples, serves to bolster confidence also in our new findings, which were not described before. Therefore, we assume that the developmental trends described here represent, to a certain degree, the interests of many students in biology.

Can Data About Students' Interest Collected in One Country Be Relevant to the Practice in Another?

The data we used originated from Israeli and international sites, hence triggers the question–whether students from various countries show similar interests in biology. The profile of the experiences and interests of students vary strongly between countries (Sjøberg, 2000). However, students in different educational and national contexts were not only experiencing very similar high school science classes, but identifying similar problems and responding in similar ways (Lyons, 2006). Furthermore, the wealth of research on students' interest from many different countries and the contribution of international studies such as ROSE (Sjøberg & Schreiner, 2002) and SAS (Sjøberg, 2000) indicate similarities in the scientific interests of western students from different countries.

What Should Be the Role of Students' Interest in Determining Biology Curricula?

It is clear that the biology curriculum cannot rely solely on students' interests. Principles in biology should be taught, even if they do not spontaneously elicit questions from the students. It appears, for example, that students' questions will not be the vehicle for bringing contemporary biology into the classroom because the children, adolescents and adults in our sample rarely asked about current topics such as biotechnology, and seldom raised open-ended questions. A similar tendency was observed by Falchetti et al. (2003), who reported very few requests for opinions on controversial issues on a scientific Italian Web site. Katz and Chard (1998) argue that:

- children's interests may actually represent passing thoughts, fleeting concerns, phobias, obsessions, or fascination with media-related characters
- just because children express interest in a given topic

does not mean that their interest deserves to be strengthened by the serious attention of the teacher
- one of the responsibilities of adults is to help children develop new intellectual interests.

Another problem is that asking a question does not always guarantee willingness to invest time and effort in learning the answer. It is not clear what would happen if students' interests were implemented into the school science curriculum. Would free-choice learning lose all of its appeal once it became compulsory? On the other hand, how can a curriculum be "relevant" to the students if it does not take into account their current and future interests? Some ideas for using students' interests are listed herein.

Implications for Teaching

In the following section we will discuss some ways in which students' generated interest in biology can be integrated into a standard-based curriculum. Hofstein & Kempa (1985) distinguished between interest arousal which can be brought about by an appropriate selection and structuring of subject matter included in a curriculum; and motivational enhancement which is brought about by the choice of pedagogical strategies. Using students' interest in the classroom, therefore, can be done in various ways, since it has to do with the content of the lesson and not with the teaching strategies used by the teacher. It should prove nearly impossible to adhere to the individual interests of each of the students in a large class. However, there are ways to incorporate students' interests into the science classroom.

- **Triggering learning of new content.** Having students answer their own questions seems to make it difficult to follow the intended curriculum, but it is common for puzzling questions to embrace topics that the teacher intended to reach sooner or latter (White & Gunstone, 1992). Students' interests can provide a positive instruction tool within the standard science curriculum, since topics that fascinate children can be related to subject matter to provide a base for new knowledge. An expert teacher can use students' individual interests as opening points or triggers for the study of less popular subjects that are required by the curricula. If the teacher is having trouble identifying the interest of his/her own students, it is possible to use the "frequently asked questions" (FAQs) section that some of the Ask-A-Scientist sites present. Teachers may consider these repeated questions to be of general interest to children, and they can search the archive for children's questions on the subject they wish to teach, at the appropriate age level.
- **Question-based curriculum.** Gallas (1995) used her elementary-school students' questions to construct a curriculum in human biology. This enabled her to build a community of learners who strive to answer their own specific questions.
- **Question-based lesson.** Kwan (2000), again an elementary-school teacher, followed a question asked by a student to develop a lesson on constructions, that was based on the child's question and her national science curriculum. Also Yerrick (2000) used lower track students' questions to guide and temper instruction in class investigations.
- **Recurring themes.** Where does the fat go when a person loses weight? Why do males have nipples? Can lions become vegetarians? Are dogs color-blind? Some questions are repeated at different ages and in different cultures, and can serve as triggers for standard science-curriculum issues, such as nutrition, evolution, ecology and the senses (respectively). Daiute (1997, p. 329) instructs teachers on how to recognize and use those topics in the classroom: When "topics emerge as recurrent themes underlying children's conversations, it is the optimal time to explore such issues in relation to subject matter in your curriculum."
- **Organization and design of teaching.** Students' questions may be used to recommend a design for teaching a certain science topic (Maskill & Pedrosa de Jesus, 1997).
- **Choice of context.** Many principles in biology can be taught using different contexts, such as human biology, zoology, botany, and microbiology. It is possible to choose a more engaging context for the target audience, rather than an alienating one. In general, it seems that zoology would appeal more to children, while human biology would appeal more to young adults.
- **Science fairs and project-based learning.** Some popular teaching strategies take into account students' interests to some degree. Science fairs and project-based learning, for example, allow students to create their own research questions within a given topic. In a teaching strategy such as K-W-L (know-want-learn), for example, teachers activate students' prior knowledge by asking them what they already know. Then students set goals specifying what they want to learn, and after reading, students discuss what they have learned (North Central Regional Educational Laboratory, 2006), this way incorporating to some degree students' views and interests in the topic.

- **Inquiry-based learning.** Students' self-generated questions can sometimes be used as a starting point for inquiry-based learning. Using student-generated questions has potential in directing students' inquiry and guiding their construction of knowledge (Chin, 2001). Question-driven problem-based learning (Q-PBL), which involves students crafting their own problems, generating questions, and investigating related learning issues, is an inquiry-based approach, in which learning is based on what the students are interested in and driven by students' need to answer their own questions (Chin & Chia, 2004). Chin and Kayalvizhi (2002) study the suitability of students' questions for classroom investigation. They found that among the questions that were posed individually, only 11.7% could be answered by performing hands-on investigations. When questions were generated in groups after examples were shown, 71% of the questions that were raised amenable to science investigations but they related to fewer topics. Thus, although there is general agreement in letting pupils investigate their own questions, pupils' "raw" questions do not seem to immediately lend themselves to practical investigations, and pupils need the teacher's help to translate such questions into testable hypotheses (Chin & Kayalvizhi, 2002).
- **Make room for students' questions.** Questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph et al., 1986; Scardamalia & Bereiter, 1992; Brill & Yarden, 2003). Our results indicate that students are able to pose science questions in informal settings, and it would be educationally beneficial if they would use this ability in classrooms as well. Many researchers recommended environments that encouraged question-asking by students, such as discussion (King, 1994), cognitive conflict (Allison & Shrigley, 1986), real-world problem-solving activities (Zoller, 1987; Chin et al., 2002), case studies (Dori & Herscovitz, 1999), biotechnology-focused modules (Olsher & Dreyfus, 1999), use of written questions (Pedrosa de Jesus et al., 2003) and learning using adapted primary literature (Brill & Yarden, 2003). Studying students' questions enables teachers to be aware of what students are interested in and what they want to know about a given topic (Chin & Chia, 2004). This way teachers can be more responsive to students' needs and interests, and tailor their instruction to cater to these individual differences (Chin & Chia, 2004).

Acknowledgments

This research was supported by The Israel Science Foundation (Grant No. 605/06), and Sacsta Rashi Fellowship for honor students in science education.

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Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (Submitted). Identifying students' interests in biology using a decade of self-generated questions.

Paper Submitted to the *Journal of Biological Education*

Identifying students' interests in biology using a decade of self-generated questions

AYELET BARAM-TSABARI

Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel, Phone number: 972-8-9342273

RICKY J. SETHI

Department of Computer Science and Engineering, University of California, Riverside, CA 91801, USA, Phone number: 626-282-1519

LYNN BRY

Department of Pathology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02115, USA, Phone number: 617-732-7383

ANAT YARDEN

Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel, Phone number: 972-8-9343793, Fax number: 972-8-9342681

Correspondence to: Anat Yarden, email: anat.yarden@weizmann.ac.il

Key words: interest, gender, free-choice environment

Running title: Students' Interest in Biological Topics

Abstract

An identification of students' interests in biology can help teachers better engage their pupils and meet their needs. To this end, over 28,000 self-generated biological questions raised by students from kindergarten through graduate school were analyzed according to age and gender. The sample demonstrated a dominance of female contributions among K-12 students, suggesting that the internet is an attractive free-choice science-learning environment for school girls. However, girls' interest in submitting questions dropped as they grew older. Topics popular among different age groups of males and females were identified, and ways in which students' interests can be incorporated into a standard-based curriculum are discussed, mainly as a trigger for the learning of less popular subjects which are required by the curricula.

Introduction

A few years ago, one of the authors was a novice biology teacher standing in front of a class of clearly uninterested 10th graders. The topic of the lesson was the basic classification of living organisms into prokaryotes and eukaryotes. The day was hot, the students' eyes were glazed over, and the only sound was the chalk strokes on the board. Suddenly, a hand went up. "Yes?"' asked the teacher, surprised and hopeful, "you wanted to ask something?" "I have a question", said a brunette girl "is it true that if you leave an egg outside the fridge a chick will hatch from it?" "No", replied the teacher, disappointed by the unrelated question, "the eggs we buy in the supermarket are not fertilized, and therefore no chick will hatch from them. The eggs will simply rot more quickly if you leave them out of the fridge for a long time". The class was now fully awake. "I think you are mistaken", said another girl, "my mother also told me that a chick would hatch from the egg". "Mine too", added her neighbor, looking skeptically at the teacher. The prokaryotes and eukaryotes were abandoned for the sake of a topic that engaged and interested the students.

Teaching students what they want to know can be a very beneficial pedagogical strategy. Positive relationships have been reported between interest and a wide range of learning indicators (Pintrich and Schunk, 2002). When allowed to pursue their own interests, students participate more, stay involved for longer periods, and exhibit creative practices in doing science (Seiler, 2006). Interest has also been found to influence future educational training and career choices (Kahle *et al*, 1993). Beyond being a useful and pragmatic practice, involving students in decisions about their lives in school is an important moral and educational principle. Jenkins (1999) examined the implications of "citizen science", i.e. science which relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday lives, for the form and content of school science education. He suggested constructing science curricula that enable young people to engage in science-related issues that are likely to be of interest and concern to them (Jenkins, 1999). This idea also appears in the recommendations of several organizations, including the National Research Council (1996) and the American Association for the Advancement of Science (1993), which have proposed that science curricula provide a common basis of knowledge while addressing the particular needs and interests of students.

However, this attention to students' interests remains mainly theoretical. Even teaching strategies which draw upon driving questions to sustain students' interest use questions developed by the teachers (Krajcik and Mamlok-Naaman, 2006), and a context designed to legitimize learning from the student's perspective by making their learning intrinsically meaningful was chosen by the curriculum developers (Bulte *et al*, 2006). However, for science to be relevant to its practitioners, the origin of the questions which are being investigated are of great importance. Therefore, the ability to identify students' own interests in biology may be used to contextualize and personalize some of the formal biology curriculum.

Research has provided some insight into students' interest in biology. It is the most popular science subject among students (Osborne and Collins, 2000; Author, 2005; Author, 2006) and adults, especially among females. Ayalon (1995) describes biology as an emerging "feminine niche" in science, being the only science subject that has escaped a masculine image.

Differences exist between the topics that males and females find interesting within biology. According to results from the ROSE project in England (Jenkins and Nelson, 2005), girls are most interested in biological topics dealing with health, mind and well-being. Moreover, interest in biology is not a constant trait: interest in zoology, for example, decreases with age, while interest in human biology increases. This trend has been identified among young (<14-year-old) Israeli children (Author, 2005) as well as adolescents from various countries (Author, 2006), and it continues among adults (Author, In press). The increased interest in human biology among adolescents is probably due to the approach of puberty and the related increasing interest in one's body. Adults seem to be more interested in human biology because they are more concerned with health issues.

Students' scientific interests are traditionally identified by questionnaire-based methods which involve asking students to tick boxes in response to a series of prepared questions or topics (e.g. Sjøberg, 2000; Sjøberg and Schreiner, 2002). However, there is an inherit bias in this methodology, since the listed topics are based on adult-centric views of what subjects should be meaningful to the students. To overcome this problem, we developed a naturalistic method for using students' self-generated questions as a source of information about their interests (Author, 2005, 2006, in press). By studying students' questions, we can learn about what students are interested in and what they want to know about a given topic (Biddulph *et al*, 1986).

Although questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph *et al*, 1986; Author, 2003), it is hard to use children's questions in a classroom setting, since they are so rare. As Dillon (1988) plainly states "Children qua students do not ask questions. They may be raising questions in their own mind…but they do not ask questions aloud in the classroom." Researchers attribute this situation to a classroom atmosphere in which revealing a misunderstanding may render the student vulnerable, open to embarrassment, censure or ridicule (Rop, 2003).

However, students are able to pose science questions in a free-choice science-learning environment, such as the world-wide web. One of the option which are open to children who are trying to find complex answers on the Web, is to submit their questions to asynchronic human-mediated question-and-answer services, which are sometimes referred to as "Ask-A" services, such as "Ask a Scientist". In this study, we collected questions from an Ask-A-Scientist site, in order to use children's self-generated questions as an indication of their interest in different biological topics.

Methodology

Data source

MadSci Network is an award-winning independent non-profit organization operating from a server in Scottsdale, Arizona, USA (http://www.madsci.org). It was founded in September 1995 as part of Washington University's Young Scientist Program, a student-run organization in St. Louis dedicated to improving science literacy among K-12 students. Today, the *MadSci Network* receives 90 to 150 questions daily, most of which are answered automatically by the site's search engine. Fewer than 20% of the questions are answered by nearly 800 globally distributed volunteer scientists, usually within two weeks.

MadSci Network covers all branches of science. It collects information and stores key demographic information, making it rather straightforward to mine the information from the archives. Many other English-language Ask-A-Scientist services are available on the net, but none were found suitable for this study. The reasons for this were varied, among them: because they do not ask for the age of the asker (e.g. services run by the Scientific American www.sciam.com, the Internet Public Library www.ipl.org/div/askus/, Yahoo! Answers answers.yahoo.com and the paid service

Google Answer www.answer.google.com/answers), they do not record all the information in their archives (e.g. Argonne National Labs www.newton.dep.anl.gov), they serve a limited age group (e.g. Ask Dr. Universe www.wsu.edu/DrUniverse/ serves mostly elementary school children), or they have a rather small database (e.g. the service run by Cornell Center for Materials Research www.ccmr.cornell.edu/education/ask/ has collected just over 1,000 questions in the eight years of its existence).

Sample characteristics

Over 146,000 questions were sent to *Madsci Network* between its establishment at the end of 1995 and the first half of 2006. Almost 79,000 of the surfers disclosed their grade level, country of origin, and filled in the name and subject fields. An analysis of all of the questions in this sample is reported in another paper (Author, submitted). This study reports a more comprehensive analysis of the questions that were allocated to the biological topics.

The questions were allocated by the surfers into one of 25 topics. Of these, the following 18 were biology topics: Biochemistry, General Biology, Zoology, Botany, Anatomy, Cell Biology, Environment and Ecology, Medicine, Genetics, Microbiology, Neuroscience, Agricultural Sciences, Evolution, Molecular Biology, Development, Virology, Immunology, and Biophysics (for examples of questions see Table 1). The topics 'Environment and Ecology' and 'Biophysics' include some questions which are not biological in nature (e.g. "Can the millions of miles of black roads be increasing global warming?").

[Table 1 about here]

Questions on these topics made up 37.65% of the overall sample, making biology the most popular field of interest. Of these 1,205 questions that were asked by teachers were not included. The resulting sample was made up of 28,484 biology questions asked by students from kindergarten through graduate school. A few questions were missing some of the data, and therefore the n values differ between variables.

Age split: 28,480 of the inquirers provided their grade level; 68.3% of the surfers were school students: 2.8% were K-3 students, 9.5% 4-6th graders, 26.2% junior-high-school students and 29.8% senior-high-school students. Undergraduates contributed 20% of the questions, science graduates 7.7% and non-science graduates 4%.

Gender split: Gender identification was based on the asker's first name. Initial classification was done semi-automatically using an English name gender finder (epublishing.nademoya.biz/japan/names_in_english.php?nid=A). In the next step, the names that were not automatically classified and appeared twice or more in the data were analyzed individually using baby name guesser (www.gpeters.com/names/baby-names.php), which operates by analyzing popular usage on the internet. In this way, we were able to identify the gender of the asker for 17,840 of the questions. The rest were either names that could equally belong to boys or girls, meaningless scrambles, or names that appeared only once in the database. Of the gender-identifiable questions, 55.7% were asked by girls (n = 9,943) and 44.3% were asked by boys (n = 7,897).

Split by country of origin: 28,402 of the inquirers indicated their country of origin. The surfers originated from 126 countries. The great majority of the questions (81%) originated from the USA, UK, and Canada. An additional 10% originated from another five English-speaking countries (not necessarily as mother tongue): Australia, India, Singapore, Philippines, and New Zealand.

Statistical analysis: Unless otherwise indicated, a two-tailed Pearson chi-square test was used to calculate probabilities. Not all the inquirers provided their full details; therefore, sample sizes differ from graph to graph and are indicated by n values. Significant differences within proportions were determined according to a cell chi-square test.

Results and Discussion

A decade of biology questions sent to an Ask-A-Scientist internet site were analyzed by age and gender in order to learn about the interests of students in biological topics.

Age distribution of female participants

Overall, females used the site more than males to ask biology questions (55.7% vs. 44.3%, respectively). This surprising majority of females should be viewed in the context of females' general reluctance to use media that foster informal learning about science or to take part in extracurricular science experiences

(Greenfield, 1998), and their relative lack of formal and out-of-school experience in using computers and the worldwide web (Kafai and Sutton, 1999). Two factors worked together to explain this female majority of contributors, who are traditionally found to be less interested in science than males: the general interest of female students in the field of biology, and the attractive and secure science-learning environment provided by the internet.

This female dominance was not constant among all age groups. Girls participated in the sample more than boys while in school (K-12), especially during the middle-school and high-school years, but their number dropped dramatically upon moving to college and even more so at the graduate level, making the males the more dominant group in this latter sample (Figure 1). Although it is known that students, especially females, tend to lose interest in science as they grow older (Greenfield, 1998), this decrease usually takes place during the middle-school and high-school years. In this free-choice online setting, the decrease seems to have been postponed (Figure 1).

[Figure 1 about here]

Identifying interest in biological topics

Not all topics enjoyed the same level of popularity. The most popular topics for questions were biochemistry, general biology, botany and zoology, each receiving approximately 10% of the questions. Anatomy, cell biology, environment and ecology, medicine, genetics, and microbiology were all quite popular, each receiving 6 to 7.5% of the questions. Questions in neuroscience, agricultural sciences, evolution, and molecular biology were scarcer, providing 2 to 4.5% of the questions. The least interesting topics to the surfers at this site were development, virology, immunology, and biophysics, with around 1% of the questions each (the full list of frequency and percentage of questions for each topic can be seen in Table 1).

Male and female students differed significantly in their interest in some of the topics ($p < 0.0001$). Females were more interested than males in asking questions about botany, cell biology, and genetics, while males were more interested than females in asking questions about medicine, neuroscience, evolution, virology, immunology and biophysics.

Although all of the questions in this sample were self-generated by the askers, it is important to note that some of them were raised by the students as a consequence of a school assignment. In a previous study, we learned that topics such as anatomy and physiology, sickness and medicine, and genetics and reproduction are all characterized by relatively more 'spontaneous' than school-related questions (Author, 2006). Botany and mycology, microbiology, virology, and cell biology yielded many more teacher- and textbook-generated questions than spontaneous ones. Topics such as ecology and neurology were almost equally distributed among the two question types (Author, 2006). From the current analysis, we learned that both males and females used the site to get help with their school-work as well as to satisfy their own curiosity, since both spontaneous and school-related topics appear to be more 'masculine' or 'feminine'.

Student interest in the various topics differed significantly among the various age groups ($p < 0.0001$). For example, interest in medicine increased with age (Figure 2A), while interest in zoology decreased as students matured (Figure 2B). This trend is in agreement with the known pattern of increased interest in human biology and decreased interest in zoology with age, which had been previously identified in several Ask-A-Scientist sites (Author, 2005, 2006, in press).

[Figure 2 about here]

Other topics which were characterized by a decrease in interest with age were environment and ecology (Figure 3A), botany (Figure 3B), and agricultural sciences (data not shown). Botany was a relatively popular topic among K-9 students. It was previously found to be a topic that elicits many questions regarding school assignments (Author, 2006). Thus, it can be assumed that this is the reason for the relatively high percentage of questions on this topic elicited by school children.

An additional four topics showed an increase in the percentage of questions with age: genetics (Figure 3C), evolution (Figure 3D), neuroscience, and biochemistry (data not shown). The first three were previously found to elicit a large number of children's spontaneous questions (Author, 2006), therefore the increase is probably not due to school assignments. The increase was not identical for males and females. While females developed an interest in genetics (Figure 3C), males asked more about evolution (Figure 3D) and neuroscience (data not shown). Biochemistry, on the other hand, appealed equally to both genders. It became popular among high-school students and retained its popularity among the older age groups (data not shown). The reason for this increase may be related to the formal study of biochemistry.

Overall, it seems that the topics which were most popular among young age groups have to do with macroscopic levels of organization and concrete entities, such as plants and animals, while topics popular among older students have to do with microscopic levels of organization and molecular entities, such as DNA, neurotransmitters and proteins, and with abstract concepts such as genes and phylogeny.

Cell biology (Figure 3E) and microbiology (data not shown) garnered an increase in interest during middle school and high school, followed by a decrease in the older age groups. This finding is in agreement with the results of previous research which found them to be topics that elicit many questions regarding school assignments and less spontaneous questions (Author, 2006).

[Figure 3 about here]

Research limitations

Non-representative sample: This research made use of a self-selected, non-control sample. Students who send questions to science web sites are probably more interested in and more knowledgeable about science than the general student population. Furthermore, there is also a marked difference in ease of access for children from different socioeconomic statuses to the internet, which was our source for the questions.

Allocation to topics: The classification of the questions to the various topics was performed by the surfers. In some cases questions were misplaced, either because the surfer did not recognize the right topic or did not pay attention to the process. We assume that most of these misplacements were distributed evenly among the topics, and therefore did not cause a major bias.

Formalizing free-choice learning: Asking a question in a free-choice environment does not guarantee willingness to invest time and effort in learning the answer in a school setting. It is not clear what would happen if students' interests were implemented into the school science curriculum. Would free-choice learning lose all of its appeal once it became compulsory?

The role of students' interests in determining the curriculum: Even if we had a clear-cut understanding of what students really wish to know, the biology curriculum would not rely solely on students' interests. Principles in biology should be taught, even if they do not spontaneously elicit questions from the students. On the other hand, how can a curriculum claim to be 'relevant' to the students if it does not incorporate any of their interests?

Implications for teaching

There are several ways in which students' interests can be incorporated into a standard-based curriculum. To list a few: a teacher can present a new principle or concept using a context which is relatively engaging rather than alienating for the target audience (e.g. in biology: zoology vs. human health, in physics, see: Haussler and Hoffmann, 2002); allow students to create their own research questions within a given topic in project-based learning or use their questions as a starting point for inquiry-based learning (Yerrick, 2000); construct a lesson based on students' questions, or even teach a whole topic using a tailor-made question-based curriculum (Gallas, 1995). In the following, we discuss another way of using students' individual interests in class, as a trigger for the learning of less popular subjects which are required by the curricula.

Let us rejoin the frustrated novice teacher from the introduction. Her goal for the lesson was to teach the fundamental classification of cells into prokaryotes and eukaryotes, but she was asked about a daily-life aspect of reproduction in birds ("Is it true that if you leave an egg outside the fridge a chick will hatch from it?"). This question could have been used as a trigger for discussing some of the differences between prokaryotes and eukaryotes—the former are simply uni-cellular creatures that usually reproduce by division, while the latter are the building blocks of all multi-cellular creatures, many of which use sexual reproduction, and ultimately, this is why unfertilized eggs do not hatch. Thus, a spontaneous question about reproduction in the context of zoology could have been converted into a formal discussion on cell biology. Seiler (2006) notes that many students' connections with science take the form of questions that a teacher might consider offhanded or even off-task, but they represent significant intellectual efforts by the students to connect science with their lives and experiences. These questions may be used as student input for the development of a student-interest-focused curriculum (Seiler, 2006).

The teacher could also have planned in advance. Since she knows that students at this age are increasingly interested in medicine, she could have started by asking the students why they think antibiotics kill bacteria, but not the person who takes it. The students would probably not be able to answer the question at that point in their education, but the question may engage and interest them.

Teachers who are attentive listeners are able to recognize and extract their students' questions and interests (Seiler, 2006), but ideas for triggering questions can be found using the "frequently asked questions" (FAQs) section presented by some of the Ask-A-Scientist sites, or just by browsing their archives. Questions such as: Where does the fat go when a person loses weight? Why do males have nipples? Can lions become vegetarians? Are dogs color-blind?, all asked by students at Ask-A-Scientist sites, may serve as triggers for standard biology-curriculum issues, such as nutrition, evolution, ecology and the senses (respectively). When choosing questions, the age of the target audience should be taken into consideration, since topic popularity varies with age. Ask-A-Scientist sites seem to be an attractive environment for girls, allowing the teacher to choose from a variety of girls' questions, which are usually rare in a school-science setting.

At Ask-A-Scientist sites the questions are asked by the learners, but the locus of control over the learning process is external, since the answers are given by asynchronic human experts (Nachmias and Tuvi, 2001). When used in class, the locus of control over the learning process is transferred to the teacher. If the questions which are used originate from the students themselves, then they receive some control over their learning, along with the engagement and interest that characterize the process of learning something that one really wants to know.

Acknowledgments

This research was supported by the ISF (grant no. 605/06), and a Sacsta Rashi Fellowship for honor students in science education. The authors would like to thank Mrs. Yetty Varon and Dr. Hillary Voet for their expert statistical advice and Mrs. Rakefet Halevi for her valuable help in coding the questions.

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Table 1. Examples of questions in biological topics, their frequency and percentage (*n* = 28,484).

Topic[a]	Frequency	Percent	Example[b] (gender, age group, country)[c]
Biochemistry	3,077	10.8	What is the chemical structure of butter, sunflower oil and olive oil? (f, undergrad); What causes a strand of DNA to twist, giving it a double helix shape? (m, 7-9, US)
General Biology	2,943	10.3	How long does it take for the calories in your body to transform into fat? (f, 7-9); How come cells can split asexually and we [humans] cannot? (m, 7-9, US)
Botany	2,766	9.7	Can we use all of spinach's iron? (m, undergraduate, Turkey); What is the chemical composition of an apple? (f, 7-9, US)
Zoology	2,760	9.7	Can a grasshopper grow back limbs? (m, undergraduate); What do you need to raise a wolf? (f, 4-6, US)
Anatomy	2,177	7.6	Is there any correlation between eye color and how well you see? (f, 4-6, US); Do children's heads stop growing at age three? (f, non-science graduate)
Cell Biology	2,129	7.5	Can stem cells be obtained from a placenta? (f, 10-12, England); Is there any DNA replication during prophase of mitosis? (undergraduate, US)
Environment & Ecology[d]	2,101	7.4	How can I measure the water retention in soil? (f, 7-9, US); Can air pollution affect the size of insects? (m, 7-9, US)
Medicine	2,036	7.1	Is there a high percentage for a boy to get diabetes if his mother has it? (f, 7-9, US); Why does an adult recover from a fracture much slower than a child? (f, undergrad)
Genetics	1,750	6.1	Can a DNA test distinguish paternity between brothers? (f, non-science graduate); Is there a genetic element that determines the sounds of our voices? (m, 10-12, US)
Microbiology	1,676	5.9	Are there bacteria that eat lava and will they destroy the earth? (m, 7-9, US); How fast do bacteria, mold-fungi or viruses grow on your body? (f, 4-6, US)
Neuroscience	1,283	4.5	How do alcohol/drugs lower inhibitions? (m, 7-9, US); how come when I flunk a test food doesn't taste good? (f, undergrad, US)
Agricultural Sciences	1,282	4.5	What are the scientific names of weeds? (f, 10-12); How would I design an experiment about the effects of gray water? (f, 10-12, Australia)
Evolution	774	2.7	What selected for, groups, organisms, or genes? (m, undergraduate, Canada); Could an herbivore evolve from a carnivore?(f, 10-12, US)
Molecular	529	1.9	2 Strands of DNA—do these make 2 different batches of proteins? (f, undergraduate, Australia);

Biology			Why can't there be more number of binding sequences for the given primer? (m, science graduate, India)
Development	375	1.3	How do cells 'know' how to form a blastula? (10-12); Babies get the food they need from the umbilical cord but how do they receive oxygen? (f, 7-9, US)
Virology	312	1.1	Why sequence Influenza virus genome? (Science graduate); How long does the polio virus usually stay in its host? (m, 7-9, US)
Immunology	266	0.9	What are cytokines, and how do they work? (f, 10-12, Kuwait); where is our immune system's 'memory' stored?(m, 10-12, US)
Biophysics[d]	248	0.9	Can you tan under black lights? (m, undergrad, US); At what temperature does popcorn pop? (m, 4-6, US)

a The topics are listed in order of popularity.

b These are verbatim quotes. In some cases only part of the question is shown.

c Where data are available. m = male; f = female; US = United States.

d Not all of the questions in this topic are strictly "biological".

Figure 1. Distribution of biology questions according to gender and age group (n = 17,838)

Figure 2. Interest in (A) medicine and (B) zoology among boys and girls in different age groups. Percentage is calculated out of the total boys' or girls' questions

Figure 3. Interest in (A) environment and ecology, (B) botany, (C) genetics, (D) evolution, and (E) cell biology among boys and girls in different age groups. Percentage is calculated out of the total boys' or girls' questions

Figure 1.

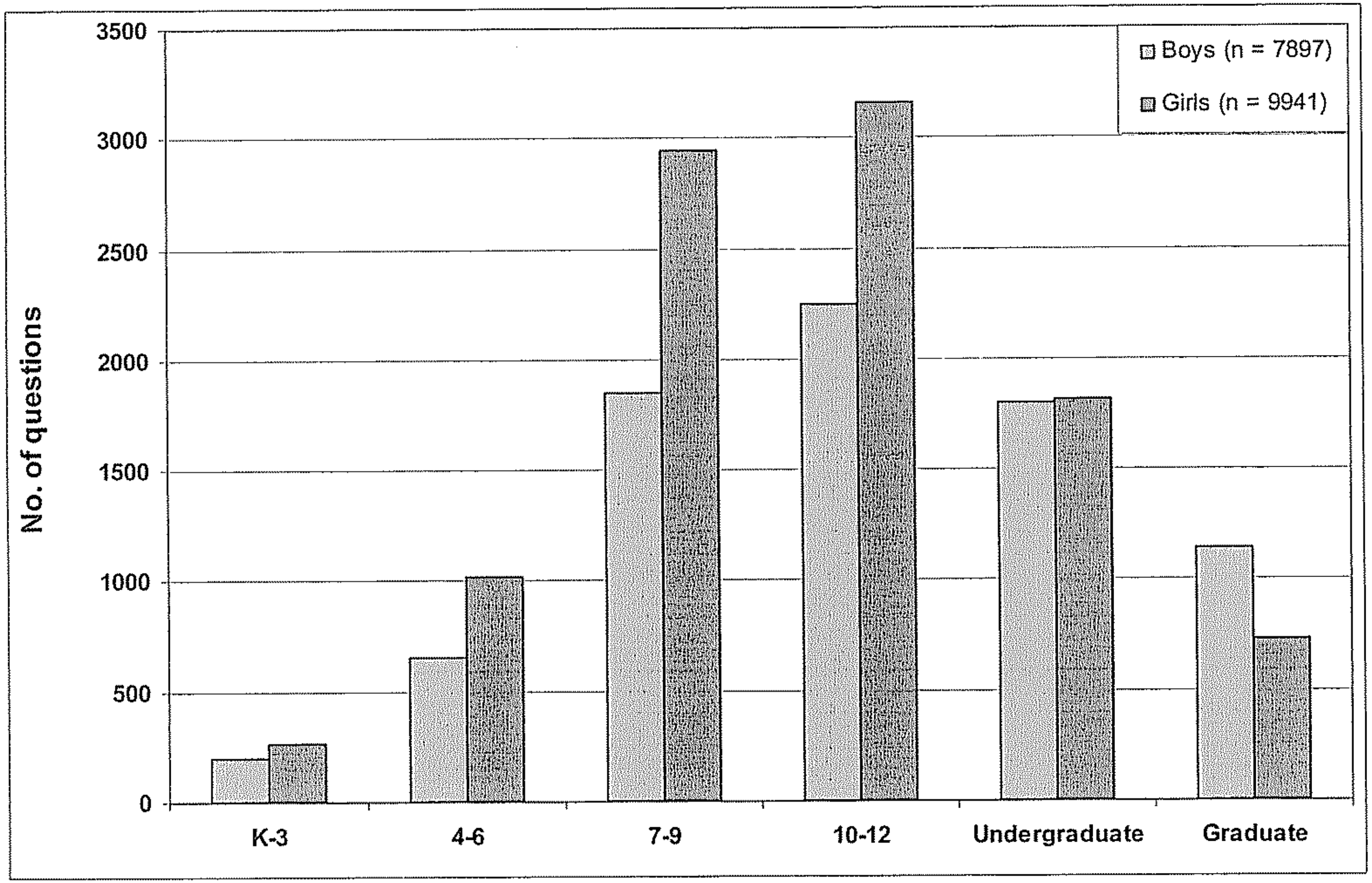
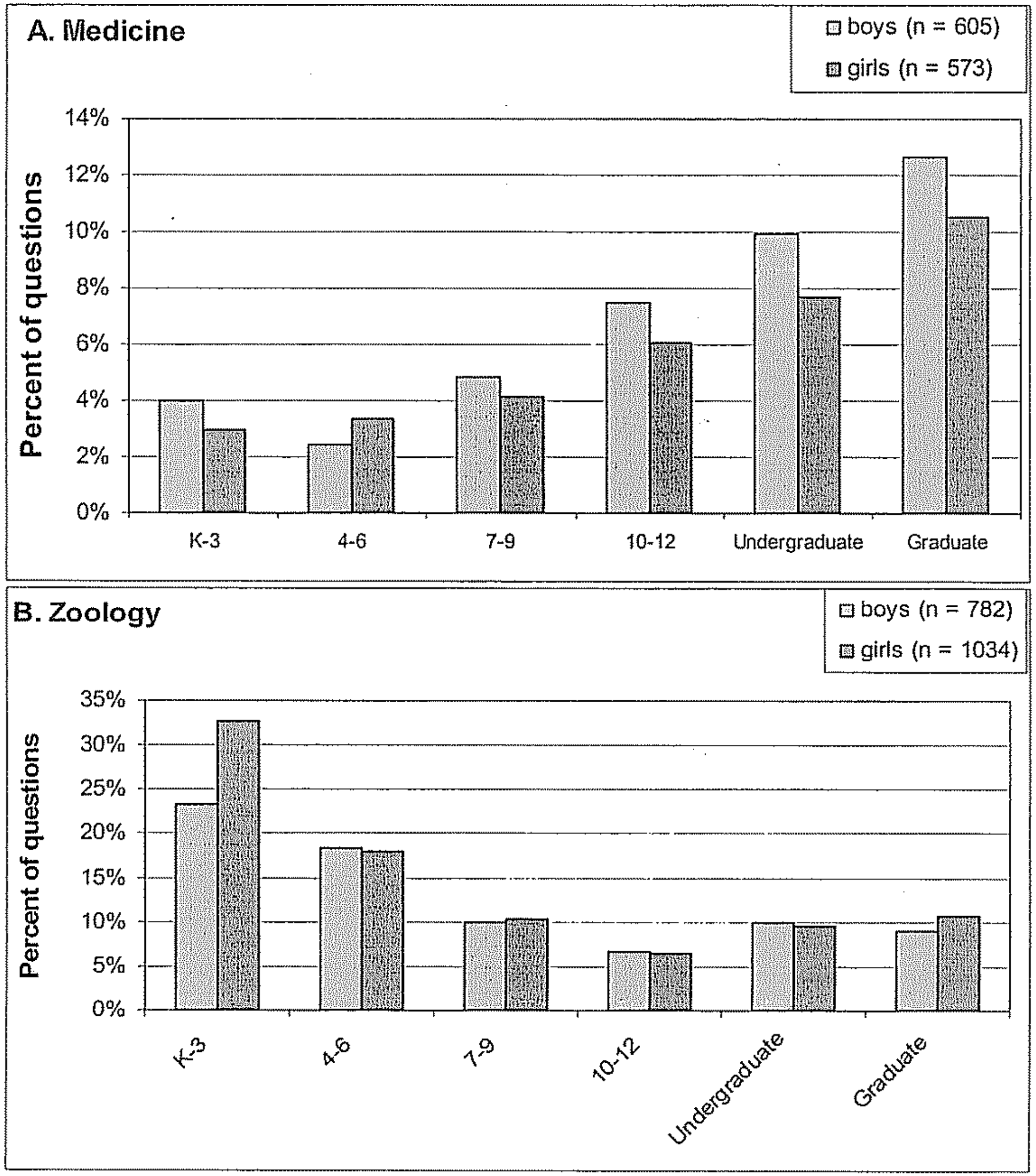
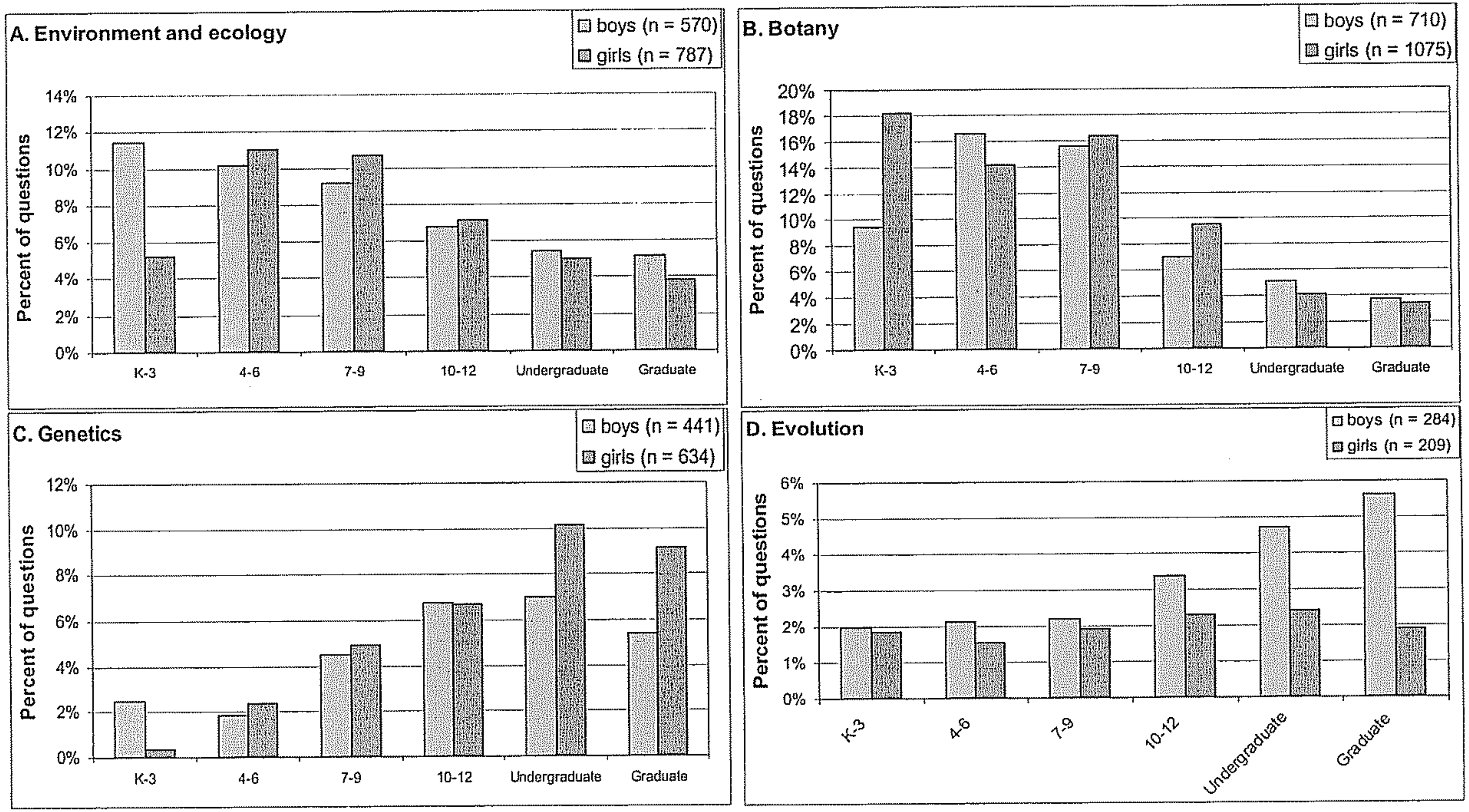

No. of questions
3500
3000
2500
2000
1500
1000
500
0
K-3
4-6
7-9
10-12
Undergraduate
Graduate
Boys (n = 7897)
Girls (n = 9941)

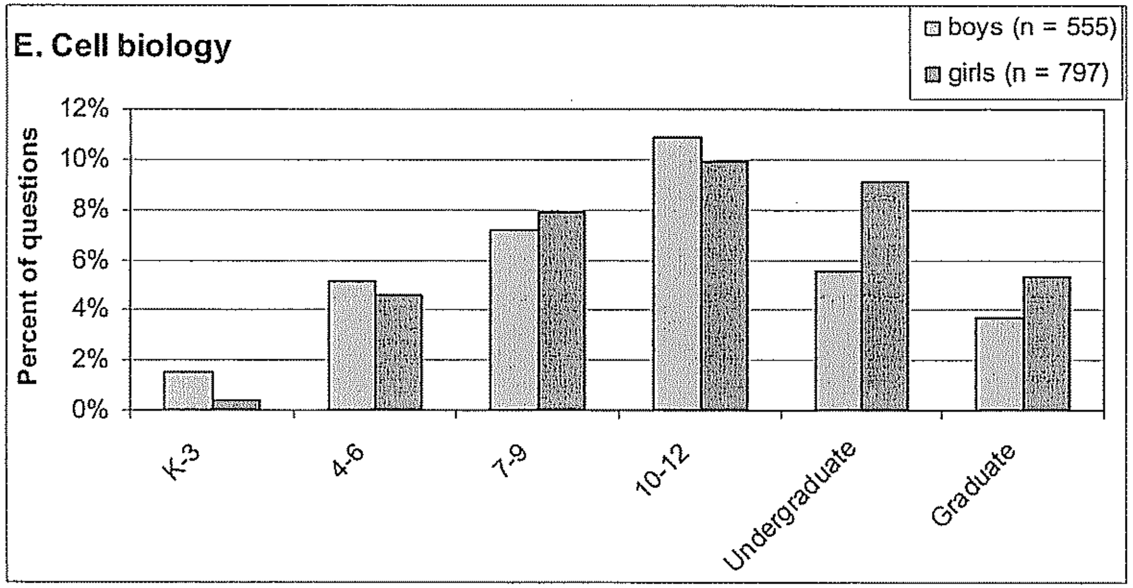
Figure 2.



A. Medicine
boys (n = 605)
girls (n = 573)
Percent of questions
14%
12%
10%
8%
6%
4%
2%
0%
K-3
4-6
7-9
10-12
Undergraduate
Graduate
B. Zoology
boys (n = 782)
girls (n = 1034)
Percent of questions
35%
30%
25%
20%
15%
10%
5%
0%
K-3
4-6
7-9
10-12
Undergraduate
Graduate

Figure 3.


A. Environment and ecology
boys (n = 570)
girls (n = 787)
Percent of questions
0%
2%
4%
6%
8%
10%
12%
14%
K-3
4-6
7-9
10-12
Undergraduate
Graduate
B. Botany
boys (n = 710)
girls (n = 1075)
Percent of questions
0%
2%
4%
6%
8%
10%
12%
14%
16%
18%
20%
K-3
4-6
7-9
10-12
Undergraduate
Graduate
C. Genetics
boys (n = 441)
girls (n = 634)
Percent of questions
0%
2%
4%
6%
8%
10%
12%
K-3
4-6
7-9
10-12
Undergraduate
Graduate
D. Evolution
boys (n = 284)
girls (n = 209)
Percent of questions
0%
1%
2%
3%
4%
5%
6%
K-3
4-6
7-9
10-12
Undergraduate
Graduate



E. Cell biology
boys (n = 555)
girls (n = 797)
Percent of questions
12%
10%
8%
6%
4%
2%
0%
K-3
4-6
7-9
10-12
Undergraduate
Graduate

Baram-Tsabari, A., Sethi, R. J., Bry, L., & Yarden, A. (Submitted). Asking scientists: a decade of questions analyzed by age, gender and country.

Paper Submitted to the *Science Education*

Asking scientists: a decade of questions analyzed by age, gender and country

AYELET BARAM-TSABARI

Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel

RICKY J. SETHI

Department of Computer Science and Engineering, University of California, Riverside, CA 91801, USA

LYNN BRY

Department of Pathology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02115, USA

ANAT YARDEN

Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel

Correspondence to: Anat Yarden, email: anat.yarden@weizmann.ac.il

Running head: Science questions analyzed by age, gender and country

Abstract

Nearly 79,000 questions sent to an internet-based Ask-A-Scientist site during the last decade were analyzed according to the surfer's age, gender, country of origin and the year the question was sent. The sample demonstrated a surprising dominance of female contributions among K-12 students (but not in the full sample), where offline situations are commonly characterized by males' greater interest in science. This female enthusiasm was observed in different countries, and had no correlation to the level of gender equity in those countries. This suggests that the internet as a free-choice science-learning environment plays a potentially empowering and democratic role which is especially relevant to populations which are traditionally deprived of equal opportunities in learning formal science. However, girls' interest in submitting questions to scientists dropped, worldwide, as they grew older, relatively to the boys' interest, and the stereotypically gendered science interests persisted in this environment as well. The strengths and limitations of using free-choice web-based data sources for studying youth interest in science are discussed.

Introduction

An earlier paper in this Journal (Baram-Tsabari, Sethi, Bry, & Yarden, 2006) drew upon the questions sent to an Ask-A-Scientist site during a three-month period at the end of 2004 in order to identify the scientific interests of children. The present paper draws upon the same source to analyze nearly 79,000 questions gathered since the establishment of the Internet site in the mid-90s (www.madsci.org), in order to learn about the interactions between age, gender, country of origin and interest in scientific topics. More specifically, we attempted to learn how the participation of female contributors changed between countries, with age and with time; and how the scientific interests, reflected by the subject of the questions, changed with age and time, between genders and between countries.

Theoretical Framework

Students' questions

Although question-asking is a basic requirement for the performance of scientific research and meaningful learning, the way in which science lessons are usually conducted does not stimulate question-asking by students, and questions are posed mainly by the teachers (Allison & Shrigley, 1986; Dillon, 1988; Dori & Herscovitz, 1999; Graesser, Person, & Huber, 1992; Marbach-Ad & Sokolove, 2000). Requests for meaningful explanations are relatively infrequent in K-12 classrooms, and students at all grades (K-12) generally ask the same number of questions (Good, Slavings, Harel, & Emerson, 1987) - approximately 1% of the questions asked in class (Graesser et al., 1992).

Many researchers recommended strategies which encourage question-asking by students, such as one-on-one tutoring sessions (Graesser & Person, 1994), discussion (King, 1994), cognitive conflict (Allison & Shrigley, 1986), real-world problem-solving activities (Chin, Brown, & Bruce, 2002; Zoller, 1987), case studies (Dori & Herscovitz, 1999), biotechnology-focused modules (Olsher & Dreyfus, 1999), use of written questions (Pedrosa de Jesus, Teixeira-Dias, & Watts, 2003) and learning using adapted primary literature (Brill & Yarden, 2003).

In spite of the effort to encourage question-asking by students, students are more often expected to answer questions than to ask them in the typical classroom setting (Chin, 2004), and the common situation in science classes is still the one described by Dillon (1988): "Children qua students do not ask questions. They may be raising questions in their own mind...but they do not ask questions aloud in the classroom." Researchers attribute this situation to a classroom atmosphere in which revealing a misunderstanding may render the student vulnerable, open to embarrassment, censure or ridicule (Pedrosa de Jesus et al., 2003). Students have described their teachers' responses to their questions as 'put-offish' or even annoyed, and their classmates' reaction as 'intolerant' (Rop, 2003).

The overall paucity of student questioning has resulted in relatively few studies of pupils' questions, simply because researchers have not been able to find enough of them to examine (Maskill & Pedrosa de Jesus, 1997; Pedrosa de Jesus et al., 2003; Watts & Alsop, 1995). Good, Slavings, Harel, and Emerson (1987) specifically note the absence of comparative studies of student-generated questions across different grade levels using the same methodology.

Dim as the picture of students'-generated questions may be, research, as well as life experience, tell us that students are capable of asking many questions when given the opportunity (Costa, Caldeira, Gallastegui, & Otero, 2000). Therefore, a better way to study children's questions might be to look for them where they are being asked fluently and voluntarily. Learners ask questions when they feel secure (Watts, Gould, & Alsop, 1997), and one place offering such security is free-choice science-learning settings on the internet.

The web as a free-choice science learning environment

Examining free-choice science learning environments can provide knowledge about the natural setting in which people learn in a self-directed, self-motivated voluntary way, guided by individual needs and interests (Falk & Dierking, 2002). An example of such a free-choice setting is the World Wide Web, which is the primary source for news and information about science for 20% of Americans, second only to Television (41%). Moreover, if people need information on a specific scientific topic the internet is the primary source to which people would turn (Horrigan, 2006). Two thirds of internet users say they have come upon news and information about science when they went online for other proposes, and half of all internet users have been to a web site which specialized in scientific content (Horrigan, 2006).

While access to the internet grows exponentially, American students are already wired: in fall 2005, nearly 100% of public schools in the United States had access to the internet, and 94% of instructional rooms in those schools had internet access (National Center for Education Statistics, 2006). In 2005 87% of all youth between the ages of 12 and 17 used the internet, and 68% of all teenagers have used the internet at school (Rainie & Hitlin, 2005). In general, youth hold positive attitudes and exhibit self confidence regarding internet use (Fidel et al., 1999; Watson, 2004). Their use of the web ranges from researching for school assignments to communicating with others and exploring their personal interests (Baram-Tsabari et al., 2006; Bilal, 2004; Hirsh, 1999; Levin, Arafeh, Lenhart, & Rainie, 2002; MaKinster, Beghetto, & Plucker, 2002; Weigold & Treise, 2004). Science web sites may influence young people's life-long interest in science and their appreciation of its beauty and importance (Weigold & Treise, 2004). However, a listing of the 15 sites most visited by teenagers did not include any sites related to science, technology or even education in general. Weigold & Treise concluded that teenagers usually go to the web to have fun and interact with others, but only occasionally use the web to learn.

There are mixed findings regarding the role of gender in using the web as a free-choice environment for science learning. Although boys have more formal and out-of-school experience using computers and the worldwide web (Kafai & Sutton, 1999; Shashaani, 1994), more girls prefer this type of lesson over traditional classroom-based science learning (Leong & Al-Hawamdeh, 1999). Ching, Kafai, and Marshall (2000) found that configuration of social, physical and cognitive gender-equitable spaces contributed to a positive change in girls' level of access to programming activities. The American Association of University Women (2004) describes girls and women as being attracted to the communicative aspects of online interactions, and therefore recommend online projects as a means of promoting gender-equitable participation.

A former study which used questions from an Ask-A-Scientist source found that among 4-12th graders, girls asked most of the questions in contributions arriving from the USA, Canada, and the UK, but not from the other countries surveyed (Baram-Tsabari et al., 2006). This female majority contradicts previous female-to-male ratios obtained from a scientific internet site based in Italy (Falchetti, Caravita, & Sperduti, 2003), a UK-based science line (K. Mathieson, personal communication, April 2, 2004), and science and technology questions at an Israeli children's website (Baram-Tsabari & Yarden, 2005). In the interactive web site *Whyville* that was designed to engage students in socially interactive, entertaining and educational activities that include inquiry science, most users were found to be girls (73% of the regular *Whyville* users who answered a survey), contrary to what might be expected from a science-oriented program (Aschbacher, 2003). The question of female usage of the web as a free-choice environment for science learning should be viewed in the context of females' general reluctance to use media that foster informal learning about science (National Science Foundation [NSF], 2004; Nisbet et al., 2002), and to take part in extracurricular science experiences (Greenfield, 1998).

Research on children's use of the World Wide Web for learning has generally been conducted in school settings (e.g. Bilal, 2001; e.g. Fidel et al., 1999; Guinee, 2004; Rogers & Swan, 2004; Slotta, 2004). The Web is seen by educators as a site for student inquiry in science, which allow students to pursue questions of personal interest (McCrory Wallace, Kupperman, Krajcik, & Soloway, 2000), since an effective search is also an exercise in inquiry and critical thinking (Brem & Boyes, 2000). However, most students have difficulty formulating and modifying search queries (Bilal, 2004; Hirsh, 1999; MaKinster et al., 2002; Wallace, Kupperman, Krajcik, & Soloway, 2000; Watson, 2004), and many of them fail to construct an accurate and broad understanding following an online inquiry (Hoffman & Krajcik, 1999).

Furthermore, children do not tend to question the accuracy of the information they find on the Web (Hirsh, 1999; Russell, Weems, Brem, & Leonard, 2001; Schacter, Chung, & Dorr, 1998; Wallace et al., 2000). This skepticism is badly needed, as Keating, MaKinster, Mills, and Nowak (1999) found that as little as 30% of the search results for science concepts actually contain at least a short operational definition or graphic display of the concept, and many of the sites contain misconceptions. Another major problem is that students believe that they should be able to find answers to complex questions on specific web pages, instead of researching to form an answer (Soloway & Wallace, 1997). To sum up, although the Internet has the potential to greatly facilitate positive changes in education, its use in school is sporadic, peripheral to the core curriculum, and simple and obvious in nature (Schofield, 2005).

Consequently, students report that there is a substantial disconnect between how they use the Internet for school and how they use the Internet during the school day and under teacher direction. For the most part, students' educational use of the Internet occurs outside of the school day, outside of the school building, outside the direction of their teachers (Levin et al., 2002). Steinkuehler (in press) suggests that in order to understand the current and potential capacities of technology for cognition, learning, literacy, and education, we must look at contexts outside the current formal educational system rather than those within. The reason would be that what students do with online technologies outside the classroom is not only markedly different from what they do with them in schools but it is also more goal-driven, complex, sophisticated, and engaged. Hence, it might prove more fruitful to study children's use of the World Wide Web for learning in free-choice settings, rather in school settings.

When children are using the Internet to research their interests, some of their complex questions are better answered by experts, rather than by a list of directories or sites. This type of service is being offered on the Web by Human-mediated question-and-answer services and are sometimes referred to as "expert services" (Janes, Hill, & Rolfe, 2001) or "Ask-A" services, such as "Ask a Scientist" (Lankes, 1999). Usually, such sites maintain searchable public archives in which previously answered questions are returned as search results, thus making this archive a resource for their users (Pomerantz, Nicholson, Belanger, & Lankes, 2004). This study uses the archives of such a web site as a data source for identifying people's interests in science.

Interest in science

Adolescents' decisions about the contents and directions of their educational training are influenced to a high degree by the topic-related interests they developed in the preceding years (Krapp, 2000). Interest was the primary reason for choosing to enroll in an advanced science class among Israeli (Levy, 2003), Swedish (Lindahl, 2007), American and Australian students (Kahle, Parker, Rennie, & Riley, 1993). Interest does not only affect the choice of courses and career, but also the ability to learn. Research indicates positive relationships between interest and a wide range of learning indicators (Pintrich & Schunk, 2002; Schiefele, 1998).

Regardless of the importance of interest, the current situation in science education was summarized by a Swedish student in the following manner: "The trouble with school science is that it provides uninteresting answers to questions we have never asked" (Osborne, 2006). The untested assumption is that the more we know about students' interests, enthusiasms, dislikes, beliefs and attitudes, the more feasible it will be to develop school science curricula that will engage their attention and help reduce long-standing gender and other differentials (Jenkins, 2006).

Within free-choice science education some attention has been given to audience's interests. Front-end studies are regularly used by museums to initiate a dialogue with visitors, enable the exhibition developers to learn about the audience assumptions, understandings, attitudes, beliefs and interests (Dierking & Pollock, 1998). Another free-choice institutes, which may benefit from tuning to its audience, are public libraries. Cooper (2004) studied children's choices for inclusion in a hypothetical library, based on the understanding that information interests and needs of children are different from those of adults, even those with the best intentions to understand and predict children's interests.

When high-school students are asked to indicate their interest in learning about various topics in their science classes, they choose topics such as disease (cancer and HIV/AIDS), drugs (therapeutic and recreational), biological and chemical weapons, the ozone layer, and greenhouse gases. Yet, the usual high-school science curriculum does not address these topics (Kwiek, Halpin, Reiter, Hoeffler, & Schwartz-Bloom, 2007). Overall, biology is the most popular science subject among students (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005; Dawson, 2000; Murray & Reiss, 2005; Osborne & Collins, 2000; Qualter, 1993), especially among females (see next section for gender aspects of interest in science). Within the field of biology, students display significant changes in the structure of their interests with age: human biology becomes important while interest in plants and animals decreases (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005, , in press; Osborne & Collins, 2000; Stawinski, 1984; Tamir & Gardner, 1989).

The profiles of students' experiences and interests vary strongly between countries (Sjoberg, 2000). Results from the ongoing international "Relevance of Science Education" [ROSE] project indicate that similarities among countries in students' responses, regarding what science topics they would like to learn, are first determined by geographical proximity, and next by the level of development, indicated by the UN's Human Development Index (Sjoberg & Schreiner, 2005). However, these differences might be much smaller within Western countries. Lyons (2006), for example, found a remarkable similarity in the experiences of school science reported by high-school students in Sweden, England, and Australia. This analysis revealed that students in different educational and national contexts were not only experiencing very similar high-school science classes, but also identifying similar problems and responding in similar ways.

Gender and interest in science

To successfully address the needs and interests of under-represented groups, we need to know not only what works, but what works for whom (American Association of University Women, 2004). Research has provided insight into these issues, especially on the role of gender in predicting scientific interest. Most of these insights are based on data collected in school science settings.

The wealth of data regarding boys' and girls' interest in science can be summarized in the following manner: boys in general are more interested in science than are girls (Gardner, 1975, , 1998; Miller, Slawinski Blessing, & Schwartz, 2006), especially in the fields of physics and technology. Girls, on the other hand, are more interested in biology than boys. Chemistry is equally interesting to both genders. These findings (or parts of them) were repeated in many countries, including Scotland (Stark & Gray, 1999), Australia (Dawson, 2000; Kahle et al., 1993; Woodward & Woodward, 1998), the USA (Farenga & Joyce, 1999; Jones, Howe, & Rua, 2000), England (Murphy & Whitelegg, 2006; Osborne & Collins, 2001; Spall, Barrett, Stanisstreet, Dickson, & Boyes, 2003), Israel (Friedler & Tamir, 1990; Trumper, 2006), Germany (Hoffmann, 2002), and in international studies such as "Science and Scientists" [SAS] (Sjoberg, 2000) and ROSE (Sjoberg & Schreiner, 2002).

The ROSE studies conducted in Denmark (Busch, 2005), England (Jenkins & Nelson, 2005), Norway (Schreiner, 2006) and Finland (Lavonen, Juuti, Uitto, Meisalo, & Byman, 2005) found that girls' interests were focused on health, medicine, the body, the mind and well-being, whereas boys wished to learn more about the dramatic aspects of physics and chemistry, and how technology works. This gender-gap in interest is also apparent among female students who are interested in science, as can be inferred from the polarized enrollment in elective biology and physics courses (Murphy & Whitelegg, 2006; Zohar, 2003), within the science-attentive students' body. It is also evident in science-interest studies, which use senior high-school science students as a sample. For example, Osborne and Collins (2001) surveyed students' views on school science using focus groups of 11^{th} graders who intended to continue with their science studies, and those who didn't. Girls' in both groups made many more negative comments about physics than boys did. Thus, it seems that the increasing access of female students to the traditionally masculine science subjects is being accompanied by the emergence of biology as a feminine niche in science (Ayalon, 1995).

Some researchers have suggested that the basis of these stereotypically gendered interests is an inborn trait which hard-wires the average girl for empathy, while the average boy is predominantly hard-wired for understanding and building systems (Baron-Cohen, 2003). Other studies, however, did not find any such difference (Hyde & Linn, 2006). A landmark MRI Study of Normal Brain Development (Waber et al., 2007) found that mental performance differs very little by gender. In her review, Spelke (2005) states that "Thousands of studies of human infants, conducted over three decades, provide no evidence for a male advantage in perceiving, learning, or reasoning about objects, their motions, and their mechanical interactions. Instead, male and female infants perceive and learn about objects in highly convergent ways."

Additional explanations, which do not assume an inborn gender difference, were subsequently suggested to explain girls' lack of interest and under-representation in science; they are traditionally divided into the three, somewhat overlapping categories suggested by Kelly (1978):

(1) *Cultural* explanations, which may be referred to as 'socialization explanations', include the masculine image of science, which is seen years prior to the actual encounter with disciplinary school science (Farenga & Joyce, 1999), lack of female role models and their image in the media (Handelsman et al., 2005; Schibeci & Lee, 2003; Steinke, 1997), lack of out-of-school experiences (Kahle & Lakes, 1983; Shakeshaft, 1995), parental gendered-beliefs regarding science (Tenenbaum & Leaper, 2003), peers views during puberty (Brownlow, Smith, & Ellis, 2002; Pettitt, 2004), girls' low self-efficacy (Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000), and issues concerning values and identity (Schreiner & Sjoberg, 2007).

(2) *Attitudinal* explanations refer to girls' negative attitudes towards science and pursuing a science-related career (Crettaz von Roten, 2004; Kahle & Lakes, 1983; Kelly, 1978; Miller et al., 2006; Simpson & Oliver, 1985; Weinburgh, 1995). Some factors, such as misuse, difficulty and masculine image, which were brought up to explain girls' less favorable attitudes toward science, apply more strongly to the physical sciences (Kelly, 1978).

(3) *Educational* explanations include school-related parameters, such as enrollment and achievement in mathematics classes, class atmosphere, teaching and assessment methods traditionally used in physics classes (Zohar & Bronshtein, 2005), gender-related differences in the notion of what it means to understand physics

(Stadler, Duit, & Benke, 2000; Zohar, 2003), and science curricula which are heavily biased towards the interests, knowledge and abilities of boys (Hoffmann, 2002; Nair & Majetich, 1995). Haussler *et al.* (1998), for example, identified five domains of interest in physics; only one of them—physics as a scientific enterprise for its own sake—is overwhelmingly dominant in physics classrooms. Other domains, such as how science can serve humankind and explanations of natural phenomena, which are of more interest to girls, are almost nonexistent (Haussler, Hoffman, Langeheine, Rost, & Sievers, 1998). Despite international reports of educational success for girls, very little has in fact changed over the past few decades with respect to their science and mathematics subject choice (van Langen, Rekers-Mombarg, & Dekkers, 2006). For a comprehensive review of recent research on girls' participation in school physics see (Murphy & Whitelegg, 2006).

Evidence from free-choice science-learning settings indicates that the polar pattern of girls' relatively high interest in biology and boys' relatively high interest in physics is similar to the situation described within formal science education. The gender gap is already evident among young elementary-school children, before biology and physics have been identified as such, and it persists all the way into adulthood (Baram-Tsabari & Yarden, 2008).

The gender effect on science-related attitudes and beliefs is not homogeneous across measures, science-content areas, racial or socioeconomic groups (Kahle et al., 1993), or cultural or situational contexts (Linn & Hyde, 1989). However, stereotypical male and female interests seem to cross borders and cultures. The SAS project, for example, found strong similarities between the lists of Norwegian and Japanese science topics favored by boys and girls, despite the strong cultural differences between these two countries (Sjoberg, 2000). Similar findings were obtained from a comparison between Israeli and international children's spontaneous interests (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005).

This similarity is also valid for enrollment rates of women in science- and technology-related occupations. In Egypt, for example, a survey by the Supreme Council of Universities for 1995-96 reports that in disciplines such as pharmacy and dentistry, more than 40% of the faculty are women; in the sciences, 25% of the faculty is women, but this decreases to less than 10% in the engineering and technology departments. These statistics are very similar to those for US universities, where women constitute 50% of the health sciences faculty, 23.8% of the biological sciences faculty, and 6.1% of the engineering faculty (Hassan, 2000). In most OECD countries, the proportion of women choosing advanced science and technology studies remains below 40%, and the choice of discipline is highly gender-dependent (Organisation for Economic Co-operation and Development [OECD], 2006).

Contrary to expectation, gender differences are not smaller in technologically advanced countries, which foster mass education and equity legislation, or in advantaged socioeconomic groups (Steinkamp & Maehr, 1984). To list a few recent examples, in Latin America and the Caribbean, women account for 46% of the reported number of researchers, while their share falls to 15% in Asia and about 30% in Africa. In Europe, 32% of the researchers are women, with only five countries reaching gender parity (UNESCO Institute for Statistics, 2006). Among school student, gender differences in science achievements are higher for fourth and eight grade students from the Netherlands, compared to students from Cyprus and Latvia (Martin, Mullis, Gonzalez, & Chrostowski, 2004; UNESCO Institute of Statistics, 2005).

Females, more than their male peers, tend to lose interest in science as they grow older, mainly during the middle-school and high-school years (George, 2006; Greenfield, 1998). American girls' attitude to science was found to become increasingly negative with age (Kahle & Lakes, 1983), a finding that was repeated among Israeli students (Friedler & Tamir, 1990; Shemesh, 1990). Furthermore, a significant decrease in the number of American girls submitting science questions to an Ask-A-Scientist site occurred during the transition from junior to senior high school (Baram-Tsabari et al., 2006). A study conducted in Germany also found a difference in the way interest in physics develops with age: girls, but not boys, find physics as a school subject less and less interesting as they grow older (Hoffmann, 2002; Hoffmann & Haussler, 1998).

Research approach

Despite recent efforts to harmonize statistical information on education at the international level, current data sets do not allow for a full comparative analysis, and may lead to conflicting interpretations (OECD, 2006). It is rather difficult to use the existing data to examine interactions between gender, age, country of origin and interest in science, as they were not specifically and deliberately addressed in advance by the researchers. The international studies SAS and ROSE describe interactions between country and gender, but they do so for a single age group (15-year-old students) in a formal science setting using questionnaires.

Interest in science have been traditionally identified using written questionnaires that rely on adult-centric views of what subjects should be meaningful to students. Cook-Sather (2002) advocates the notion that there is something fundamentally amiss about building and rebuilding the educational system without consulting those it is ostensibly designed to serve. We believe that relying on children's spontaneous ideas and questions will enable progress towards incorporation of their views, more than using their responses to an adult-written questionnaire. Therefore, we recently suggested using children's self-generated science-related questions as a tool to probe students' scientific interests (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005, , 2008, , in press). Self-generated questions can help reveal the asker's reasoning, alternative views, and interests (Biddulph, Symington, & Osborne, 1986), and studying students' questions can make teachers aware of what students are interested in and what they want to know about a given topic (Chin & Chia, 2004).

Web-based research

The potential for online experimental laboratories for the social and behavioral sciences was already described a decade ago, in 1997 the NetLab report (National Science Foundation, 1997), which suggested that the web could enable experiments to (i) be scaled up to include hundreds or even thousands of subjects; (ii) cross many boundaries, bringing new population samples into the laboratory; (iii) mimic lengthy time periods in which subjects interact with one another over long intervals; and (iv) make laboratory experimentation a part of the routine education of undergraduates. Ten years latter, in a *Science* paper, entitled "The scientific research potential of virtual worlds", Bainbrifge (2007) introduce a number of possible research methodologies for web-based research, including formal experimentation, observational ethnography, and quantitative analysis.

The actualization of the potential of web-based research was rather modest so far: the overall incidence of articles using web-based research in APA journals during 2003-2004 was relatively low (1.6%) (Skitka & Sargis, 2006). Skitka & Sargis (2006) classified studies that do use the web for data collection into three types of web-based psychological research:

(1) Translational research, which involves adapting materials and methods originally developed for offline use for use on the internet.

(2) Phenomenological research, which focuses on the specific nature of how internet use and internet-based interaction (e.g. anonymous interaction) influence people's thoughts, feelings, and behavior.

(3) Novel methodological use of the internet, such as use of information freely available on the net.

Among the translational research one can name Web surveys, which are having a profound effect on the survey research industry (Couper, 2000). The BBC, for example, commissioned a large-scale web-based survey to investigate sex differences (Reimers, 2007). During three month of data collection over quarter of a million participants concluded the long survey which took about 40 minutes to complete.

An expanding theme for phenomenological research, are studies of massively multi-user online role-playing games. Yee, who used online survey data that were collected from 30,000 users over a three year period to explore gamers' demographics, motivations, and derived experiences (Yee, 2006), suggest that these online environments could potentially be unique research platforms for the social sciences and clinical therapy, but it is crucial to first establish that social behavior and norms in virtual environments are comparable to those in the physical world. In an observational study of the virtual community Second Life, Yee, Bailenson, Urbanek, Chang, and Merget (2007) found that social norms of gender, interpersonal distance, and eye gaze transfer into virtual environments even though the modality of movement is entirely different (i.e., via keyboard and mouse as opposed to eyes and legs).

Massively multiplayer online games are also a platform for novel methodological use of the internet, such as the study of cognition, learning and literacy in online digital contexts (Steinkuehler, in press). An online forum discussion of the online game *World of Warcraft*, for example, was used to evaluate the scientific habits of mind used by the participants (Steinkuehler & Chmiel, 2006). In another research, Kafai, Feldon, Fields, Giang, and Quintero (2007) infected communities in Whyville.net, a teen online community with over 1.5 million registered players ages 8-16, with a virtual epidemic called Whypox, in order to understand the impact of the event on different aspects of community life and its potential as a model for educational interventions.

As access to and use of the internet becomes more widely and representatively distributed globally, new opportunities exist for behavioral researchers to collect data online (Rhodes, Bowie, & Hergenrather, 2003). However, promising as it may be, web-based research raises many methodological considerations. Six preconceptions that have been raised as likely limitations of internet questionnaires were put into the test by Gosling, Vazire, Srivastava, and John (2004), who found that Internet samples are shown to be relatively diverse with respect to gender, socioeconomic status, geographic region, and age. They also found that Internet findings generalize across presentation formats, are not adversely affected by nonserious or repeat responders, and are consistent with findings from traditional methods (Gosling et al., 2004). Rhodes et al (Rhodes et al., 2003) conclude that many of the criticisms of online data collection are common to other survey research methodologies.

Here we use data gathered in a web-based free-choice science-learning environment to learn more about these multidimensional interactions, using questions sent to an international Ask-A-Scientist site by people from various age groups and countries. Our study falls into the second and third categories of Skitka & Sargis (2006) classification of studies that use the web for data collection: It is a phenomenological research, in the sense that it compares girls interest in science in online and offline situations, and it is a novel methodological use of the internet, in the sense that it makes use of information freely available on the net. Our research questions are:

1. How did the percentage of questions asked by females change between countries, with age and with time?
2. How did the scientific interests, as they were reflected by the subject of the questions, change with age and time, between genders and between countries?

Methodology

Data source

MadSci Network is an independent, award-winning nonprofit organization operating from a server in Scottsdale, AZ (http://www.madsci.org). It was founded in September 1995 as part of Washington University's Young Scientist Program, a student-run organization in St. Louis dedicated to improving science literacy among

K-12 students. Today, the *MadSci Network* receives 90 to 150 questions daily, most of which are answered automatically by the site's search engine. Fewer than 20% of the questions are answered by nearly 800 globally distributed volunteering scientists, usually within two weeks.

Unlike most Ask-A-Scientist services (see further on), *MadSci Network* covers all branches of science, and does not focus on a specific subject area. It collects as much, and possibly more, information than most Ask-A-Scientist services, and stores key demographic information as metadata, making it easier to mine the information from the archives. Many other English-language Ask-A-Scientist services are available on the net, but none of them was found suitable for this study. The reasons for this were varied, among them: because they do not ask for the age of the asker (e.g. services run by Scientific American,[1] the Internet Public Library,[2] Yahoo! answers[3] and the paid service Google answer[4]), do not record all the information in their archives (e.g. Argonne National Labs[5]), serve a limited age group (e.g. Ask Dr. Universe[6] serves mostly elementary-school children), have a rather small database (e.g. the service run by Cornell Center for Materials Research[7] has collected just over 1,000 questions in the eight years of its existence), or answer questions only on a specific topic (e.g. Howard Hughes Medical Institute[8] receives only biology questions, Stanford University operates an Ask-a-Geneticist[9] service which receives only genetics questions, and Ask Dr. Math,[10] obviously, deals with math questions).

Sample characteristics

Over 146,000 questions were sent to *Madsci Network* between 1996 and the first half of 2006. Almost 79,000 of the surfers disclosed their grade level, country of origin, and filled in the name and subject fields. These questions were used in our analysis. Even after this preliminary filtering, a few questions were missing some of the data, and therefore the n values differ between the variables.

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[1] http://www.sciam.com/page.cfm?section=expertform
[2] http://www.ipl.org/div/askus/
[3] http://answers.yahoo.com/
[4] http://www.answer.google.com/answers/
[5] http://www.newton.dep.anl.gov/archive.htm
[6] http://www.wsu.edu/DrUniverse/
[7] http://www.ccmr.cornell.edu/education/ask/
[8] http://www.hhmi.org/askascientist/
[9] http://my.thetech.org/askScientist/askquestion.php
[10] http://mathforum.org/dr.math/ask/submit.html

The number of questions was not evenly distributed between years. In two cases, changes that were made in the site explain the decline in the number of questions relative to the previous year. For a full list of the number of questions for each year see appendix 1.

Age split: 78,517 of the inquirers provided their grade level, and 66% of the surfers were school students: 2.4% were K-3 students, 10.5% 4-6th graders, 26% junior high-school students and 27.9% senior high-school students. Higher-education undergraduates contributed 17.6% of the questions, science graduates 7.5% and non-science graduates 4.2%. Teachers sent in 4% of the questions.

Gender split: Gender identification was based on the asker's first name. Initial classification was done semi-automatically using an English name gender finder.[11] Next, the names that were not automatically classified and appeared twice or more in the data (~3,500 names) were analyzed individually using a baby name guesser,[12] which operates by analyzing popular usage on the internet. In this way, we were able to identify the gender of the asker in 48,360 of the questions. The rest were either names that could equally belong to boys or girls, meaningless scrambles, or names that appeared only once in the database. Of the gender-identifiable questions, 51.63% were asked by boys (n = 24,968) and 48.37% were asked by girls (n = 23,392).

Split by country of origin: 78,657 of the inquirers indicated their country of origin. The surfers originated from 143 countries that were grouped into 14 socio-geographic zones (Table 1), with 90% of the questions originating from eight English-speaking countries (not necessarily as mother tongue): USA, UK, Canada, Australia, India, Singapore, Philippines, and New Zealand.

The number of questions arriving from the different countries was found to be weakly, but significantly, correlated to the country's Gross Domestic Product (GDP) per capita (n = 120 countries,[13] p = 0.006) and to its number of internet users per 1,000 people (n = 85 countries,[13] p = 0.04) according to data from the 2005 *Human Development Report* (United Nations Development Programme, 2005).

[Table 1 about here]

[11] Japan Online Directory: http://epublishing.nademoya.biz/japan/names_in_english.php?nid=A
[12] http://www.gpeters.com/names/baby-names.php
[13] Number of countries that appeared in the sample and had the relevant data in the report

Subject of questions: The questions were allocated by the surfers into one of 25 topics. For clarity, we pooled them into seven main fields of interest, appearing here in their order of popularity: Biology (e.g. How long does it take for the calories in your body to transform into fat?), Chemistry (e.g. Will a coke fizz if it is opened in equal pressure?), Physics (e.g. If I want to find out the volume of myself using a bath tub, how do I do it?), Technology (e.g. can you give me any links to research of language translation by inserting a chip into a persons brain?), Earth Sciences (e.g. why can't Hawaii get rid of its trash by putting it in a volcano?), Astronomy (e.g. why do Meteorites in the same orbit enter atmosphere at different angles?), and Science History (e.g. when did scientists realize that the brain, not the heart, was used for thought?).

Biology includes the following *Madsci* topics (in order of popularity): Biochemistry, General Biology, Zoology, Botany, Anatomy, Cell Biology, Environment and Ecology, Medicine, Genetics, Microbiology, Neuroscience, Agricultural Sciences, Evolution, Molecular Biology, Development, Virology, Immunology, and Biophysics. Technology includes the *Madsci* topics Engineering and Computer Science. The other topics were not further subdivided by the web site's operators.

Although all of the questions in this sample were self-generated by the askers, it is important to note that some of them were school-related. These questions were not spontaneously raised by the students, but were the consequence of a school assignment. In the current study we did not identify these school-related questions. However, in a previous study, that rigorously examined a three-month sample of 4^{th}-12^{th} graders' questions sent to the same web site, questions were classified as "school related" if it was explicitly stated in the question that the information is required for a school assignment, such as a science fair project, report, and homework (e.g. Who wrote the origin of species? it is for a bonus question) (Baram-Tsabari et al., 2006). In that analysis we learned that chemistry is characterized by a relatively large number of school-related questions, while this is less true for astrophysics. Biological topics such as anatomy and physiology, sickness and medicine, and genetics and reproduction were all characterized by relatively more 'spontaneous' than school-related questions. Botany and mycology, microbiology, virology and cell biology yielded many more teacher- and textbook-generated questions than spontaneous ones. Topics such as ecology and neurology were almost equally distributed among the two question types (Baram-Tsabari et al., 2006).

Statistical analysis: Unless otherwise indicated, a two-tailed Pearson chi-square test was used to calculate probabilities. Not all of the inquirers provided their full details; therefore, sample sizes differ from graph to graph and are indicated by n values. Significant differences within proportions were determined according to a cell chi-square test.

Findings

A decade of questions sent to an Ask-A-Scientist internet site, which were analyzed by age, gender, country of origin and the time they were sent, provided answers to questions concerning the level of female participation and topics of interest in science as they were reflected by the subjects of the questions.

Age and geographical distribution of female participants

Overall, among the gender-identifiable questions, 51.63% were asked by boys ($n = 24,968$), 48.37% by girls ($n = 23,392$). However, among K-12 students, we found a dominance of female contributors (see below). Different countries displayed different female-participation patterns ($p < 0.0001$).

Female participation rates in 39 countries that contributed 25 or more gender-identified questions were analyzed ($n = 47,749$). The most 'feminine country' with a female participation of 61.1% was Egypt, followed by Hong Kong, Colombia, Philippines, Switzerland, Iran and Indonesia, which all presented more female contributions than male ones. US, Ireland, Australia and New Zealand had an almost equal gender split, while the remaining countries all presented male dominance. Completing the list was Sweden with only 5.6% of the contributions sent by girls, and Peru, the Netherlands, Brazil, Romania and Denmark close behind (Figure 1).

[Figure 1 about here]

Female participation was found to be correlated ($n = 40$ countries, $r = -0.36$, $p = 0.02$) with the difference between males' and females' science scores in the 8^{th} grade among countries who had participated in the TIMSS research (Martin et al., 2004). A correlation was not found, however, with the gender-related development index of the UN[14] (United Nations Development Programme, 2005), indicating that the female participation in this free-choice science activity was not related to the level of equity in the different countries.

A significant difference ($p < 0.0001$) was found in the female participation among the different age groups (n = 46,578). Overall, females sent the majority of contributions among K-12 students, but their percentage dropped upon moving from junior high to high school, they became the minority among undergraduates and even more so among graduates (Table 2, last row).

One might conclude that the decrease in female's contributions with age was due to their loss of interest and not to an increase in male interest, since the decrease in the girls' contributions percentage was accompanied by a decrease in their absolute number, while the boys' contributions percentage increase was also accompanied by a decrease in their absolute number. This decrease in absolute numbers was due to a general decline in the number of questions sent by the older age groups: 26% were sent by junior high-school students, 27.9% by senior high-school students, 17.6% by undergraduates and only 11.7% by graduates. It should be noted that we are not suggesting that students tend to lose interest in science as they grow older on the basis of the drop in the absolute questions' number in our sample, since a specific internet site, such as *MadSci*, has a target audience, and is not equally appealing to every age group. Moreover, the older people may have found other sources for answering their questions.

[Table 2 about here]

The decrease of female participation with age was observed all over the world. This pattern was clearly displayed for questions arriving from the US, UK, Canada, and Australia & New Zealand (Table 2). Girls from the Far East dropped their participation rates sooner: from almost 70% among the K-3rd graders to 49% among 4-6th graders, 40-43% in high school and 37-35% among undergraduates and graduates. The same happened in Latin America, where the female majority among 4-

[14] Human development reports, Technical Note 1: The gender-related development index (GDI) adjusts the average achievement of a country to reflect the *inequalities* between men and women using three basic dimensions of human development: (1) A long and healthy life, as measured by life expectancy at birth. (2) Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary and tertiary gross enrolment ratio (with one-third weight). (3) A decent standard of living, as measured by GDP per capita.

9th graders became a minority in high school (40%), and even more so among undergraduates and graduates (20%).

In Southeast Asia, the female participation rate for 7-12th graders was 47-48% and 27% for undergraduates and graduates. In Africa, girls' participation gradually fell from 59% in junior high school to 14% among graduates. The same was found in data from Turkey, Iran and the Arab world, where girls' participation gradually fell from 74% in junior high school to 44% among graduates. In Western Europe, girls' participation grew as long as the girls were K-12 students, reaching almost 50%, and then fell to 32-33% among undergraduates and graduates. In Northern Europe, girls contributed 56% of the high-school questions, but only 3% of the undergraduate and 15% of the graduate questions. The remaining socio-geographical zones did not provide enough data to allow this kind of analysis.

The rate of female participation changed between the years 1996 and 2006 ($p < 0.0001$); however, a constant trend was not found, and females' percentages fluctuated between years (1996, 36.9%; 1997, 44.7%; 1998, 52.4%; 1999, 42.6%; 2000, 47.6%; 2001, 47.1%; 2002, 50.8%; 2003, 51.9%; 2004, 49.8%; 2005, 49.2%; 2006, 45.4%). A constant trend was not identified in any of the separate socio-geographical zones either.

Identifying scientific interests

Overall, the questions referred to the following scientific disciplines, appearing here in their order of popularity: Biology (42.5%), Chemistry (19.1%), Physics (17.9%), Technology (7.2%), Earth Sciences (6.4%), Astronomy (5.6%), and History of Science (1.4%).

As expected, a significant difference ($p < 0.0001$) was found in the distribution of question topics between boys and girls (n = 42,705). Boys were more interested than girls in physics (23.5% vs. 11% of the boys' and girls' questions, respectively) and technology (9.2% vs. 3.2% of the boys' and girls' questions, respectively), while girls were more interested than boys in biology (51.1% vs. 36.6% of the girls' and boys' questions, respectively) (Figure 2). Statistical differences between girls and boys were found in all subjects, but those which contributed the most to the differences were physics, technology and biology.[15]

[15] According to a cell chi-square test

[Figure 2 about here]

Question topic differed significantly ($p < 0.0001$) between age groups (n = 69,529). Interest in physics and technology increased with age (physics: from 13% among K-3 to 24% among graduates; technology: from 4% among K-3 to 15% among graduates), while interest in the earth sciences decreased with age (from 9.9-13.3% among K-6 to 3.7% among graduates). Interest in chemistry peaked to 25% during the high-school years, probably due to the relative abundance of school-related questions in this subject among this age group (Baram-Tsabari et al., 2006).

The two genders developed different scientific interests as they grew: distinctively different trends were identified in the development of interest in biology and physics (n = 41,028). Males developed interest in physics with age (from 16.3% of the questions among K-3 to 30.5% among graduates), while females did not seem to develop such an interest to the same degree (9.8% of the questions among K-3 and 12.4% among graduates). Males lost some interest in biology with age (from 45.5% of the questions among K-3 to 31.1% among graduates), while females actually showed more interest in the subject with age (from 49.5% of the questions among K-3 to 60.3% among graduates) (Figure 3).

The initial gap in the interests of K-3 boys and girls refers only to physics, but as the children mature, the gap between their stereotypically gendered science interests widens and refers to biology as well.

[Figure 3 about here]

A significant difference ($p < 0.0001$) was found in the distribution of the questions topics with years (n = 69,869). Some of this difference might originate from a decrease in interest in astronomy (from 10.8% in 1996 to 4.8% in 2006) and an increase in interest in technology (from 4.1% in 1996 to 8.4% in 2006). The rest may originate from nondirected fluctuations between the years that were found to be significant only due to the massive sample size. Changes in question topics' across years could have relationship to science-related current events, such as Hurricanes. In such cases the site operators provide a link to frequently asked questions on the subject in a visible place on the homepage[16]. However, when we specifically looked for an increase in questions about Tsunami after the deadly Tsunami hit countries in South Asia in December 2004, we found only a few questions about the topic.

We found a significant difference ($p < 0.0001$) in the distribution of question topics between different geographic zones, with the biggest differences between the US and countries in Southeast Asia. Since the female participation at this site was very different in these two geographical zones (51% in the USA vs. 32% in Southeast Asia), the distribution of question topics was compared for each gender separately. Regardless of the large stereotypical gender-related differences in interests, both male and female Americans were more interested in chemistry, earth sciences and astrophysics than male and female students from southeast Asia, but less interested in physics and technology than their overseas peers.

Discussion

Almost 79,000 questions sent over the course of a decade to an international Ask-A-Scientist site were used to learn about the scientific interests of boys and girls of different age groups from various countries in an online free-choice science-learning environment. The site was found to serve as a web-based bypass for traditional gender inequities in science education, while maintaining the usual gender gap in interest in biology and physics.

One finding emerging from the analysis was the absence of correlation between the gender-related developmental index of the UN and the level of female participation among the contributions originating from different countries. In other words, countries that emphasize equity in their education policy and legislation did not have a higher percentage of girls sending questions to this science site than countries which do not promote gender equity.

Gender equity has been a dominating political and educational concern in Scandinavian countries since the mid-1970s (Sjoberg, 2000). For example, for the past 20 years Sweden has launched general information campaigns aimed at broadening girls' educational and occupational choices, and stimulating their interest in science and technology, promoted intervention projects for teachers and science centers, reviewed girls' attitudes and issued relevant policies. In Denmark, among

[16] http://www.madsci.org/FAQs/earth/hurricanes.html

other initiatives, the government has placed equal-opportunities consultants in employment offices, and groups of women science teachers have been linked to tertiary institutions (Harding & Parker, 1995). At the same time, in many Muslim countries, gender-based discrimination, coupled with social and cultural barriers, limits women's access to and participation in higher education, and career opportunities for female science graduates are more limited than for their male counterparts (Hassan, 2000).

Nevertheless, Egypt, Iran and Indonesia (ranked 119, 99, and 110, respectively, in the UN's Gender-Related Development Index [GDI]) displayed a female dominance among contributors, while Sweden, Denmark, and the Netherlands (ranked 6, 14, and 12, respectively, in the GDI) had among the lowest percentage of female contributors in our research. The relationship between the GDI and female participation is neither linear nor inverted—it simply does not exist. For example, the Philippines (ranked 84 in the GDI) displayed a female majority, while Peru (ranked 79 in the GDI) displayed only a small minority of girls.

It might prove fruitful to view these findings in light of the results from the international project "Science and Scientists" (Sjoberg, 2000), which found that children in rich and technologically developed countries show a low or moderate interest in learning science topics, with Japan, Norway, and Sweden being the lowest. Children from developing countries, on the other hand, appear to be very interested in learning science. The gender profile is also intriguing: in most developed countries, boys are more interested in learning science than girls, while in most developing countries, the opposite is true (Sjoberg, 2000). Sjøberg tentatively explains this pattern with the idea that obtaining an education is a luxury in developing countries, especially for girls, while it is perceived as a burden by many students in developed countries. This finding was repeated in results from the ongoing international "Relevance of Science Education" [ROSE] project which found that the higher the level of development in a country, the lower the level of interest expressed by students towards learning about science- and technology-related topics and having a career in those fields (Sjoberg & Schreiner, 2005). Sjøberg & Schreiner suggest that this pattern might reflect the post-materialistic values of youth in developed societies, in contrast to the view of science in developing countries as a key for improving the quality of life. Schreiner (2006) interpreted interest as a sign of late-modern identity, and explained that the more modernized a country, the more its girls accentuate their femaleness and boys their maleness.

One can suggest that if a school in developed western country provides a richer environment for science learning, maybe girls just do not need the ask-a-scientist tool. However, this does not explain why boys from the same country do need the tool. Moreover, research tells us that gender differences are not smaller in technologically advanced countries or in advantaged socioeconomic groups with regard to percentage of female researchers (UNESCO Institute for Statistics, 2006) and gender differences in science achievements are higher among school students (Martin et al., 2004). We can further hypothesize that females in developed countries have a wider range of educational and occupational possibilities, and therefore do not view science as a unique escape route from their traditional gender roles. It is also possible that females' interest in science is a product of their wish to impact society, or even a form of rebellion against a limiting society, similar to the way in which forming a reading group of English literature served the participating women in "Reading Lolita in Tehran" (Nafisi, 2003).

The case of Iran presents the most fascinating paradox: on the one hand, post-revolutionary educational policy in Iran is characterized by the banning of coeducation, compulsory veiling of female students over the age of 6, explicit gender stereotyping in school textbooks, guiding female students toward feminine specializations and occupations (such as sewing, nursing and teaching), and creating a traditional atmosphere in schools in order to educate 'modest girls and courageous boys' (Mehran, 2003). The republic's education plan assigns different roles and responsibilities to boys and girls, embedded in principles such as: "The Iranian educational system should recognize the identity of a woman and her role in the family and the society on the basis of Islam and plan for the content and method of her schooling accordingly," and "...their [girls'] vocational guidance should take into consideration the kinds of occupations needed by women, best fulfilled by women, or most fit their role and responsibility in the family." On the other hand, since the Islamic revolution there has been a significant increase in female enrollment at every educational level, including university (Mehran, 2003), Iran presents no gender gap in science achievements in the last TIMSS research (Martin et al., 2004), and it is among the few countries in our study that displayed a female majority among contributors of science questions.

This paradox may indicate that the internet as a free-choice science-learning environment has a potentially empowering and democratic role which is especially relevant to populations which are deprived of equal opportunities to learn formal science. Indeed, according to estimations, internet use in Iran is more common than in any other country in the Middle East except for Israel, and Farsi is the fourth most prevalent language on the internet (Menshari, 2007). Rahimi (2003) argues that the internet, as an advancing new means of communication, has played an important role in the ongoing struggle for democracy in Iran, allowing internet users--especially women--.to take advantage of the freedom provided by the internet, as an alternative medium for expression that is denied to them in real public spaces (Rahimi, 2003).

Inequitable social distribution of knowledge and access to knowledge is not merely a phenomenon of non-Western cultures—such inequities exist within Western cultures as well (Kyle, 1999). The Internet seems to provide an attractive science-learning environment for female students, who are traditionally found to be less interested in science than males in offline situations, but constitute the majority of contributors among K-12 age groups in our sample. A female majority was found in other web-based free-choice science learning environments, such as *Whyville* (Aschbacher, 2003), *KidsConnect* (Lankes, 2003), Ask-A-Geneticist (our unpublished results), and Argonne National Labs (our unpublished results), but not in Ask-A-Scientist TV-shows for kids (Baram-Tsabari & Yarden, 2005), and adults (Baram-Tsabari & Yarden, 2008). The difference in female participation between web-based and TV-based settings might be a product of the level of anonymity and safe atmosphere they provide. Furthermore, the textual modality of web-based Ask-A-Scientist answer is better suited to lengthily explanations and essay-like answers which demands deep understanding, rather than short factual "right answers" which are known to be less female-friendly (Behling, 2002). Former studies on students' questions found that on the average, girls are more interested in asking for explanations than boys, while the boys are more interested in factual and methodological information than girls (Baram-Tsabari & Yarden, 2005, , 2008). It is interesting to note that we did not find an increase in female participation over the decade in which the questions were asked, which may mean that the internet as a science-learning setting has not become more female-friendly over the years.

Attractive and inclusive as it may be, girls seem to lose their wish to submit science questions to the web site as they grow older. This finding mirrors previous research in which American girls' attitude to science was found to become increasingly negative with age (Kahle & Lakes, 1983), as well as studies carried out in Israel (Friedler & Tamir, 1990; Shemesh, 1990) and the UK (Murphy & Whitelegg, 2006).

It is possible that the core of the decrease in female contributions with age is gendered philosophies or perspectives, rather than science interest specifically. Schreiner and Sjøberg, for example, suggest (2007) that young western people, especially girls, do not want to have an identity that is seen to be connected with being a physicist or an engineer. Such a tendency might be a reason for loosing interest in science. In this study, we are unable to identify gender-related and gender-unrelated reasons for loosing interest in science. It is important to note, however, that the decrease in female contributions in our sample occurs at the same time that it is expected from school-based findings, were girls were found to lose interest in science upon moving from junior to senior high school and into higher education.

We found the polar pattern of girls' higher interest in biology and boys' greater interest in physics in free-choice science-learning settings to be similar to the situation described within formal science education. However, this seemingly spontaneous interest might be to some extent a result of formal schooling, and not a completely independent measure of out-of-school interest.

However, an interesting disagreement was found regarding the development of interest in physics. A study conducted in German schools reported that girls find physics as a school subject less and less interesting as they grow older, while boys do not lose their interest (Hoffmann, 2002; Hoffmann & Haussler, 1998). Based on our data it seems that girls do not lose their interest in physics, but simply never develop such an interest.

Using our current analysis it is impossible to tease apart the apparent connection between course-taking patterns, historically noted in the literature, and interests as they are reflected by self-generated questions. However, this finding is aligned with results obtained in a former study which used only spontaneously asked questions (non school-related) from three different databases that provided Ask-A-Scientist applications for different age groups in different countries and languages (Baram-Tsabari & Yarden, 2008). It is possible that the seemingly contradictory findings obtained in German schools result from the different settings and methodologies used for gathering the data. We suggest that this inconsistency be further studied.

Methodological considerations and limitations

After discussing the above findings, it is important to acknowledge some limitations of the research methodology and the uncontrolled sample that was used in this study.

Coverage error is presently the biggest threat to inferences from Web surveys, at least to groups beyond those defined by access to or use of the web (Couper, 2000). Coverage error is a function of the mismatch between the target population (the set of people one wishes to study) and the frame population (the proportion of the target population that potentially can be reached via the web) (Couper, 2000). However, the most recent Pew Internet Project survey finds that 87% of all American youth between the ages of 12 and 17 use the internet (Rainie & Hitlin, 2005), and in the fall of 2003, nearly 100% of public schools in the US already had access to the internet (National Center for Education Statistics, 2005), theoretically allowing all students to send their questions and be part of our sample.

However, use of the web has linguistic and socioeconomic aspects as well. To state one example, a sample of the geographical distribution of visitors to a science controversies online forum that deals with genetically modified food showed heavy participation from the US. The study's authors assumed that this was a reflection of the number of people with internet access and fluency in English rather than an interest in debates about food (Triunfol & Hines, 2004). We assume that the heavy participation of users originating from English-speaking countries, particularly the US, is in no way representative of the level of interest in science in different countries.

The nature of our data poses some methodological problems too. In our dataset, the askers are the ones who allocated the question to a certain subject area, and we can not guarantee that this topic classification would be identical to a classification done by a science education researcher. We attempted to maximize the reliability of the data by including in the analysis only questions from participants who provided background data regarding their name, age and origin. Our intention was to exclude "causal" participants who just happen to click with no formulated question in mind, and saboteurs, who just wanted to send meaningless scrambles or annoy the site operators (and the scientific community in general). However, there may be a sampling bias in who reports their real name as opposed to meaningless scrambles.

The self reported nature of the dataset is actually one of the strengths of this study. A problem of surveys in general are measurement errors – the deviation from the answers of responders from their true values on the measure (Couper, 2000). Traditional questionnaire-based interest-studies relay on self-reporting to measure interest, this study, however, does not ask students to respond to our requests, but observe cases in which they initiate action themselves for their own purposes.

The self-selecting sample used in this research does not represent all children in a particular country. It represents a group of children who might be more interested in science and have easier access to resources than the child population as a whole. There is a marked difference in the access of children from different socioeconomic statuses to the internet, which was our source for the questions. Furthermore, students who are not motivated to learn science are probably not represented in this self-selecting sample at all, regardless of their socioeconomic status. Other children that may be very interested in science but do not send questions are also not represented. Therefore, the opportunistic nature of the sample places some constrictions on the validity of our results.

The validity of the study can be supported by the notion of using data that originates from the researched population itself, not as a response to a stimulus from a researcher, thus ensuring high ecological validity. However, it is important to note that although students generated all of the questions in our sample, not all of the questions were the outcome of an intrinsic motivation to know. Many of the questions were required for school assignments and were originally raised by teachers or textbooks. This setback is even more true to studies, which examine students' questions in a classroom setting. For a list of school-related versus spontaneous topics, see (Baram-Tsabari et al., 2006).

Another way to achieve validation is by comparing any conclusions drawn with other independent observations: Using an informal data source and a new methodology our results confirm and reinforce what was revealed using the traditional questionnaire methodology in formal setting. This agreement with findings described in the literature that were gathered using control samples, serves to bolster confidence also in our new findings, which were not described before. Therefore, we assume that the trends described here represent, to a certain degree, the interests of many children, and that posing questions represents a measure of student orientation of science interest. It is also important to note that in formal settings as well certain students are more likely to ask questions than others, with low-achiving students becoming less active participants with age (Good et al., 1987). Reliability may be assured by the use of a very large sample (Reid, 2006).

Although web-based experiments of the kind used here are more difficult to control in some respects than are experiments conducted in a classroom setting, they present an important methodological advantage for studying students' self-guided science learning, taking into consideration that this kind and amount of data does not exist anywhere outside the web. Therfore, this methodology is better suited to studying the dynamic educational reality of the last decade.

Acknowledgments

This research was supported by the Israel Science Foundation (grant No. 605/06), and Sacsta Rashi Fellowship for honor students in science education. The authors would like to thank Mrs. Yetty Varon and Dr. Hillary Voet for their expert statistical advice, Mrs. Rakefet Halevi for her valuable help in the coding of the questions, and Professor Edgar Jenkins and the three anonymous reviewers for their insightful remarks on an earlier draft of this manuscript.

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Appendix

Distribution of questions sent to *Madsci Network* since its establishment

Year	Questions submitted	Questions used for the analysis	Comments
1995	21	——	The pilot year. Data were not included in the analysis.
1996	1,165	961	
1997	8,002	1,659	Over 5,000 of the surfers did not disclose their age.
1998	14,327	3,047	Over 10,000 of the surfers did not disclose their age.
1999	20,088	6,133	Over 10,000 of the surfers did not disclose their country of origin.
2000	25,165	10,438	Over 10,000 of the surfers did not disclose their country of origin.
2001	18,372	13,291	In the fall of 2001, an additional page was placed before the Ask-A-Scientist form and all questions were run through the local search engine before writing to the site.
2002	9,659	7,016	
2003	14,947	11,205	
2004	14,802	10,888	
2005	15,667	11,171	
2006	4,314	3,056	At the beginning of the year, a search engine

			form was placed on every page, and question volume dropped by ~50%. The questions were collected until June 15.
Total	146,529	78,865	

Table 1. Distribution of questions by country of origin

Country zone	Frequency	Percent[a]	Contributing countries[b]
USA	52,594	66.7	**USA**, Puerto Rico
UK	5,437	6.9	**UK** (England, Scotland, Wales, Northern Ireland), Cayman Islands, British Virgin Islands
Canada	4,802	6.1	**Canada**
Australia & New Zealand	3,618	4.6	**Australia, New Zealand**
Southeast Asia	3,580	4.5	**India**, **Pakistan**, Nepal, Sri Lanka, Bangladesh, Burma
Far East	3,127	4	**Singapore, Philippines,** *Malaysia, China, Hong Kong, Japan, Indonesia, Thailand,* Taiwan, Korea, Vietnam, Papua New Guinea, Mongolia, Brunei
Western Europe	1,841	2.3	*Ireland, Germany, Israel, Netherlands, France, Italy, Greece, Belgium,* Switzerland, Spain, Portugal, Austria, Malta, Cyprus, Luxemburg, Gibraltar
Turkey, Iran & the Arab World	1,024	1.3	*Iran, Turkey, Egypt, United Arab Emirates,* Lebanon, Oman, Saudi Arabia, Qatar, Palestinian authority, Kuwait, Iraq, Jordan, Bahrain, Morocco, Syria, Libya, Afghanistan, Algeria, Tunisia

Africa	832	1.1	*South Africa, Nigeria,* Ghana, Ethiopia, Mauritius, Kenya, Tanzania, Namibia, Uganda, Zimbabwe, Somalia, Mozambique, Malawi, Eritrea, Botswana, Gambia, Rwanda, Lesotho, Zambia, Chad
Latin America	744	0.9	*Brazil, Mexico,* Barbados, Nicaragua, Colombia, Argentina, Peru, Venezuela, Chile, Guyana, Costa Rica, Guatemala, Honduras, Dominican Republic, Ecuador, Panama, Bolivia, Paraguay, El Salvador, Belize, Saint Lucia, Antigua & Barbuda, Dominica, Uruguay, Venezuela
Northern Europe	628	0.8	*Sweden*, Norway, Denmark, Finland, Iceland
Former Communist Countries	296	0.4	Russia, Romania, Poland, Croatia, Hungary, Lithuania, Bulgaria, Latvia, Slovenia, Estonia, Albania, Czech Republic, Kazakhstan, Macedonia, Serbia & Montenegro, Ukraine, Slovakia, Belarus, Yugoslavia[c]
English-Speaking Caribbean	107	0.14	Jamaica, Trinidad & Tobago, Bahamas, Saint Kitts & Nevis, Bermuda
Pacific Ocean Islands	37	0.05	Cook Islands, Marshall Islands, Samoa, Guam

[a] 209 entries were classified as "unknown".

[b] In **bold**: over 500 entries, in *Italic*: 100-500 entries.

[c] No longer exists.

Table 2. Percentage of female participation in different age groups in various socio-geographic zones, sorted by average female participation

Socio-geographic zone[a]	K-3 (n=1,089)	Elementary (n=5,132)	Junior high school (n=13,140)	Senior high school (n=13,401)	Under-graduates (n=8,475)	Graduates (n=5,236)	Significance[c]	Average female participation[d]
USA (n=33,604)	56.98	59.54	58.46	51.55	40.44	23.85	***	51.00%
Australia & NZ (n=2,168)	47.22	67.07	60.25	56.07	35.93	27.07	***	50.60%
Canada (n=2,825)	51.28	51.64	64	50	38.25	27.24	***	49.59%
Turkey, Iran & the Arab world (n=259)	na[e]	na	73.68	51.09	55	43.56	*	49.42%
UK (n=3,569)	51.19	50.49	57.87	51.63	42.64	21.16	***	44.21%
Far East (n=1,234)	69.57	49.06	40.08	42.73	37.41	35.81	*	40.84%
Western Europe (n=877)	16.67	42.11	47.5	49.54	33.5	32.99	**	37.86%
Latin America (n=383)	na	61.54	61.76	40.46	20	19.84	***	32.11%
South-East Asia (n=695)	na	na	48	47.33	27.31	27.03	**	31.94%
Africa (n=297)	na	na	58.62	42.11	24.07	13.75	***	29.29%
Northern Europe (n=381)	na	na	na	56.25	3.21	14.75	***	10.24%
All Sample (n=46,473)[b]	54.91	58.83	58.45	51.24	38.21	25.23	***	48.89%

[a] Only socio-geographic zones that had more than 200 gender-identified contributions were included in this analysis.

[b] Including the less represented zones that do not appear in the table.

[c] Significance of gender vs. age group comparison. Marked: $***p < 0.0001$, $**p < 0.001$, $*p < 0.05$.

[d] Percentage does not include teachers and contributors who did not disclose their age group.

[e] Age groups that had less than 10 gender-identified contributions were not included in this analysis. na = not analyzed.

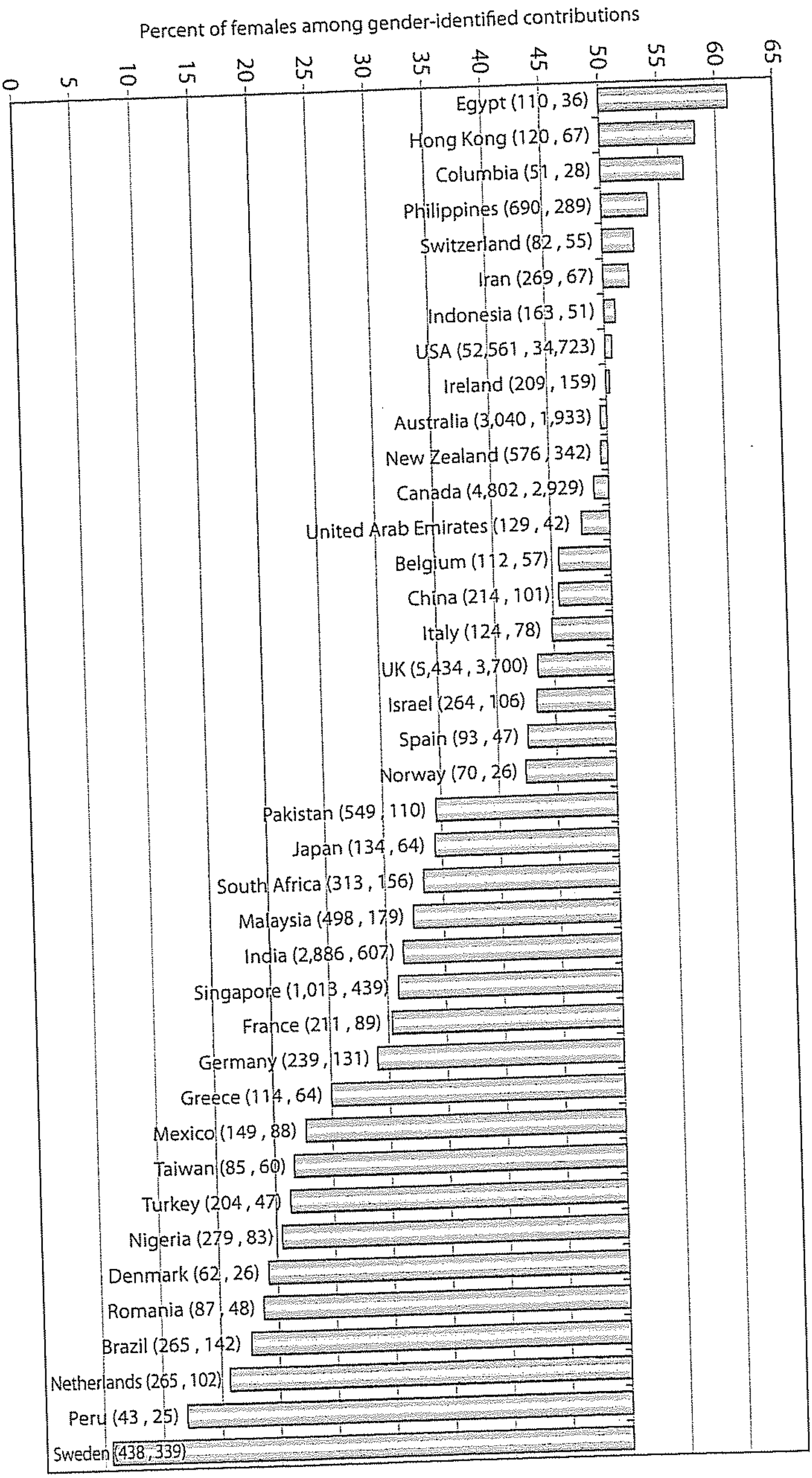
Percent of females among gender-identified contributions
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Egypt (110 , 36)
Hong Kong (120 , 67)
Columbia (51 , 28)
Philippines (690 , 289)
Switzerland (82 , 55)
Iran (269 , 67)
Indonesia (163 , 51)
USA (52,561 , 34,723)
Ireland (209 , 159)
Australia (3,040 , 1,933)
New Zealand (576 , 342)
Canada (4,802 , 2,929)
United Arab Emirates (129 , 42)
Belgium (112 , 57)
China (214 , 101)
Italy (124 , 78)
UK (5,434 , 3,700)
Israel (264 , 106)
Spain (93 , 47)
Norway (70 , 26)
Pakistan (549 , 110)
Japan (134 , 64)
South Africa (313 , 156)
Malaysia (498 , 179)
India (2,886 , 607)
Singapore (1,013 , 439)
France (211 , 89)
Germany (239 , 131)
Greece (114 , 64)
Mexico (149 , 88)
Taiwan (85 , 60)
Turkey (204 , 47)
Nigeria (279 , 83)
Denmark (62 , 26)
Romania (87 , 48)
Brazil (265 , 142)
Netherlands (265 , 102)
Peru (43 , 25)
Sweden (438 , 339)

Figure 1. The percentage of female contributors of questions from various countries ($n = 47{,}749$). X axis passes at 50%. Only countries which had 25 gender-identifiable contributions or more are shown. In brackets: number of contributions from the specific country, number of gender-identified contributions. Difference between countries is significant at $p < 0.0001$.

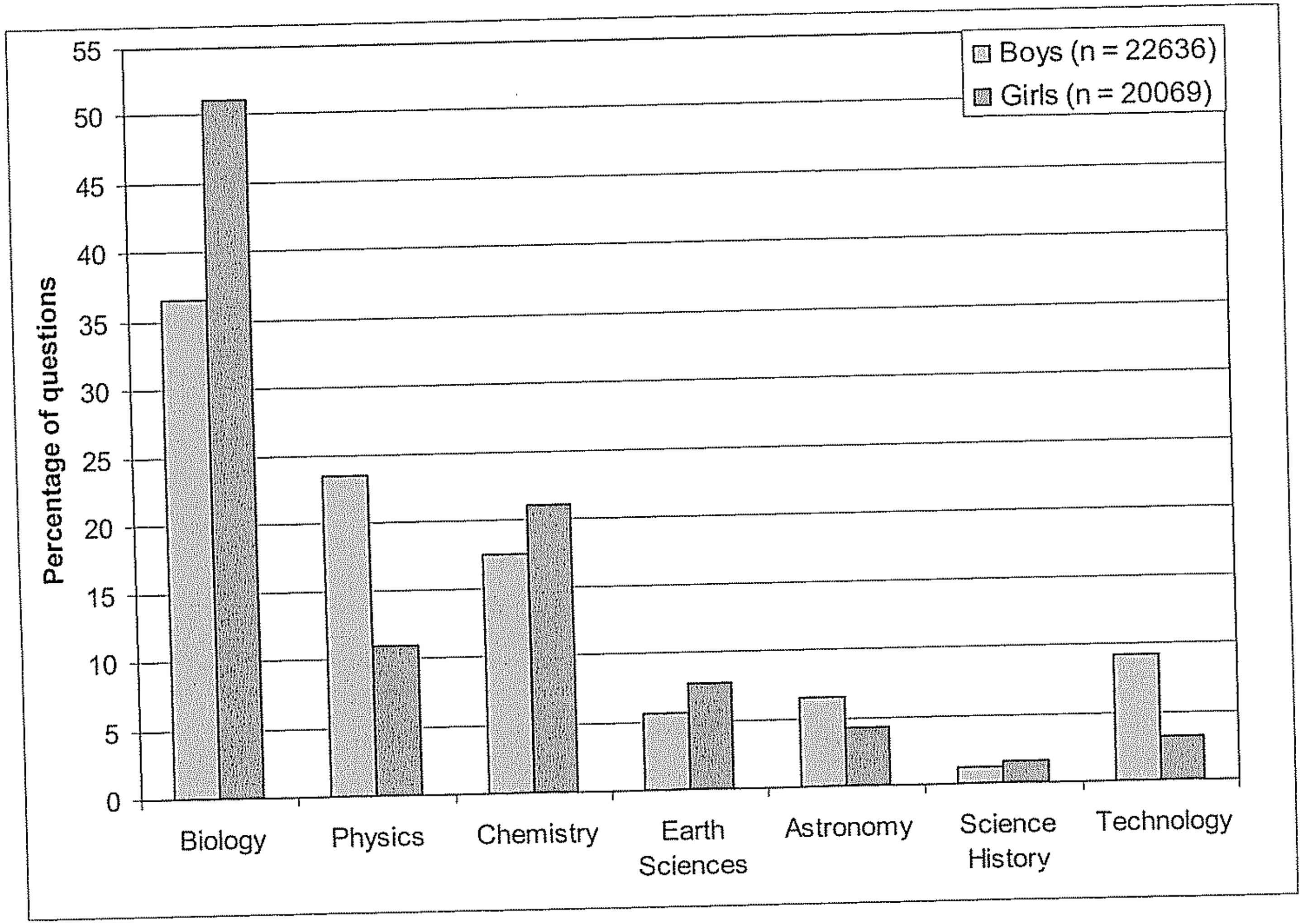

Figure 2. Scientific interests of males and females, as reflected by the subject of their questions (n = 42,705).

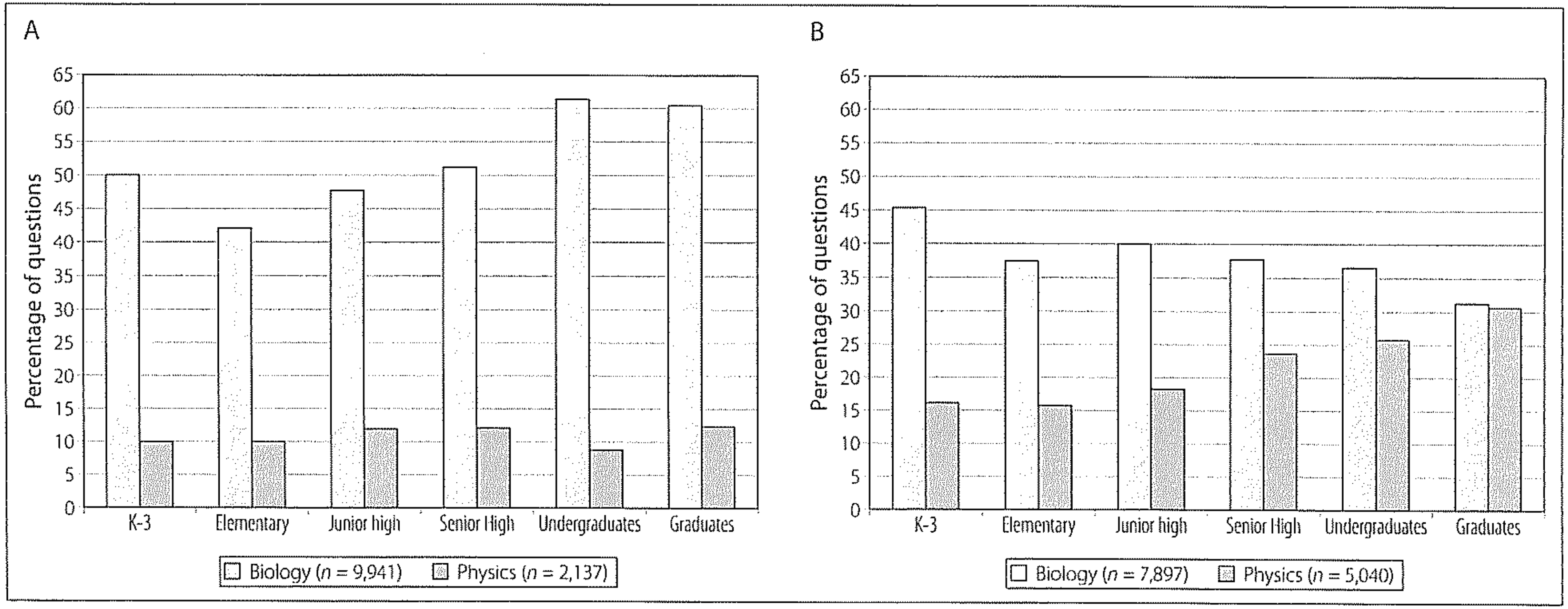

Figure 3. Development of interest in biology and physics among (A) females (n = 19,501) and (B) males (n = 21,527). In the K-3 group, difference significant at $p < 0.01$; among 4^{th}-6^{th} graders and the older age groups, difference between the genders significant at $p < 0.0001$. Percentage does not add up to 100 because questions in chemistry, earth sciences, astrophysics, and technology are not shown. Questions that did not fall under a specific topic were not included in this analysis.

Baram-Tsabari, A., & Yarden, A. (2008). Girls' biology, boys' physics: evidence from free-choice science learning settings. Research in Science Technological Education, 26(1), 75-92.

Research in Science & Technological Education
Vol. 26, No. 1, April 2008, 75–92

Routledge
Taylor & Francis Group

Girls' biology, boys' physics: evidence from free-choice science learning settings

Ayelet Baram-Tsabari and Anat Yarden*

Weizmann Institute of Science, Rehovot, Israel

Many of the explanations for girls' disinterest in physics focus on the role of the educational system in creating this situation. Here, we use evidence from free-choice science learning settings to study if this lack of interest is also expressed in non-school settings. Three sets of self-generated questions raised by children, adolescents and adults in the fields of biology and physics were used. The outcomes of this analysis show that the polar pattern previously described in school science settings, in which physics proves significantly less interesting to girls than to boys, while biology is of greater interest to girls than to boys, also appears in free-choice science learning settings. While boys develop an interest in physics with age, girls do not develop such an interest to the same degree. Thus, the initial gap in interest is probably not based on school-related causes, but its widening in later years probably is. A difference was also found between the genders in the type of information requested and in the motivation for raising the questions. Using topics that appeal to girls' interest as the context of science learning could prove beneficial in the process of mainstreaming science education. These topics can be identified using girls' spontaneous questions.

AQ1 **Keywords:**

Introduction

Science education has a strong gender-related dimension, since boys in general have a greater interest in science than girls (Gardner 1975, 1998; Miller et al. 2006), as well as more positive attitudes towards studying and having a career in science (Kelly 1978; Kahle and Lakes 1983; Simpson and Oliver 1985; Weinburgh 1995; Crettaz von Roten 2004; Miller et al. 2006) and higher achievements in school science (Kelly 1978; Tamir 1988; Mullis et al. 2000). There are studies which describe another picture, in which young girls are actually more interested in science topics than boys are (Craig and Ayres 1988; Matthews 2007). However, the level of interest among girls drops considerably by the time science courses become elective (Craig and Ayres 1988). Many studies found that the gender-gap in interest, attitudes and achievements in science widens with age (Friedler and Tamir 1990; Shemesh 1990; Shakeshaft 1995; Mullis et al. 2000), but the stereotypical perception of science as a male domain is seen years prior to the actual encounter with disciplinary school science (Farenga and Joyce 1999).

Adolescents' decisions about the contents and directions of their educational training are influenced to a strong degree by the topic-related interests they developed in preceding years (Krapp 2000). In a study conducted among Israeli tenth graders, interest was the primary reason for choosing to enroll in an advanced science class (Levy 2003). Similarly, American and Australian 9- and 10-year-olds' explanations for having a desire to pursue a career in science tended to reflect the students' interest in science or a belief in their own ability to do science (Kahle et al. 1993). Interest doesn't only affect choice; it also affects the ability to learn. Research

*Corresponding author. Email: anat.yarden@weizmann.ac.il

ISSN 0263-5143 print/ISSN 1470-1138 online

DOI: 10.1080/02635140701847538
http://www.informaworld.com

indicates positive relationships between interest and a wide range of indicators of learning (Schiefele 1998; Pintrich and Schunk 2002). Barmby and Defty (2006), for example, found that the grade students expected to receive in a particular science subject correlated quite strongly with their liking of that subject. These expected grades were found to be lowest in physics, particularly for female pupils.

Taking into consideration the gender gap in interest, it is not surprising that the proportion of people choosing advanced science and technology studies who are women remains below 40% in most OECD countries, and that the choice of discipline is highly gender-dependent (OECD 2006). In 2003, 42% of the graduate students in the US were female, but only 20–30% of the students in the fields of engineering, computer science and the physical sciences were women. In the biological sciences, however, females made up more than half of the graduate students (National Science Foundation 2004).

Students do not perceive science as a homogeneous subject (Spall et al. 2003). The most profound differences between girls' and boys' scientific interests and achievements have been found with regard to biology and physics (Kelly 1978; Tamir 1988; Mullis et al. 2000). In fact, Reid and Skryabina (2003) condense the whole problem for girls in science into a problem for girls in physics.

Numerous studies have shown that while physics proves significantly less interesting to girls than to boys, biology is of greater interest to girls than to boys. This result was repeated in Scotland (Stark and Gray 1999), Australia (Kahle et al. 1993; Woodward and Woodward 1998; Dawson 2000), the US (Farenga and Joyce 1999; Jones et al. 2000), England (Osborne and Collins 2001; Spall et al. 2003; Murphy and Whitelegg 2006), Israel (Friedler and Tamir 1990; Trumper 2006), Germany (Hoffmann 2002) and in international studies such as 'Science and Scientists' (SAS) (Sjøberg 2000) and 'The Relevance of Science Education' (ROSE) (Busch 2005; Jenkins and Nelson 2005; Lavonen et al. 2005). The ROSE studies, conducted in Denmark, England and Finland, found that girls' interest was focused on health, medicine, the body, the mind and well-being, whereas boys wished to learn more about the dramatic aspects of physics and chemistry, and how technology works. This gender-gap in interest is also apparent among female students who are interested in science, as can be inferred from the polarized enrolment in elective biology and physics courses (Zohar 2003; Murphy and Whitelegg 2006) within the science-attentive students' body. It is also evident in science-interest studies which use senior AQ2 high school science students as a sample. For example, Osborne and Collins (2001) surveyed students' views on school science using focus groups of eleventh graders who intended to continue with their science studies, and those who didn't. Girls in both groups made many more negative comments about physics than boys did. Thus, it seems that the increasing access of female students to the traditionally masculine science subjects is being accompanied by the emergence of biology as a feminine niche in science (Ayalon 1995).

Gender-related differences in interest were also found within the field of biology: high school girls were shown to display greater interest in human biology than boys, both in Israel (Tamir and Gardner 1989) and England (Taber 1991). Results from the ROSE project in Finland indicated that boys are more interested than girls in basic processes in biology (such as ecology and cell biology), while girls find human biology and health education more interesting than boys do (Uitto et al. 2005). Gender-related differences exist within physics as well. Girls are much more drawn to themes that are perceived to have a high social relevance, while boys tend to be more attracted to those themes that are perceived to have high mechanical or practical relevance (Reid and Skryabina 2003).

Interest is not a constant trait – it changes with age. Stawinski (1984) found that among 13- to 16-year-old biology students, human biology becomes important while interest in plants and animals decreases. Older pupils' interest in human biology is well-attested to by a number of studies, including one conducted in England (Osborne and Collins 2000), and another in Israel (Tamir and Gardner 1989). It was also shown that young children are very interested in animals, and their interest shifts toward human biology as they approach puberty (Baram-Tsabari and Yarden 2005, forthcoming; Baram-Tsabari et al. 2006). A study conducted in Germany also found a difference in the way interest in physics develops with age: girls, but not boys, find physics as a school subject less and less interesting as they grow older. At the end of the fifth grade, about 40% of girls and about 60% of boys find physics lessons very interesting or interesting. At the end of the tenth grade, only about 20% of the girls still find it interesting whereas the boys' interest remains constant at 60% (Hoffmann and Haussler 1998; Hoffmann 2002).

Girls' disinterest in physics, which results in their under-representation in advanced physics classes, is unsettling from two points of view: from the social justice perspective, it blocks their future career opportunities; and from the perspective of society's economic competitiveness, it limits the number of potential employees in many fields which require a background in physics (Rees 2001; Zohar and Bronshtein 2005).

Many reasons have been suggested to explain girls' under-representation in science, specifically in physics. A Harvard University president, for example, claimed that differences in innate aptitude more than different socialization were to blame for women's failure to advance in high-end science careers (Summers 2005). However, the claim that cognitive sex differences account for the differential representation of men and women in high-level careers in mathematics and science is not supported by research on cognitive development in human infants, pre-school children and students at all levels. Rather, the research suggests that our species' talent for mathematical and scientific thinking has a considerable genetic basis which is equally available to males and females (Spelke 2005). Barres (2006) believes that the foremost factor to blame for women's slow advance in science is actually the societal assumption that women are innately less able than men.

Kelly (1978) shifted the explanation for women's under-representation in science from girls' alleged deficiencies to a focus on deficiencies in educational experience. She proposed that early differences between boys and girls in science appear to be magnified by cultural influences from society and schools in the following manner: science is seen as a masculine activity. Girls, who are striving to attain a feminine identity, reject everything scientific, while boys try to adopt scientific ways in their play activities and hobbies. Boys thus gain an initial lead over girls in science achievement. Feedback loops then operate in the schools to increase this lead between the ages of 10 and 14 (Kelly 1978). Complementary explanations were subsequently suggested, and they are traditionally divided, as Kelly suggested, into three, somewhat overlapping categories: cultural, attitudinal and educational.

Cultural explanations, which may be referred to as socialization explanations, include the masculine image of science, a lack of female role models, a lack of outside-of-school experiences and girls' low self-efficacy (students' judgment of their own capabilities for a specific learning outcome[1]). In a study which investigated the family as a context for the gender-typing of science achievement, for example, there were no differences in children's science-related grades, self-efficacy, or interest. However, parents were more likely to believe that science was less interesting and more difficult for daughters than sons. In addition, parents' beliefs significantly predicted children's interest and self-efficacy in science (Tenenbaum and Leaper 2003). Kahle and Lakes (1983) found that by age nine, females had consistently fewer experiences in science than boys of the same age, even though they expressed similar or greater desires to participate in such activities. The result is that, early in their lives, both men and women hold to a set of implicit hypotheses about sex differences, which later play a central role in shaping men's and women's professional lives, by affecting expectations from and evaluations of their work (Valian 1998). Pettitt (2004) found that with advances in pubertal status, adolescents increasingly perceived that peers thought mathematics was of more value for boys than girls and that the social domain was of more value for girls than boys. Schreiner and Sjøberg suggest (2007) that young people, especially girls, do not want to have an identity that is seen to be connected with being a physicist or an engineer. Furthermore, it has been reported that people judge a girl to be less sociable when she is committed to being a chemist compared to when she studies humanities, and boys do not want to date her (Brownlow et al. 2002).

Attitudinal explanations refer to the afore-described girls' negative attitudes towards science and science careers. To put it simply – girls don't do or succeed in science because, on average, they don't like it as much as boys do. Some factors, such as impersonality, misuse, difficulty and masculine image, which were brought up to explain girls' less favorable attitudes to science, apply more strongly to the physical sciences (Kelly 1978). Spall et al. (2003), for example, found that a quarter of the biology undergraduates they surveyed thought that physics was more suited for males, while half of the physics undergraduates agreed with this idea, and a quarter of the physics students also thought that females were better suited to biology (Spall et al. 2003). It seems that the substantial differences characterizing the cultures of the different disciplines in science, engineering, mathematics and technology contribute to notions of climate in each field, which are particularly attractive to one gender (Rosser 2004).

Educational explanations include school-related explanations, such as enrollment and achievement in mathematics classes, class climate, teaching and assessment methods traditionally used in physics classes (Zohar and Bronshtein 2005), and gender-related differences in the notion of what it means to understand physics (Stadler et al. 2000; Zohar 2003). On the other hand, Kleinfeld (1998) opposes the idea that girls receive inferior education in American schools, a notion that was advocated by the American Association of University Women (1992). She claims that in some areas, females do better than males, and in other areas, males do better than females. Females lag behind in two academic areas: mathematics and science achievement, but males lag behind females in two other academic areas, by far wider margins: reading achievement and writing skills (Kleinfeld 1998). However, studies did identify unequal science training during elementary (Kahle and Lakes 1983) and secondary school (Jones and Wheatley 1990). A longitudinal study that lasted two academic years in middle school confirmed that boys and girls are treated differently in science class interactions (Wilson Morse and Handley 1985).

The American Association of University Women (1999) stresses that equitable education should address the needs of both girls and boys, rather than questioning whether each receives the same things in order to achieve a standard of excellence. Gender equity in the classroom may mean more than providing the same science classes to males and females. The same classroom experience may engage the interests of males more than females, which results in a lack of equity (Miller et al. 2006). Hoffmann (2002) claims that particularly in the so-called 'hard' science subjects, the supposedly equal treatment offered by coeducation in schools proves to be an extremely subtle form of unequal treatment. This is due to the fact that the syllabus and the modes of behaviour of both male and female teachers are mainly influenced by the interests, knowledge and abilities of the boys. For example, a study that took a close look at the experiences of women in undergraduate computer science who were once very enthusiastic revealed some ways in which male behaviour and interest become the standards for 'the right fit' and success, resulting in many of the women believing that they are losing interest and switching subjects (Margolis et al. 2000).

As already mentioned, many of the explanations for girls' disinterest in science in general and physics in particular focus on the role of the educational system. Therefore it might prove useful to collect data outside the formal schooling system, in order to eliminate some of these explanations. Here we suggest using evidence from free-choice science learning settings (Falk 2001) to answer the following research questions:

(1) Do gender-related differences in interest in biology and physics exist in free-choice science learning settings?
(2) Do stereotypic interest patterns change with age?
(3) Are there gender-related differences in the type of information requested and in the motivation for asking science questions?

Methodology

Research approach

Gender-related differences in science interest have been traditionally identified using written questionnaires that rely on adult-centric views of what subjects should be meaningful to students. Cook-Sather (2002) advocates the notion that there is something fundamentally amiss about building and rebuilding the educational system without consulting those it is ostensibly designed to serve. We believe that relying on children's spontaneous ideas and questions will enable progress towards incorporation of their views, more than using their responses to an adult-written questionnaire. Therefore, we recently suggested using children's self-generated science-related questions as a tool to probe students' scientific interests (Baram-Tsabari and Yarden 2005; Baram-Tsabari et al. 2006).

Posing questions is an important skill of scientific inquiry (National Research Council 1996). Self-generated questions can help reveal the asker's reasoning, alternative views and interests (Biddulph et al. 1986). Studying students' questions can give teachers an awareness of what students are interested in and what they want to know about a given topic (Chin and Chia 2004).

Attitudinal research has traditionally been dominated by positivistic perspectives and quantitative methods (Krogh and Thomsen 2005). Since many features of qualitative methodology contrast with the conventional research on students' attitudes, there has been very little subsequent dialogue or transfer of knowledge between the two inquiry perspectives (Krogh and Thomsen 2005). Our naturalistic method of interpreting questions that have spontaneously emerged from the subjects might be a step forward in enabling such a dialogue, since we are using quantitative methods to analyze qualitative data.

The sample

Three sets of self-generated questions raised by children, adolescents and adults were used in this research.

Children

1676 science questions submitted by Israeli children to an Internet site (www.logi.tv) which accompanies a series of television programs were collected. The program might be described as a hybrid of two formats; 'ask the experts' and a competition to find information. The introduction to the Internet site that accompanies the programme told children that 'This is the place to ask any question in the world'. The program did not encourage the children to ask about content that was already broadcasted or to ask school-related questions, but to submit their own spontaneous questions. As a consequence no school-related questions were found in the sample. In this sample, 49.6% of the questions (n = 831) were biological in nature and 4.2% were asked in the context of physics (n = 71) (Baram-Tsabari and Yarden 2005). Among the 1140 gender-identifiable questions,[2] 43.5% were asked by girls and 56.5% by boys. Most questions were submitted by children in the later years of elementary school and in the early years of junior high school (ages 9- to 12-years). This sample is described in detail elsewhere (Baram-Tsabari and Yarden 2005).

Adolescents

1555 science questions submitted during a three-month period in 2004 by fourth- through twelfth-grade students to an 'Ask-A-Scientist' service on an international Internet site (www.madsci.org) were collected. In this sample, 44% of the questions (n = 684) were about biology and 12.9% of the questions (n = 201) concerned physics (Baram-Tsabari et al. 2006). Over 94% of the contributors originated from English-speaking countries. Among the 1167 gender-identifiable questions,[3] 56.4% were asked by females and 43.6% by males. Most of the questions were asked by junior and senior high school students. This sample is described in detail elsewhere (Baram-Tsabari et al. 2006). Although all of the questions collected from this data source were self-generated by the students, it is important to note that some of them were school-related. These questions were not spontaneously raised by the students, but were the consequence of a school assignment. These questions were not included in this analysis.

Adults

633 science questions submitted by Israeli television viewers to a popular-science television series (news.shmone.co.il) were collected. In this sample, 40.3% of the questions (n = 255) were about biology and another 13.4% of the questions (n = 85) were about physics. Among the 538 gender-identifiable questions,[4] only 30.5% were asked by females and 69.5% by males. Most of the questions (65%) were sent by young adults under the age of 30. Although all of the questions collected from this data source were self-generated by the viewers, some of them were not spontaneously raised, but were the consequence of an item presented in the show (e.g., 'how can I get in touch with the doctor that was interviewed?'). These questions were not included in this analysis.

All the spontaneous biological and physical questions that were gender-identifiable were pooled from the three different sources. The resulting sample included 955 biology questions, from which 462 were asked by males and 493 by females, and 214 physics questions, from which 159 were asked by males and 55 by females. Since the target audience age range of the three databases overlapped somewhat, the questions in the pool were re-divided into four separate age groups: elementary school (up to 12-years-old), junior high school (13- to 15-years-old), senior high school (16- to 18-years-old), and adults (over 18).[5] This cross-aged approach allowed us to see a snapshot of interests held by children and adults at various stages of their lives.

Classifying the questions

Classification was performed on the basis of coding schemes that had been developed and used in our previous research (Baram-Tsabari and Yarden 2005; Baram-Tsabari *et al.* 2006). The coding schemes used here were as follows.

Interest in biological or physical topics

All the questions were classified into one of 16 biological topics or six physical topics: anatomy and physiology; sickness and medicine; nutrition; biotechnology; genetics and reproduction; behaviour; neurobiology; evolution; extinct animals; ecology; man and animal relationship; botany and mycology; history of biology; microbiology and virology; cell biology; other topics in biology; modern physics; sound and optics; electricity and magnetism; mechanics; history of physics, and units. For examples of this coding scheme, see Table 1.

Table 1. Examples of questions classified according to field of interest.

Topic	Example[a] (gender, age, country of origin)[b]
Anatomy and physiology	Why is blinking your eyes involuntary? (f, high school, US)
Genetics and reproduction	What is the difference between an egg that a little chick is coming out from and an egg that we eat? (f, IL)
Neurobiology	Are scents tied to memory? (high school)
Behaviour	If dogs were abused when they were young, will they be bad when they are older and living with a good family? (f, 8, IL)
Ecology	Is there an animal that no other animal can prey on? (m, 11, IL)
Botany and mycology	Why do trees give oxygen in the morning, but not during the night? (m, 12, IL)
Modern physics	How does antimatter work? I'm asking this question because I'm interested in science and i want to know how it works and can u make it from a regular piece of matter. (m, high school, US)
Optics	How does gelatin magnify? (m, elementry school, US)
Electricity and magnetism	When lightning strikes the ocean, do many animals die? I was wondering how far the charge is carried as lightning hits the ocean, and if animals die within a certain radius? Though the ocean is vast, I would think that there would still be no chance for anything surviving close to where the lightning strikes. (f, junior high school)
Mechanics	How come a fly inside a moving car moves with it and does not stay in place and hit the rear window? (m, adult, IL)

Notes: [a]These are verbatim quotes, or translations of verbatim quotes. In some cases, only part of the question is shown. [b]Where data is available. m = male; f = female; IL = Israel; US = United States.

Motivation for raising the question

The two main categories chosen were non-applicative and applicative motivation. The former was subdivided into general curiosity, spectacular aspects of the field, and seeking an explanation for a direct observation. Applicative questions were subdivided into personal use, health and life-style, and school- and job-related questions. For examples of this coding scheme, see Table 2.

Type of requested information

A typology was developed that describes the nature of the question and the knowledge it generates. A category of requests for 'Factual' information included terminological, historical, descriptive and confirmatory items. It also included requests for further information on a topic. Requests for 'explanatory' information were basically 'how' and 'why' questions. 'Methodological' information had to do with scientific ways of finding things out and with scientific and technological procedures. The 'open-ended' type of question dealt with opinions, controversial themes, and futuristic questions that science cannot answer for the time being. For examples of this coding scheme, see Table 2.

Reliability

Classification and categorization of questions in each database were performed independently by two researchers, with a satisfactory level of agreement between the coders: 100 children's questions, 85%–90% agreement for the various schemes; 150 adolescents' questions, 84%–98% agreement for the various schemes; 50 adults' questions, 82%–90% agreement for the various schemes. To test for internal consistency of the data, a modified split-half test was performed on

Table 2. Examples of questions classified according to motivation for raising the question and to type of information requested.

Motivation	Type	Example[a] (gender, age, country of origin)[b]
Non-applicative: General curiosity	Factual	What makes up a Quark? What is inside a Quark? Is a Quark the smallest particle? I am asking this because I am extremely interested, and one day (I am nine right now) to be a Scientist. (m, 9, Canada)
Non-applicative: Direct observation	Explanatory	I've noticed that I can tap on almost any book thicker than about an inch and it makes a sound as though it is hollow. What's happening to cause this sound? (f, junior high school, US)
Applicative: Health and lifestyle	Factual	Is there a way to help the body get taller during adolescence? (f, 15, IL)
Applicative: Personal use	Methodology	I got a microscope for my birthday, but I don't know how to use it. My question is how do you use a microscope? (m, 7, IL)
Non-applicative: Spectacular aspects	Open-ended	What is the most important experiment in Physics that was ever performed? (m, 10, IL)

Notes: [a] These are verbatim quotes, or translations of verbatim quotes. In some cases, only part of the question is shown.
[b] Where data is available. m = male; f = female; IL = Israel; US = United States.

each dataset: random halves of the data (odd and even observations) were compared. Consistency was found in the distribution of all variables between the two halves.

Statistical analysis

Unless otherwise indicated, a two-tailed Pearson Chi-Square test was used to calculate probabilities. Not all the inquirers provided their full details; therefore, sample sizes differ from graph to graph and are indicated by n values. Post-hoc multiple comparisons in sample proportions and Goodman's simultaneous confidence-interval procedure (Marascuilo and McSweeney 1977) were used to find significant differences within proportions after the Chi-Square test.

Results and discussion

Consistent with previous studies, the girls in our sample found physics significantly less interesting than the boys did, whereas biology was of greater interest to girls than to boys: biology questions made up 53.8% of the females' science questions, but only 38.3% of the males' science questions. Physics questions made up 6% of the females' science questions, versus 13.2% of the males' science questions. To refine our analysis, we then compared girls' and boys' interests in various biological and physical topics (Figure 1). The five topics that were of more interest to girls than to boys were all biological, and had to do with human health and well-being, animals and ecology. On the other hand, four out of the five topics which were of more interest to boys than to girls were taken from the physical sciences. The one exception – anatomy and physiology – was the most popular topic among both boys and girls, but more so among boys (Figure 1).

This list of gender-related learning interests also fits well with known stereotypic preferences for specific topics (Jones et al. 2000; Sjøberg 2000). The outcome of this analysis suggests that girls and boys follow certain content-related stereotypic science interests in their free-choice science learning activities that are similar to what was found in school-based studies.

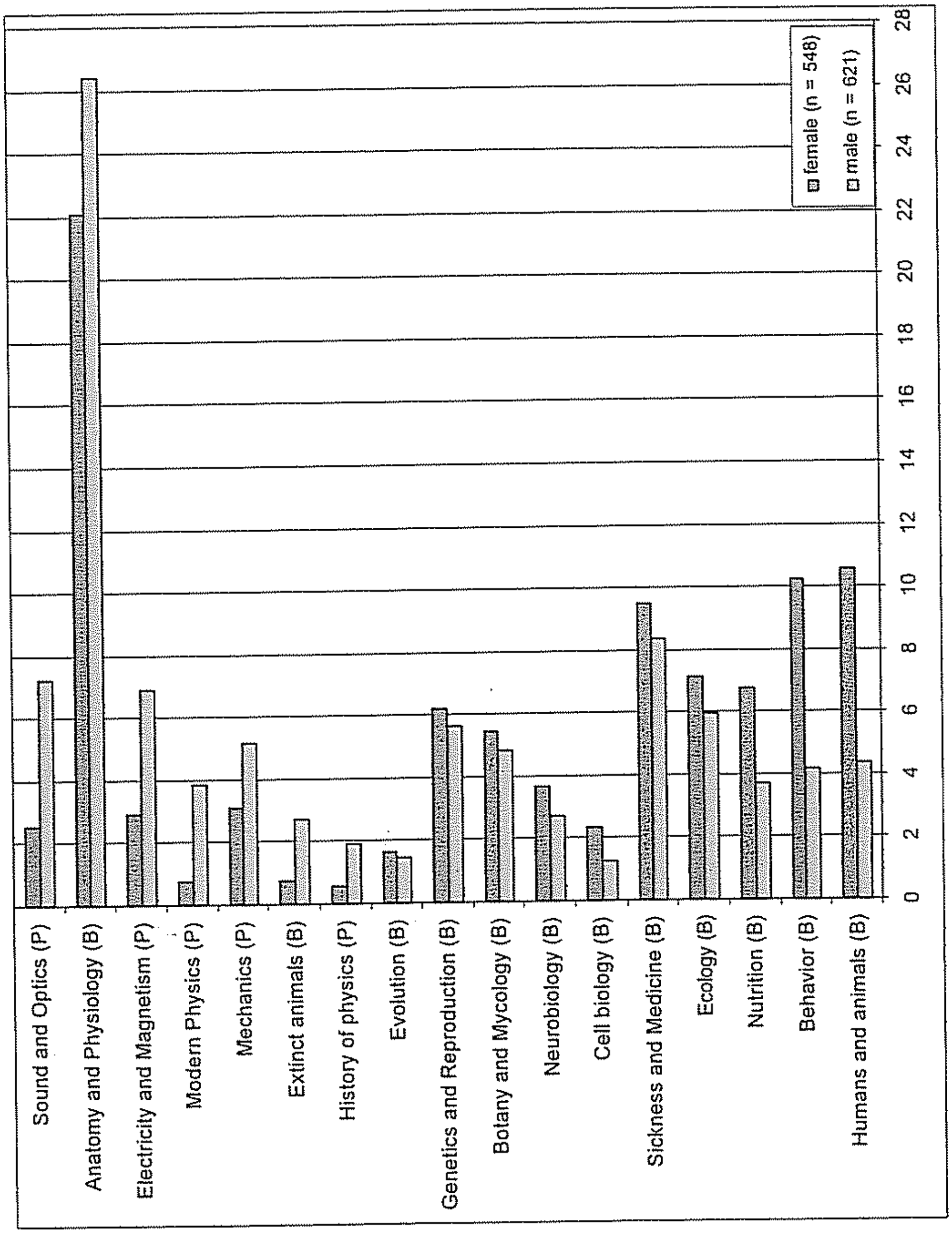

Figure 1. Male and female spontaneous interest in biology and physics topics, ordered by the difference between the genders. Topics favoured by males are shown in the upper part of the figure, topics favoured by females are shown at the bottom, and topics favoured similarly by both genders are presented in the middle. Five topics which yielded a small number of questions were not included in the graph. B = biology, P = physics.

The gender gap is already evident among young elementary school children, before biology and physics are identified as such, and persists all the way to adulthood (Figure 2). However, according to our analysis, the stereotypic interest patterns change with age. The gap between girls' and boys' interests widens with age: it is significant at $p < 0.05$ among elementary and junior high school students, and at $p < 0.001$ among senior high school students and the adult group. However, the gender gap widens not because girls lose interest in physics with age as described in the literature (Hoffmann and Haussler 1998), but rather because they do not seem to develop interest to the same degree as boys (Figure 2). We suggest that this inconsistency needs to be studied further.

While boys develop an interest in physics with age, girls seem to develop such an interest to a lesser degree. Thus, the initial gap in interest is probably not based on educational causes, but its widening in later years probably is. The idea that the initial gap in interest is not school-related, but originates from either social or attitudinal causes, is supported by previous research findings. Farenga and Joyce (1999) found that both boys and girls perceive physical science and technology-related courses as appropriate study subjects for boys and life sciences as appropriate subjects for girls. In a study in which 9- to 13-year-old children hypothetically chose courses for themselves and for a member of the opposite gender, students' future science course selections resembled concurrent enrollment data of masters and doctoral candidates. The authors concluded that students' perceptions of science can be observed years prior to their actual encounter with the science courses in school.

A cross-cultural analysis by Kahle et al. (1993) found that American and Australian 9- and 10-year-olds report high interest in science, but their interest patterns differ: boys, on average, are more interested in science associated with matter and energy, whereas girls are more interested in science associated with plants and animals. Accordingly, Eccles and Blumenfeld claimed that students start school with sex-differentiated goals and attitudes, and teachers play a rather passive role in their maintenance (Eccles and Blumenfeld 1985).

These sex-differentiated goals are also mirrored by the type of information sought and the motivation for raising questions. Boys and girls in our sample tended to ask for different types of information ($p < 0.04$), with the boys favouring factual and methodological types (54.1% and 5.2% of the boys' questions *vs.* 49.5% and 2.9% of the girls' questions, respectively), and the girls asking for more explanatory information (45.8% of the girls' questions *vs.* 38.7% of the boys' questions). Boys and girls also tended to ask questions stemming from different motivations ($p < 0.001$). Girls tended to ask more applicative questions than boys (25% of the girls' questions *vs.* 15.3% of the boys' questions), with reference to personal use and health issues. Within the non-applicative questions, boys tended to pose spectacular and general curiosity questions (64.9% and 7.3% of the boys' questions *vs.* 56.6% and 2.9% of the girls' questions, respectively), whereas girls sought straightforward explanations for their own direct observations (15.5% of the girls' questions *vs.* 12.6% of the boys' questions).

This female interest in the practical aspects of science was previously described by Margolis *et al.* (2000), who found that women are concerned with the usefulness of computers and with their people-oriented purposes, and by Miller et al. (2000) who suggested that women and men enter science and medicine via different routes, a reflection of their different motivations: women choose medicine for its people-oriented social usefulness, because of their interest in improving the human condition. Some researchers have explained that girls in general are more person-oriented, while boys are object-oriented, and this is also the basis for their differentiated interest in biology and physics. The psychologist Baron-Cohen plainly states 'The female brain is predominantly hard-wired for empathy. The male brain is predominantly hard-wired for understanding and building systems' (Baron-Cohen 2003). Miller *et al.* (2006) related this idea to science AQ3
education, when they found that female high school students in the US were more people-oriented

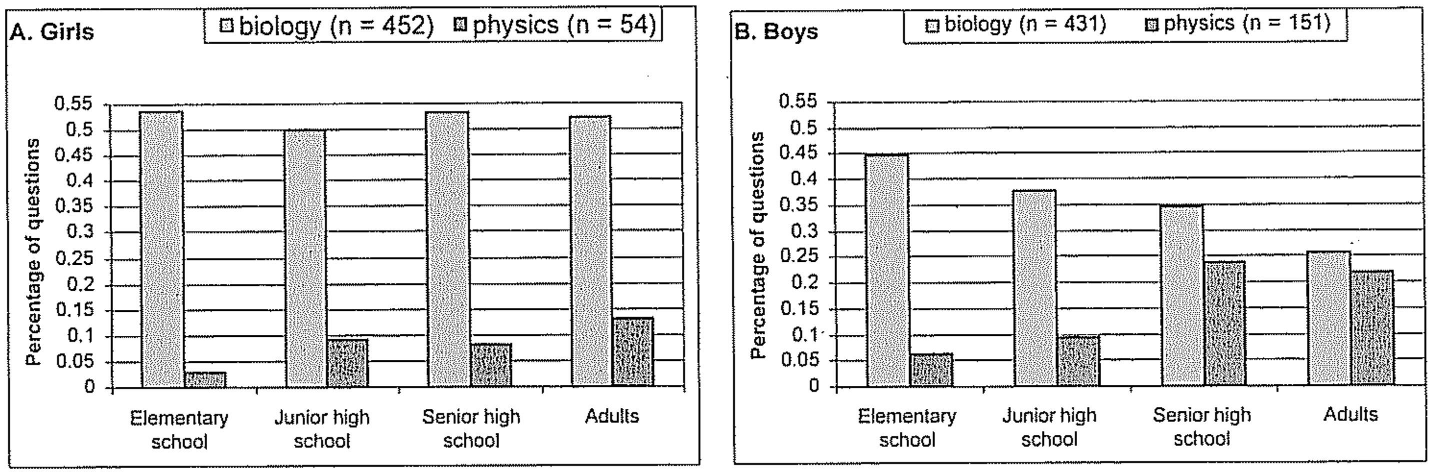

Figure 2. Developmental shift in the interest of girls (A) and boys (B) in biology and physics along four age groups. The age of 81 askers was not specified, and they were not included in this analysis.

in their interests than were the males. They preferred courses in the humanities over the physical sciences or mathematics, which suggests that females' desire to help others is related to their selection of a career at least as early as high school.

If this is true, and gendered patterns concerning biology and physics appear because of the person *vs.* object orientation of girls and boys, respectively, then why are we continually shocked by survey results which show that our students believe this as well? Stewart (1998) suggests that: 'The problem of girls and physics is our own making because of the implicit assumption that a subject perceived to be "masculine" must inevitably be of high status and thus worthy of study in preference to "feminine subjects"'. AQ4

Other studies, however, did not find such a difference in the hard-wiring of the female and male brains. In her review, Spelke (2005) states that:

> Thousands of studies of human infants, conducted over three decades, provide no evidence for a male advantage in perceiving, learning, or reasoning about objects, their motions, and their mechanical interactions. Instead, male and female infants perceive and learn about objects in highly convergent ways. AQ5

A landmark MRI Study of Normal Brain Development conducted by the National Institutes of Health (Waber et al. 2007) in which structural and metabolic brain development and behaviour were followed longitudinally from birth to young adulthood in a population-based sample of healthy children found that mental performance differs very little by gender: Girls performed better on measures of processing speed and motor dexterity and showed a slight advantage on verbal learning, while boys were better at perceptual analysis, but not at perceptual reasoning. A difference was not found with regard to performance in calculation, indicating that at least at the procedural level of mathematics, boys and girls do not differ.

If gendered patterns with respect to biology and physics appear for socialization and not inborn reasons, then it seems that the search for those reasons and their remedy should start at earlier ages, rather than focusing on those who are already studying physics and biology at school.

Research limitations

Although the study described here sheds some light on girls' and boys' interest in biology and physics, respectively, and its development with age, caution is needed in identifying implications for science education in schools. Here we will discuss a few issues concerning the methodology that was used and the interpretation of the findings.

Uncontrolled sample

The self-selecting sample used in this research does not represent all children. It represents a group of children that might be more interested in science and have more access to resources than the child population as a whole. There is a marked difference in the access of children from different socioeconomic groups to the Internet, which was our source for the questions. For example, during the year 2005, 49% of the households in Israel were connected to the Internet. Among the upper decile of the population, 81% subscribed to the Internet, as compared to 60% of the 7th decile, 40% of the 4th decile and 15.4% of the lowest decile of the population (Central Bureau of Statistics 2006). Furthermore, students who are not motivated to learn science are not represented in this self-selecting sample at all, regardless of their socioeconomic status. Other children that may be very interested in science but do not send questions are also not represented. Therefore, the opportunistic nature of the sample places some limitations on the validity of our results.

However, the validity of the study can be supported by the notion of using data that originates from the researched population itself, not as a response to a stimulus from a researcher, thus ensuring high ecological validity. Another way to achieve validation is by comparing any conclusions drawn with other independent observations: using an informal data source and a new methodology, our results confirm and reinforce what was revealed using the traditional questionnaire methodology. This agreement with findings described in the literature that were gathered using control samples, serves to bolster confidence also in our new findings, which were not described before. Therefore, we assume that the trends described here represent, to a certain degree, the interests of many children. Reliability may be assured by the use of a very large sample (Reid 2006), as was done in this study.

Although web-based experiments of the kind used here are more difficult to control in some respects than are experiments conducted in a classroom setting, they present an important methodological advantage for studying students' self-guided science learning, taking into consideration that this kind and amount of data does not exist anywhere outside the web. Therefore, this methodology is better suited to studying the dynamic educational reality of the last decade.

Differences between the databases

Differences exist between the three databases used in this research. The *Madsci Network* is an interactive science teaching and community outreach tool, while the two Israeli databases are accompaniments to television shows, and as such might draw different types of questions. The gender split is also very different between the databases. The gender split found in the two Israeli databases, and much more strongly in the adult one, has a male majority. It mirrors that found in an analysis of questions submitted to a scientific Internet site based in Rome (Falchetti et al. 2003), and a UK-based science line (K. Mathieson, personal communication, 2 April 2004), as well as results from the 1999 US Science and Engineering Indicators, which showed that women are less likely than men to use media that foster informal learning about science (Nisbet et al. 2002; National Science Foundation 2004) and to take part in extracurricular science experiences (Greenfield 1998). At the same time, the international database shows the opposite picture, with female K-12 students asking most of the questions. This female dominance was apparent in questions sent from the US, Canada and the UK, but not in those from other countries surveyed in this research. These differences trigger the question as to whether students from various countries show similar interests in science. It seems indeed that the profile of the experiences and interests of students vary strongly between countries (Sjøberg 2000). However, students in different educational and national contexts were not only experiencing very similar high school science classes, but identifying similar problems and responding in similar ways (Lyons 2006). Furthermore, the wealth of research on students' interest from many different countries and the contribution of international studies such as ROSE (Sjøberg and Schreiner 2002) and SAS (Sjøberg 2000) indicate similarities in the scientific interests and a common pattern of responses among students in western industrialized countries. Matthews (2007) generalize that there is far more agreement than disagreement across countries about what students would like and would not like to learn about.

School-related effect on interest in free-choice science learning settings

We have found that the polar pattern of girls' higher interest in biology and boys' greater interest in physics in free-choice science learning settings is similar to the situation described in formal science education. However, this seemingly spontaneous interest is to some extent a result of formal schooling, and not a completely independent measure of outside-of-school interest.

Implications

Here we describe ways in which the research findings may be put to use by curriculum developers. Regardless of the initial reason for the interest gap between the genders, in the current abundant physics curriculum, examples are drawn from predominantly male contexts. Sports and weapon deployment dominate mechanics courses and ignore the background of female students as they attempt to understand or visualize situations (Nair and Majetich 1995). Rosser (1990) has proposed the following six stages for transforming the science and mathematics curriculum: (i) ignoring the absence of women; (ii) recognizing that most scientists are male and that science may reflect a masculine perspective on the natural world; (iii) identifying barriers that prevent women from entering science; (iv) searching for women scientists and their unique contributions; (v) science being done by women; (vi) redefining and reconstructing science to include us all. However, science, mathematics and engineering faculties appear much more willing to change their pedagogical approaches than their syllabi and curricular content, even when curricular reform is the main focus of the reform projects (Rosser 1997). The reasons for this might be the dearth of information available, and the idea that science is objective and therefore gender-free – meaning that the faculty has not progressed beyond the first phase of the transformation process (Rosser 1997).

Current curriculum topics may promote unfair competition between genders (Farenga and Joyce 1999), since girls have less extracurricular science experiences and use of their informal science knowledge and tools is not recognized as such (Shakeshaft 1995). Therefore, activities which are based on past experiences may widen the gender gap (Farenga and Joyce 1999). One solution to this problem might be to use the informal experiences that females do have as a bridge to school science (Shakeshaft 1995). A way to learn about these informal experiences and interests might be through the girls' spontaneous science questions.

It is vitally important to balance a physics syllabus so that topics that have a natural appeal for girls, as well as those preferred by boys, are both included (Reid and Skryabina 2003). Our analysis identified some scientific topics that appeal to both sexes or predominantly to girls. Therefore, it seems possible to teach scientific concepts and ideas in the context of topics which are not profoundly preferred by boys, but rather preferred by girls or equally attractive to both genders (Steinkamp and Maehr 1984; Hoffmann and Haussler 1998; Krapp 2000; Labudde et al. 2000; Sjøberg 2000). Haussler *et al.* (1998) identified five domains of interest in physics, only one of which – physics as a scientific enterprise for its own sake – is overwhelmingly dominant in the physics classroom. Other domains, such as how science can serve humankind and explanations of natural phenomena which are of more interest to girls, are almost non-existent (Haussler *et al.* 1998). Girls in particular respond very sensitively to a change of context (Murphy and Whitelegg 2006). For example, girls are much more interested in learning more about pumping blood by an artificial heart than about pumping petrol from great depths, whereas for boys both are similarly interesting. Therefore, human biology, medicinal uses or natural phenomena could be introduced as contexts for physics lessons, topics which would take the interests of girls into account (Hoffmann 2002). Using such topics, which can be identified using spontaneous questions, as the context of science learning could prove beneficial in the process of mainstreaming science education.

Acknowledgments

This research was supported by The Israel Science Foundation (grant No. 605/06), and a Sacsta Rashi fellowship for honor students in science education. The authors would like to thank Mrs Yetty Varon for her expert statistical advice and the reviewer for her/his insightful remarks on an earlier draft of this manuscript.

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Unpublished results:

Additional patterns whithin the data

Background

An attempt to reveal additional patterns within the data has been done using nearly 6,000 science questions that were asked by K-12 school students and were collected from five different web-based, TV-based and school-based sources. The questions were analyzed according to their subject, thinking level, motivation for raising the question, the object of interest and its magnitude, and the psychological distance of the object in question from the asker. Characteristics of the asker, such as gender, grade level, and country of origin were also considered, alongside characteristics of the data source, such as language, setting (internet, school, TV), and the potential science-attentiveness of the users.

Here I present the methodology and the results sections of the study. The background and the discussion sections are not written at this point in time.

Methodology

Data sources

Logi. '*Lechu hapsu*' (roughly translated as 'Go and find out') is an Israeli television programme for children, broadcast on 'Logi', a cable channel available upon subscription. This data source was described in detail in an earlier paper (Baram-Tsabari & Yarden, 2005), and it will be only briefly described here.

'*Lechu hapsu*' might have been described as a hybrid of two formats; 'ask the experts' and a competition to find information. The introduction to the Internet site that accompanied the programme tells children that 'This is the place to ask any question in the world' and that 'We will help you find the answer, as well as the way to get it'. It also advised that the answers will be broadcast.

According to the programme editor, approximately 90% of the children send their questions via the specified Internet site, the remainder doing so via the telephone (all of the questions were sent in Hebrew). Only the questions submitted via email are used in this study. The programme was first broadcast in August 2003 and by early January 2004 over 3,100 questions had been accumulated in an email database. Of these, 1,676 questions fell in the following science and technology-related categories: Animals, Health & Medicine, How stuff works, Nature & Science, Earth & Space, Computers & Internet, and Inventors & Inventions. Of these, 1,486 questions that provided the age of the askers, and that had a science-related topic, were used in the current study. For key characteristics of the sample see table 1.

MadSci Network. *MadSci Network* is an independent, award-winning nonprofit organization operating from a server in Scottsdale, AZ (www.madsci.org). This data source was described in detail in an earlier paper (Baram-Tsabari et al., 2006), and it will be briefly described here.

MadSci Network was founded in September 1995 as part of Washington University's Young Scientist Program, a student-run organization in St. Louis dedicated to improving science literacy among K-12 students. Today, the *MadSci Network* receives 90 to 150 questions daily, most of which are answered automatically by the site's search engine. Fewer than 20% of the questions are answered by nearly 800 globally distributed volunteering scientists, usually within two weeks.

All questions submitted to the MadSci Network by 4th- through 12th-grade students from August to October 2004 were collected, resulting in a sample number of 1525. Questions automatically answered by the archives search engine were not included, since the system did not record them. Questions asked by populations other than 4th- through 12th-grade students, and questions asking about non-scientific topics (including mathematics) were also excluded. For key characteristics of the sample see table 1.

Bashaar. Bashaar is an Israeli Ask-A-Scientist internet site operated by "Bashaar" academic network (www.bashaar.org.il), a non-profit organization established in 1998 by a group of faculty members drawn from all the universities in Israel. This Ask-A-scientist service is primarily aimed at answering teachers' questions, especially those who live in the periphery of the country. However, over a third of the questions (42%) submitted to the site actually originates from school students.

All questions submitted to the "Bashaar" website by school students from October 2003 to January 2007 were collected, resulting in a sample number of 962. Of these 795 questions that provided the age of the asker and that had a science-related topic, were included in the analysis. For key characteristics of the sample see table 1.

Newton. *Newton BBS* is an Internet based Ask-A-Scientist service, which is operated by Argonne National Laboratory (www.newton.dep.anl.gov) since November 1991. This Ask-A-scientist service is primarily aimed at answering questions of K-12 educators and their students. At the time of the data collection it received an average of between 85 to 125 questions daily, of which 2.5-5% is being sent to scientists. Today, due to funding cuts, Newton webmaster has reduced the amount of time the window is open for questions. At the same time, questioning density has increased (Personal communication with N. Unterman, Nov 4, 2007).

All questions submitted to *Newton* from June 22 to November 5 2006, excluding questions arriving between August 20 and September 1, were collected, resulting in 6348 questions. This sample was reduced by excluding all users who did not provide status and grade level, who are not K-12 students, that their gender could not be identified, and users who did not provide country of origin. Finally, 1693 questions that were asked by gender identifiable school students who provided their age group and that had a science-related topic, were included in the analysis. For key characteristics of the sample see table 1.

School. In order to include self-generated questions asked in a formal setting, 526 questionnaires filled by Israeli 4-12th graders were collected during the 2006/7 school year in 17 classes from five different schools. The questionnaire contained two sections. In the first students were prompt to raise their own science questions and explain why they thought they were interesting. On the second part, which was distributed only after the first section was collected, students were asked to mark questions they were interested in learning about from a mixed list of student-generated and textbook questions. Only the questions that were self-generated by the students in the first section and that had a science-related topic, were included in this analysis, resulting in a sample of 446 questions. For key characteristics of the sample see table 1.

Classifying the questions

Database characteristics

Setting. The setting in which a question was asked was recorded. Questions were either asked in a web-based setting (*MadSci Network, Newton, Bashaar*), in a school-based setting (*School*), or in a TV-based setting (*Logi*). The questions in the Logi database were submitted via email, however the children were advised that their question might be broadcasted, therefore, the basic characteristic of anonymity of the net was violated.

Language. The language in which the question was asked was recorded. The *Madsci Network* and *Newton* databases accepted questions in English, while *Bashaar, School* and *Logi* databases included questions in Hebrew.

Attentiveness. Not all publics are interested in science to the same degree. Individuals who report a high level of interest in science and technology policy issues and a sense of being very well informed about those issues are called the attentive public for science and technology policy (Miller, 1986). We used the act of voluntarily submitting a science question to an Ask-A-Scientist site or science-related TV-program as a mark for science-attentiveness. Questions that were asked in a school setting did not fulfill this requirement and therefore were termed as non-attentive general audience. However, 33 questions that were asked by high school students who major in biology were labeled as "science-attentive" as well.

User characteristics

Age. In some databases surfers used free writing to indicate their age, while in others they had to choose their grade level from a fixed list. In order to compare data from different sources, we sorted all the age related information into four age groups: K-3rd graders; 4-6th graders; 7-9th graders (junior high school), and 10-12th graders (senior high school).

Gender. Hebrew is a gender-identifying language. As a result, some of those submitting questions automatically revealed their sex through the use of verb gender indicators; for example, 'I'm checking' translates as '*ani bodeket*' (feminine) or '*ani bodek'* (masculine). Children's names provided a further indication of the sex of the questioner, although some names (e.g. 'Liron') could be associated with either a boy or a girl. For the English questions gender identification was based on the asker's first name. For the *Newton* database initial classification was done semi-automatically using an English name gender finder.[1] Next, the names that were not automatically classified were

[1] http://epublishing.nademoya.biz/japan/names_in_english.php?nid=A

analyzed individually using a baby name guesser,[2] which operates by analyzing popular usage on the internet. All the names from the *Madsci Network* database were identified manually.

Country of origin. Madsci Network and *Newton* databases both received questions from all over the world. Many of the users indicated their country of origin using a fixed list. A huge majority of the questions in these databases originated from the USA, but Canada, UK, India, Australia, Mexico, and Korea were represented as well. All the questions in the Hebrew databases were labeled as originating from Israel.

Question characteristics

Topic of the question: Subject and Sub-subject

Questions in this coding scheme were placed in one of the following categories: 'Biology', 'Physics', 'Chemistry', 'Earth sciences', 'Astrophysics', 'Nature of science (NOS) inquiry', and 'Technology'. 'Earth sciences' and 'Astrophysics' were kept as distinct categories since each accommodated a significant number of questions. 'NOS inquiries' were general questions about how scientists develop and use scientific knowledge (Ryder, Leach, & Driver, 1999) without reference to a specific scientific context. 'Technology' questions were categorized by defining technology as the development, production, and maintenance of artifacts in a social context, as well as the artifacts themselves (Gardner, Penna, & Brass, 1996). Questions in the field of mathematics and questions that did not have a science topic were not included in our sample. Each of the categories (except for NOS) was further divided into subcategories, resulting in a total of 55 subcategories: 17 in biology, 5 in physics, 9 in chemistry, 8 in earth sciences, 6 in astrophysics, 1 in NOS, and 9 in technology.

Cognitive level of the question: Type and Order of Information Requested

Two classification methods were used to hierarchically describe the cognitive level of the questions: order of information requested and type of information requested (see further on). Both were already described in earlier works (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005), however they will be briefly described here again, due to small modifications.

[2] http://www.gpeters.com/names/baby-names.php

But first, a word of clarification why existing classification schemes for the cognitive level of students' questions were not used. Many such schemes were suggested, but they did not fit the nontraditional sample used in this research for various reasons. For example, because they are only suitable for questions asked in the context of a textbook (Shepardson & Pizzini, 1991), a discourse (Graesser et al., 1992), or a classroom setting where questions are categorized with respect to the task at hand (Marbach-Ad & Sokolove, 2000a; Pedrosa de Jesus et al., 2003). This was also the reason that we could not use Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956)—if a student has previously encountered a question similar to the one he or she is asking, then a higher order question may turn into a lower order question (Dori & Herscovitz, 1999). Our sample includes specific, stand-alone questions generated by knowledge-deficient mechanisms. This was also the reason we could not use the Scardamalia and Bereiter (1992) classification of basic information or wonderment questions. In this sample, all the spontaneous questions (see further on) were wonderment questions.

I. Order of the Requested Information. A modified typology, based on one defined by Dillon (1984) and Brill and Yarden (2003), was used to classify questions according to a gradual increase in the cognitive level required to answer them: (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 outlined in the question. This category includes any non-causal connections between two or more variables, such as confrontations (3) "causal relationships"—answering questions in this category requires finding the relation, correlation, conditionally, or causality of the subjects in question. Usually, questions from the properties category refer to one variable, whereas questions from the comparisons and causal relationships categories refer to at least two variables. For examples of the application of the categories in this coding scheme, see table 2.

II. Type of Information Requested. A typology influenced by Bloom's taxonomy (Bloom et al., 1956) and Bybee's classification for research questions (Biological Sciences Curriculum Study [BSCS], 1993). The typology describes the nature of the question, and the knowledge it generates, along a gradually increasing cognitive-level continuum. The lowest category consists of requests for "factual" information which included terminological (What is www?), historical (When was the computer invented?), descriptive (What does a male mosquito eat?), and confirmatory (Is it true that earth's core is liquid?) items. The second category consists of requests for "explanatory" information, with basically "why" and "how" questions. The third category, consisting of questions asking for "methodological" information, has to do with scientific ways of finding things out and with scientific and technological procedures. The highest categories were "predictions and contradictions"—cases in which the asker described a science-related situation and asked what its' results would be, or describes a contradiction between two pieces of her/his scientific knowledge, and requests for "open-ended" type of information which deal with opinions, controversial themes, and futuristic questions that science cannot answer for the time being. For examples of the application of the categories in this coding scheme, see table 2.

Reason for raising the question: Motivation and Level of Autonomy

An attempt was also made to identify and classify the questioners' reason for raising their questions. Since it was not possible to ask the children why they sent their questions, it was necessary to interpret their possible motivation from the way in which their questions were worded and phrased.

I. Motivation. Two categories were chosen: 'Non-applicative' and 'Applicative'. A question was labeled as "Applicative" if it was clear from the question that the answer is going to be used in some way – e.g. for building something, decision making on health and lifestyle issues and fulfilling school assignments. Motivation was determined for only 83.5% of the questions. For examples of the application of the categories in this coding scheme, see table 2.

II. Level of Autonomy. Gross (2001) makes a distinction between questions that are self-generated (internally motivated by personal context) and those that are imposed (thought up by one person, such as a teacher, and then given to someone else, such as a student, to resolve). Intrinsic motivation refers to doing something because it is inherently interesting or enjoyable. Extrinsic motivation refers to doing something because it leads to a separable outcome (Ryan & Deci, 2000) as a means to an end, such as praise or avoiding punishment (Vallerand et al., 1992). In school, intrinsic motivation becomes weaker with each advancing grade (Ryan & Deci, 2000). Most learning in school is extrinsically motivated, and the acquisition of knowledge is rarely enjoyed for its own sake (Csikszentmihalyi & Hermanson, 1995).

Although all of the questions in our sample were generated by students, not all of them were the outcome of an intrinsic motivation to know. Many of the questions were required for school assignments and were originally raised by teachers or textbooks. To differentiate between the two types of motivation for raising the question, we classified the questions as either "spontaneous," which can serve as an indication of intrinsic motivation to know, or "imposed," which can serve as an indication of an extrinsic motivation for seeking an answer. Questions were classified as "imposed" only if it was explicitly stated in the question that the information is required for a school assignment, such as a science fair project, report, or homework. All other questions were classified as spontaneous. This classification was not applied to questions that were collected in school setting, since the students were prompt by an external agent to ask questions. For examples of the application of the categories in this coding scheme, see table 2.

Properties of the object of interest: Magnitude, Human/Zoology focus and Psychological distance

Three classification schemes were used in order to describe the object of interest in the question. Two of these schemes did not apply to all the questions, and were used only when relevant.

I. Magnitude. The order of magnitude of the object in question was noted. This scheme was inspired by the concept of "level of organization", which is abundantly used in biology education research (e.g. Knippels, 2002; Songer & Mintzes, 1994; Verhoeff, 2003). The levels chosen for this scheme were population (e.g 'if dolphins are mammals, where is their hair?'), macroscopic level (e.g 'what causes black spots on Bananas?'), microscopic (e.g 'if Basophils release histamine which cause inflammation, why do we have Eosinophils? Don't they just cancel each other out?'), molecular (e.g 'how do you know when one gene is being affected or controlled by another gene?'), and Nano-scale (e.g 'what is the purpose of Electrons?'). This classification was relevant only to 77.3% of the questions, mostly in the fields of biology, chemistry and physics.

II. Human/Zoology focus. Many questions were embedded in the context of human biology or the zoology of non-humans, e.g. "Is our inability to synthesize vitamin

C an inborn error of metabolism?", "Do dogs have a dominant paw that they prefer to use?" were classified as portraying either a 'Human' or 'Zoology' focus, respectively. This classification was relevant only to 32.7% of the questions (mostly biology questions).

III. Psychological distance. The questions were also coded according to the psychological distance of the asker from the object of the question. Bar-Ana, Liberman and Trope (2006) describe four dimensions of psychological distance: (a) spatial—how distal in space is the target from the perceiver; (b) temporal—how much time (past or future) separates between the perceiver's present time and the target event; (c) social—how distinct is the social target from the perceiver's self (e.g., self vs. others, friend vs. stranger); (d) hypothetically—how likely is the target event to happen, or how close it is to reality, as construed by the perceiver. The zero-anchoring point of all four dimensions is the perceiver's direct experience, the stimuli sensed in the here and now, whereas psychologically distal entities are objects and events that are not part of the perceiver's direct experience. We would like to add another dimension, which is scale – objects, which are too small or big to be experienced with our senses. We have classified the objects of interest into three levels: 'myself', 'direct environment' that the asker may observe and interact with, and 'distant environment'. A model for this classification is presented in Figure 1.

The sample

Preparing the sample

The preparation of the sample included several stages. First, all the data from the various sources was collected and the questions were classified. Each data source was studied and coded independently. Since the coding of the questions was not done simultaneously, there were some differences in the coding scheme used for the different sources. Therefore, our second step was to create a unified coding scheme, and to correct any deviations from the scheme. For example, questions that were classified as 'low-tech' at the '*Logi*' database were added to the 'technology: other' sub-subject, and questions which dealt with issues such as myth, religion, and unnatural phenomena, in the '*School*' database, were re-coded as 'undistinguishable'. In another case, two chemistry categories 'what things are made of' and 'bonding and structure' were united. These corrections were first done semi-automatically using 'Access' software, and then manually during the iteration that followed. As part of the unification classifications that were missing from the original coding were added. Classification according to 'Psychological distance', for example, was added to all the databases.

Our third step was to clean impurities from our data. Questions with no clear science field were deleted ('undistinguishable'), as well as questions that dealt with mathematics. All the cases in which the grade level of the askers was not clear or that he/she was not a K-12 student, were removed at this stage as well.

Sample characteristics

The sample used in this study was made of 5945 self-generated science-related students' questions, collected from five different data sources. Of these questions 95% were asked by 4-12th graders, and a small minority by K-3rd graders. Only 84% of the questions were gender-identifiable and female students asked 55% of them. Almost half of the questions (46%) were collected from Israeli sources, and the rest were collected from two international web sites. For questions from these sites 76% included information regarding country of origin, resulting in a great majority of users from the USA (93%). The rest of the questions originated from Canada, UK, and India, and few arrived from Australia, Mexico and Korea.

Over two thirds of the questions were collected in a web based setting, and another 25% were collected via email in a TV-setting. The rest of the questions were collected in school setting (7.5%). Some of these questions were labeled as "non-attentive" since the askers did not voluntarily display interest in science. Overall, 93% of the sample was labeled as questions asked by science attentive audience.

Statistical analysis

Cluster Analysis. Clustering is the grouping of entities into subsets on the basis of their similarity across a set of attributes (Lorr, 1983). The technique of cluster analysis was chosen to help identify and describe multi-dimensional clusters of questions within this complex data set. These clusters gave us a starting point from which to further study the data using other statistical methods.

Cluster analysis was carried out using 'ClustanGraphics'[3]. This software was chosen due to its ability to deal with mixed data types (ordinal, binary and nominal variables, see table 1) and with missing values. Few studies used hierarchical methods of clustering to investigate interest-related issues such as patterns of vocational interest (Wolfe, 1978); library and information science students' orientation (Khoo, Higgins, Foo, & Lim, 2001), and an analysis of terms used for searching on the internet (Ross & Wolfram, 2000). However, hierarchical cluster analysis methods function well for a relatively small number of cases.

The procedure used in this study was k-Means Analysis, which can treat mixed data types, allows for missing values, and functions well with big samples. The k-Means cluster analysis groups cases (questions in our study) into clusters, based on their similarity. The distances between the cases are calculated using simple Euclidean distance. This procedure was previously used for explore Norwegian youth's orientation towards science (Schreiner, 2006).

The procedure was run several times, using different threshold values such as outliers distant, cluster number and minimum cluster size. Finally, we have chosen to limit the cluster size to over 50 cases, and the total number of clusters to less than 20. The number of iterations was limited to 100, and the outlier distance was set to 500 in order to prevent a massive losing of cases.

Contingency tables analysis. Contingency tables analysis was done using 'R'[4], a free software environment for statistical computing and graphics. Probabilities were calculated using χ^2 test.

Issues of reliability and validity are addressed in the "research approach, assumptions and limitations" section on p 19.

[3] www.clustan.com
[4] www.r-project.org

Findings

Stage I: General classification

Nearly 6,000 science questions collected from five different web-based, TV-based and school-based sources were rigorously analyzed in order to identify K-12 students' interest in science. The most popular subject was biology (46.3%), followed from a distance by chemistry (15.1%), technology (11.8%), physics (10%), astrophysics (8.4%), earth sciences (7.2%), and nature of science (1.2%). The 10 most popular sub-subjects were: anatomy and physiology (10.7% of all questions), botany and mycology (6%), ecology (5.4%), what thing are made of and bonding and structure (5.4%), sickness and medicine (4.2%), the solar system (4%), computers and Internet (3.8%), behavior (2.9%), genetics and reproduction (2.7%), and mechanics (2.7%). The least popular sub-subjects were history of biology (0.2%), the end of the world (0.3%), and chemical language (0.3%).

Most of the questions that were coded for magnitude (77% of the questions, n = 4594) were asking about macroscopic entities (78%) and of those which were classified for object of interest (33% of the questions, n = 1946), 54% were asking about animals, and the rest about human biology. Most of the questions (67%) were asking about objects which are not experienced directly by the asker, but found in his/her distant environment, 27% of the questions dealt with objects found in the direct environment of the asker, and 6% were asking about themselves.

Some science topics were the focus of a relatively large proportion of questions about oneself. The topic 'neurobiology and the mind', for e.g., which was the focus of 102 questions, had over one forth of the questions asking about oneself. Other relatively self-centered topics were: sickness and medicine (26% of the questions in this sub-subject); nutrition (23%); anatomy and physiology (20%), and genetics and reproduction (13%). Many more questions were asking about things which are found in the direct environment of the students. The leading topics in this category were computers and Internet (86%); man and animal relationship (74%); media and communication (68%); robotics and electronics (55%); inventions and patenting (50%); behavior (49%), and Low tech and other technologies (45%).

The motivation for raising the questions was largely non applicative, with 31% of the questions asking for an applicative information. 20% of the questions were classified as "imposed", meaning that they were not though of by the asker, but imposed on him/her by a school assignment.

The level of thinking expressed in the questions was higher than expected from the literature. With regard to the order of information 22% of the questions made comparisons and another 7% asked about causal relationships. With regard to the type of information, only 49% of the questions asked for factual knowledge, while 36% asked for explanations, 7% for methodological information and the rest made predictions, pointed at contradictions or asked open-ended questions.

Stage II: Unearthing hidden trends using cluster analysis

The cluster analysis procedure created 18 clusters, after ignoring 46 outliers. These clusters were rearranged according to increasing age, according to the percentage of elementary school students in the cluster (fig 2). Using this new arrangement I was able to identify 3 major types of science questions typically asked by young students, and 3 major types of science questions typically asked by older school students. Only one cluster, the smallest one yielded in this analysis (n = 51), which dealt with questions about the nature of science inquiry was not included. The merging process was subjective, and might have resulted in different groups if conducted by another researcher.

Young students major types of science questions

Animal biology: 2 clusters (# 18, 6[5]) were focused on the biology of animals, in the context of behavior, ecology, man and animal relationship, anatomy and physiology. This type of questions (n = 1024) were asked mainly by Israeli elementary school students in a TV setting. Some of these questions were applicative in nature, but non were imposed by school assignments. The bigger cluster contained simple requests for factual data, and information about properties of only one variable. Many of these questions dealt with spectacular aspects of the animal kingdom. The smaller cluster,

[5] In there order of appearance on figure 2

which was characterized by a female dominance, was made of explanatory type of questions, asked as a result of a direct observation.

In a galaxy far, far away: 4 clusters (# 12, 11, 13, 5) were asking about the distant environment, in the fields of astrophysics and earth sciences. This type of questions (n = 673) was characterized by a dominance of male elementary and junior high school students. Clusters 11,12,13 were all comprised of astrophysics questions, and they were differentiated by the type of information they asked for: factual (# 12), explanatory (# 11), or more complex types (# 13). This third cluster, which was also the smallest, was characterized by a relatively high proportion of questions collected in schools from non-attentive general audience. These children focused more than other groups on the question of the existence of extra terrestrial life. Cluster 5, which contained many open-ended questions in the field of earth sciences was included here due to its focus on issues, which are remote from the daily experiences of the asker.

High and low tech: 3 clusters (# 2, 10, 1) were assembled of mainly questions in the field of technology. This type of questions (n = 848) was characterized by a dominance of elementary and junior high school Israeli male students. A relatively high proportion of questions from non-attentive audience were gathered in the youngest cluster in this analysis (# 2), asking for simple factual knowledge and information regarding the properties of a single variable, in the context of the history of technology, low tech, and computers and the internet. Many of these questions were asked about the distant environment. The most 'masculine' cluster in this analysis (# 10) included questions in various fields, with 61% of the questions dealing with computers and the internet. These were methodological questions, asked for applicative reasons about the direct environment, by a science attentive group of students. Another group (# 1) of relatively non-attentive young students asked for explanatory information regarding issues in earth sciences - mainly meteorology, and technology - mainly computers and internet, transportation, low tech, robotics and electronics.

Older students major types of science questions

My biology: 3 clusters (# 3, 14, 8) were comprised of questions which focused on the human biology of the asker herself/himself. Some of these questions were applicative, and they were characterized by asking for a rather high order of information – comparisons and causal relationships, and about relatively smaller scales of magnitude. The variable that differentiated between the three clusters was the type of information requested. In one cluster the questions asked for factual knowledge (# 3), in another for explanatory information (# 8), and in the third (and smallest) cluster for complex methodological information, open-ended information, and predictions and contradictions (# 14). These questions (n = 1063) were characterized by a rather even gender and language distribution (relatively to the whole sample) and older age group (mainly 10-12 graders).

Imposed questions: 3 clusters (# 16, 9, 4) were comprised of questions that were imposed by school assignments and not raised out of intrinsic interest. These clusters contained a mix of questions from all the science subjects, and the popular sub subjects were: what things are made of and bonding and structure, anatomy and physiology, sickness and medicine, botany and mycology, ecology, and mechanics. Two of the clusters asked for methodological information and questions in the third cluster asked for factual information. Questions form this type (n = 1168) were characterized by a substantial female dominance, and they were asked in an English-based internet environments.

Small magnitude, high cognitive level: 2 clusters (# 15, 17) contained requests for high order of information (mainly comparisons) in the fields of physics and chemistry, with relatively many questions dealing with nano-scale objects, and no applicative motivation for asking the question. This type of questions (n = 1072) were asked mainly by high school students, and collected from English based resources. The Chemistry cluster was characterized by a female dominance (# 17), while the physics cluster was characterized by a strong male dominance (#15).

The rearrangement of the clusters according to increasing age also provided a sense of some of the patterns, interactions and trends, which were hidden in the data. It was suddenly apparent that the *cognitive level* of the questions (order and type of information) increased with age, while the *psychological distance* of the object and its *order of magnitude* decreased. Other trends which were familiar to us from former research were visible as well, such as the interest of young age groups in zoology (Baram-Tsabari & Yarden, 2005; Baram-Tsabari & Yarden, 2007c), and the tendency of high school students to ask questions imposed by their teachers (Baram-Tsabari et al., 2006). We subsequently closely examined these patterns, in order to find out if they are statistically significant using conventional statistical procedures.

Stage III: Studying the trends using contingency tables analysis

Age effects

Interest in the different seven science subjects change with age ($p < 0.001$). Specifically, interest in physics and chemistry increases with age, while interest in earth sciences, astrophysics and technology decreases. A deeper examination revealed a pattern in this developmental shift: the classical science disciplines which are being studied at school (biology, physics, chemistry) were increasingly present in students' questions, while non-classical science subjects, which are not universally studied at school (earth sciences, astrophysics, nature of science, and technology) were disappearing from students questions. In order to neutralize the effect of school assignments on this analysis, we have repeated the procedure independently for spontaneous and imposed questions (figure 3). The effect seems to be true for both kinds of questions: both imposed questions, and to a lesser, but significant extant, spontaneous questions were increasingly focused on biology, physics, and chemistry, as children get older, while interest in non-classical science subjects decreased. At all age groups, more questions in non-classical science subjects were spontaneously asked, rather than being imposed by school assignments.

Several reasons might be at the basis of this effect. Children might be naturally loosing interest in earth sciences, astrophysics, and technology, while gaining interest in biology, physics, and chemistry as they grow up. Another possibility is that the attention of those who are attentive to science is being focused on certain subjects by the formal schooling system. If the second explanation is true, it seems that the formal schooling system is failing to capture, build on and capitalize the interest that young students spontaneously have in certain science subjects.

More specific topics which were of great interest for elementary students, but less so for older age groups were anatomy and physiology; computers and the Internet; history of technology; man and animal relationship, the solar system, extinct animals, and behavior. All of these were also characterized by a rather small proportion of imposed questions at all age groups.

Another developmental shift with age was an increase in the thinking level expressed in the questions. It might seem like proving the obvious, but we are not aware of any research showing such a trend. The thinking level was found to increase using the two measures used: students tended to ask for higher order of information as they grew up ($p < 0.001$) – more comparisons and causal relationships and less for the properties of a single object (figure 4a); and for more complex types of information ($p < 0.001$) – explanatory, methodological, predictive and open-ended information, and less factual information (figure 4b). This trend was true for both the spontaneous and the imposed questions.

As age increased the order of magnitude of the objects in question deviated from macroscopic scale to organization levels which are not exposed to the naked eye ($p < 0.001$). While 83% of the questions asked by K-3 students dealt with macroscopic entities, this proportion dropped to 75% among 4-6th graders, 61% among junior high school students and 48% among senior high school students. The other organization levels: population, microscopic, molecular and Nano-scale were popular to a similar degree among junior and senior high school students. Among elementary school students "population" was the object of more question than the smaller organization levels (figure 5).

Gender effects

It is widely agreed in the literature that girls' and boys' science interests differ from each other, with boys, on the average, being more interested in physics and technology than girls, and girls on the average being more interested in biology than boys (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2008; Dawson, 2000; Farenga & Joyce, 1999; Friedler & Tamir, 1990; Hoffmann, 2002; Jenkins & Nelson, 2005; Jones et al., 2000; Kahle et al., 1993; Murphy & Whitelegg, 2006; Osborne & Collins, 2001; Schreiner, 2006; Spall et al., 2003; Stark & Gray, 1999; Woodward & Woodward, 1998).

This sample demonstrated a gender gap in interest as well ($p < 0.001$), but this gap was not always apparent. At the youngest K-3 age group, there was no statistical difference between the science fields asked by the two genders. However, this gap appeared on the older grades of the elementary school and dramatically widened latter on (figure 6).

In order to compare the gap between the science interests of boys and girls in the different age groups, each distribution of interests was expressed as coordinate in a 7 dimensional space, with each of the dimensions representing one of the science subjects. Then, the distance between the girls' and the boys' coordinate for the same age group was calculated, and expressed as a uni-dimensional number with arbitrary units. It was found that the difference between boys' and girls' interests increases over 30 fold as they grow up. Furthermore, the gap widened in the most stereotypical manner with girls being increasingly interested in biology and boys were asking more about physics and technology.

This tendency is also apparent when reviewing the ten most "masculine" topics that were more interesting to boys than to girls. These were: computers and Internet; modern physics; transportation; the universe; electricity and magnetism; history of technology; meteorology; robotics and electronics; optics, heat and sound; and extinct animals. Four of these topics are sub-subjects of technology, and another 3 are sub-subjects of physics. The ten most "feminine" topics that were more interesting to girls than to boys were: botany and mycology[6]; what things are made of and bonding and structure; ecology; nutrition; behavior; sickness and medicine; man and animal relationship; microbiology and virology; cell biology; and environment. 9 of these topics are sub-subjects of biology.

A difference was also found in the type of information asked for by male and female students ($p < 0.05$). While boys asked for more factual and methodological information than girls did, girls asked for more explanatory information than did boys. The trend was stronger when testing only the spontaneous questions ($p < 0.001$), and no such difference was found with regard to the imposed questions. Boys and girls had different reasons for asking questions. More girls than boys (34% and 29%, respectively)

[6] Some of the "feminine" topics are also characterized by a large proportion of imposed questions, due to the greater tendency of female students to submit this type of questions.

were asking for applicative information ($p < 0.001$), and more girls than boys (25% and 16%, respectively) were asking imposed questions ($p < 0.001$).

Effects of the level of autonomy

Different science subjects had different likelihood of being the focus of an imposed question ($p < 0.001$). The most "school-related" subject was chemistry, with 50% more imposed than spontaneous questions (21% and 14% of the overall imposed and spontaneous questions, respectively), and followed by biology with 53% of the imposed and 45% of the spontaneous questions. The most "spontaneous" subjects were astrophysics (3% of the imposed and 10% of the spontaneous questions) and technology (5.5% of the imposed and 12.5% of the spontaneous questions). The sub-subjects that were characterized by the greatest proportion of imposed questions were: botany and mycology; ecology; what things are made of and bonding and structure; microbiology and virology; mechanics; cell biology; stoichiometric, and chemical reaction. The sub-subjects that were characterized by the greatest proportion of spontaneous questions were: anatomy and physiology; computers and Internet; the solar system; history of technology; man and animal relationship; the universe; behavior; genetics and reproduction, and space missions.

Imposed questions were focused less on human biology, and much less on zoology ($p < 0.05$) than spontaneous ones. Imposed questions were also less likely to ask about macroscopic entities than spontaneous ones ($p < 0.001$).

The psychological distance of the object in interest was found to be different between spontaneous and imposed questions ($p < 0.001$). Among the imposed questions there were almost no questions about oneself (1%), whereas 6% of the spontaneous questions were asking about "myself". No difference was found between females' and males' questions with regard to psychological distance, neither for the spontaneous or the imposed questions, and no such difference was found between the different age groups. There is, however, one group which was significantly different with regard to this variable ($p < 0.001$). The non-attentive group displayed much more interest in asking about themselves (15.5% of their questions) relatively to the attentive group. The non-attentive students were relatively more interested than the attentive ones in the following topics: robotics and electronics; evolution; transportation; genetics and reproduction;

behavior; computers and Internet; the universe; neurobiology and the mind; the big bang and star formation; extra-terrestrial life, and the end of the world. All these are also characterized by being spontaneous topics of interest, which are not usually the focused of imposed questions.

Another characteristic of the imposed questions is the relative lack of open-ended questions, and questions which present predictions or contradictions ($p < 0.001$; figure 4b). It was, on the other hand, a rich source for methodological questions, which deal with ways of knowing in science. Imposed questions were also characterized by a relatively high proportion of question asking for causal relations (16% of imposed questions, 5% of the spontaneous questions; $p < 0.001$).

Table 1. Basic demographic characteristics of the different data sources and the overall sample.

Variable/databases	Description	Logi (n = 1486)	Madci (n = 1525)	Bashaar (n = 795)	Newton (n = 1693)	School (n = 446)	Overall sample (n = 5945)
Askers' characteristics							
Age group	Ordinal: K-3, 4-6, 7-9, 10-12	97% K-9th graders	4-12th graders	79% 10-12th graders	85% 7-12th graders	4-12th graders	95% 4-12th graders
Gender[1]	Binary: female, male	43% female	56% female	62% female	60% female	47% female	55% female[1]
Country[2]	Nominal: Israel, USA, Canade, UK, India, Australia, Mexico, Korea[3]	Israeli	84% Americans	Israeli	99.5% Americans	Israeli	46% Israelis 93% of questions in the international sites from the USA[2]
Database characteristics							
Language	Binary: Hebrew or English	Hebrew	English	Hebrew	English	Hebrew	54% English
Setting	Nominal: Internet, TV, School	TV[4]	Internet	Internet	Internet	School	67.5% internet, 25% TV, 7.5% school
attentiveness	Binary: attentive and non-attentive	attentive	attentive	attentive	attentive	Partly: 413 non attentive[5]	93% attentive

[1] Only 84% of the questions were gender-identifyable. The percentage of female contributaions is calculated from the identified cases.
[2] Only 76% of the questions collected from the two international web sites included information regarding country of origin. The percentage of American contributaions is calculated from the identified cases.
[3] Countries are listed in order of their frequency.
[4] In this TV-show, the answers were given on TV, but questions were sent by email.
[5] Some questions that were asked in a school setting did not fulfil the requirment of showing an interest in science, and therefor we could not assume that the askers are attentive to science.

Table 2. Examples for classification of questions according to topic, cognitive level, and reason for asking the question

Topic: Subject; Sub-subject	**Cognitive level:** Order and Type of information	**Reason for asking:** Motivation, Autonomy	Example[1] (gender, age group)[2]
Technology: computers and the Internet	Properties, Explanatory	Applicative; Spontaneous	I want to add a chat application to my Internet site, what should I do? (m, Junior high school, IL)
Earth sciences: Oceanography	Comparisons; Explanatory	Non-applicative; Spontaneous	Why and how salt got in the sea and why is it not in lakes? (m, high school, US)
Physics: Mechanics	Causal relationships; Prediction and contradiction	Non-applicative; Spontaneous	Gravity pulls everything down …then how come that fire goes up? (m, K-3, NA)
Biology: Botany and mycology	Properties; Methodological	Non-applicative; Spontaneous	How are seedless oranges made?(repeated question)
Chemistry: Acids and bases	Comparisons[3]; Explanatory	Applicative; Imposed	My teacher is having us do an experiment where we place an egg in vinegar...My Dad found out that an eggshell is mostly calcium carbonate and Vinegar contains acetic acid in water. Are the bubbles C02? If so, what is the chemical reaction that is occurring to generate CO2? (f, Junior high school, US)
Biology: Evolution	Comparisons[4]; Prediction and contradiction	Non-applicative; Spontaneous	How can scientists even stand by evolutionary theories of cells being formed out of a "soup" and then evolving into the entire animal and human races and species, and yet, they can't reproduce the effect themselves? Where is the scientific evidence? (f, high school, US)

[1] These are verbatim quotes, or translations of verbatim quotes. In some cases only a part of the question is shown.
[2] Where data is available. m = male; f = female; IL = Israel; US = United States; NA = not available.
[3] This is an example for a non-causal connection between two variables.
[4] This is an example for a confrontation between two variables.

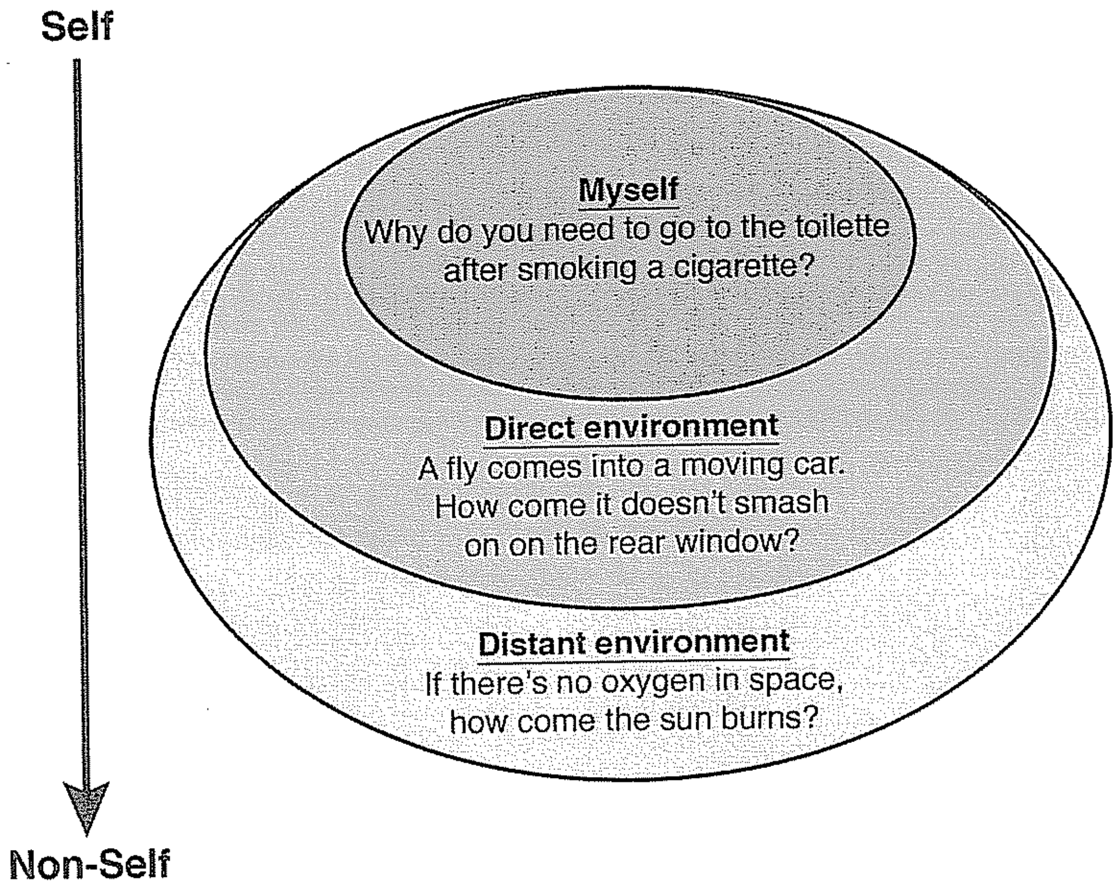


Fig. 1. A model for classification according to psychological distance. The object which is the focus of the question was classified into one of three levels, according to its' psychological distance from the asker. An example is provided to each level.

Fig 2. Results of a cluster analysis procedure. 5899 questions were classified into 18 clusters using k-means procedure. Cells were shaded only when the content of the cell was significantly different from the overall sample. The clusters were rearranged according to decreasing percentage of K-6 graders in the cluster.

[1] Shades of blue – male dominance; shades of pink – female dominance
[2] Pale blue – Hebrew dominance; red – English dominance
[3] Light orange – bigger organization scales; Dark orange – smaller organization scales
[4] Only 33% of the questions were coded for object of interest. Results are shown only for the biology questions. Pale blue – human biology; Pink – animal biology
[5] Light green – lower order of information; darker green – higher order of information
[6] Light blue – simpler type of information; darker blue – complex type of information
[7] Light orange – shorter psychological distance; dark orange – longer psychological distance

Cluster #	2	18	6	12	10	1	11	13	5
Size: # of cases	247	387	637	259	280	321	143	65	206
Grade: dominant age group	K-6	K-6	K-6	K-9	4-9	4-9	K-6	4-9	7-9
Gender: % of girls [1]	41.9	58	53.4	46.4	35.4	47	47.7	44.8	50.8
Language: % of English questions [2]	26.3	28.4	38.3	37.8	34.6	38.3	53.1	35.4	60.2
Setting: dominant source	tv	tv	tv	tv	tv			school	
Attentiveness: % of attentive	85.4	92	96.9	94.6	92.9	84.7	88.8	76.9	93.2
Subject	Technology	Biology	Biology	Astrophysics	Technology (76% of the questions)	Earth sciences and Technology	Astrophysics	Astrophysics	Earth sciences
Sub subject: dominant topics	history of technology, low tech and other technologies, computers and internet	Behavior, ecology, man and animal relationship	anatomy and physiology, ecology	the solar system, the universe, space missions	computers and internet (61% of the questions)	meteorology, computers and internet, transportation, low tech and other technologies, robotics and electronics	the solar system, the universe, big bang and star formation	the solar system, the universe, space missions, extra-terrestrial life	all earth science topics
Magnitude: dominant groups [3]	macro	population, micro	population, macro, micro		macro	macro			
Object of interest: % of zoology questions [4]		zoology	zoology						
Order: dominant groups [5]	all properties	connections and properties	properties	all properties	all properties			connections and properties	properties
Type [6]	factual	explanatory	factual	factual	methodology	explanatory	explanatory	open-ended, contradictions and predictions, methodology	open-ended
Autonomy									
Motivation		some applicative	some applicative		applicative				
Psychological Distance [7]	lots of distant environment	lots of direct observation	no self questions	distant environment	lots of direct observation	no self questions	distant environment	distant environment	distant environment

3	14	15	8	16	17	9	7	4
440	135	469	488	454	603	471	51	243
10-12	10-12	9-12	10-12	9-12	9-12	10-12	7-9	7-12
56.7	56.7	41.1	62.6	66.6	61.1	63.1	58	71.5
56.6	45.9	67.6	54.7	71.4	83.3	70.5	78.4	60.1
				internet	internet	internet		internet
93.9	88.9	93.4	86.7	98.9	96.4	98.5	86.3	99.6
Biology	Biology	Physics	Biology	All subjects	Chemistry	All subjects	NOS	Biology (90%)
anatomy and physiology, sickness and medicine, nutrition, genetics and reproduction, neurobiology and the mind, botany and mycology	botany and mycology, anatomy and physiology, sickness and medicine, nutrition, biotechnology	all physics topics	anatomy and physiology, sickness and medicine, genetics and reproduction, botany and mycology	what things are made of and bonding and structure, anatomy and physiology, sickness and medicine, botany and mycology	all chemistry topics	ecology, what things are made of and bonding and structure, mechanics	NOS	botany and mycology, ecology
macro, micro, molecular	all	macro, nano-scale	macro, micro, molecular	all	nano-scale, molecular, macro	all	population, micro	Pupolation, macro, micro
human	human		human	human		zoology		zoology and human biology
causal relationship	causal relationship and connections	connections and properties	connections	properties	connections		properties	causal relationship and connections
factual	open-ended, contradictions and predictions, methodology		explanatory	factual		methodology	open-ended methodology	methodology
				imposed		imposed		imposed
some applicative	some applicative		some applicative	applicative		applicative	some applicative	applicative
lots of myself	lots of myself	lots of distant environment	lots of myself		no self questions	lots of direct observation	lots of distant environment	lots of direct observation

Legends for figures 3-6

Fig. 3. The change in the proportion of classical (biology, physics, chemistry) vs. non-classical (earth sciences, astrophysics, nature of science, and technology) science subjects in four age groups, among spontaneous (on the left) and imposed questions (on the right). The width of a rectangale is proportional to the contribution of that particular age group, and its' length represents the non-classic/classic science subjects ratio.

Fig. 4a. The change in the proportion of requests for different levels of order of information (in increasing order: properties, comparisons, causal relationship) in four age groups, among spontaneous (on the left) and imposed questions (on the right). The width of a rectangale is proportional to the contribution of that particular age group, and its' length represents the proportion of different orders of information.

Fig. 4b. The change in the proportion of requests for different types of information (factual, explanatory, and complex types: methodological, open-ended, predictions and contradictions) in four age groups, among spontaneous (on the left) and imposed questions (on the right). The width of a rectangale is proportional to the contribution of that particular age group, and its' length represents the proportion of different types of information.

Fig. 5. The change in the order of magnitude of the object in interest between four age groups.

Fig. 6. The change in male and female students' interest in seven science subjects with age. The length of the eight large rectangles represents the male:female ratio in that age group, and its' width represents the relative contribution of that age group to the sample. Each of these rectangles is divided into 7 narrower rectanles, representing the relative popularity of different science subjects within that gender and age group. The 7 dimentional distance between the preferences of males and females in each age group is marked by a grey dot.

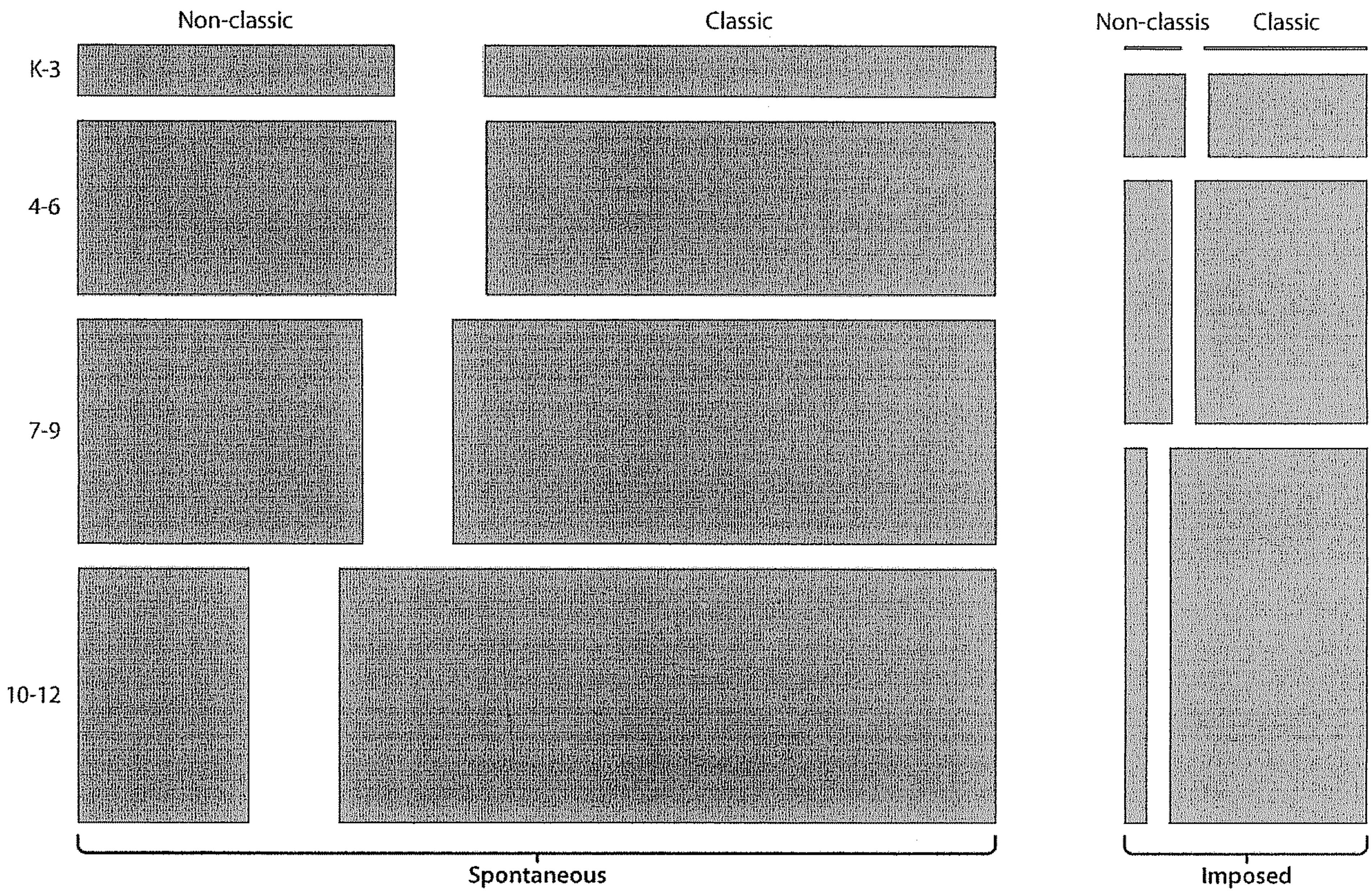
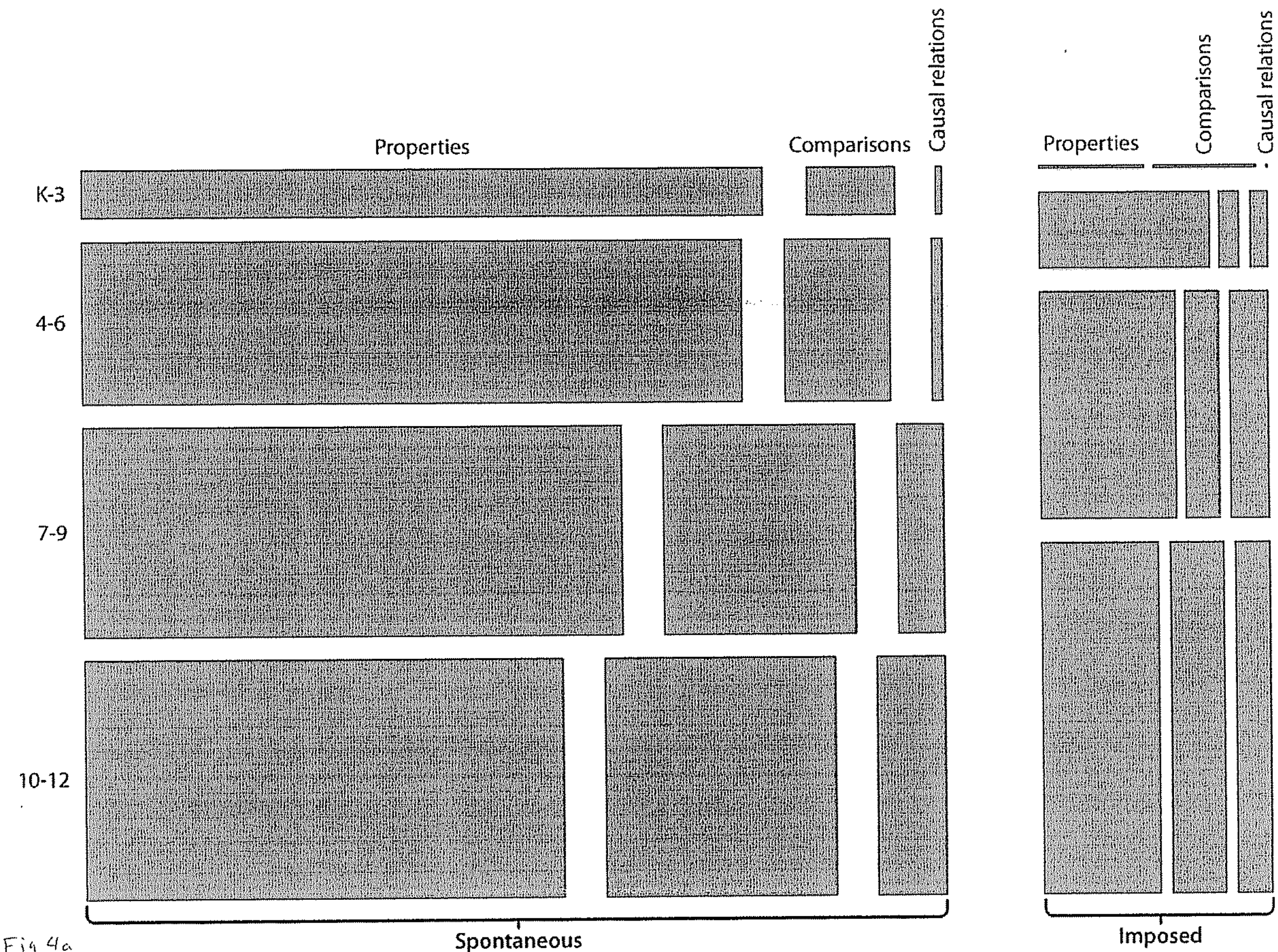
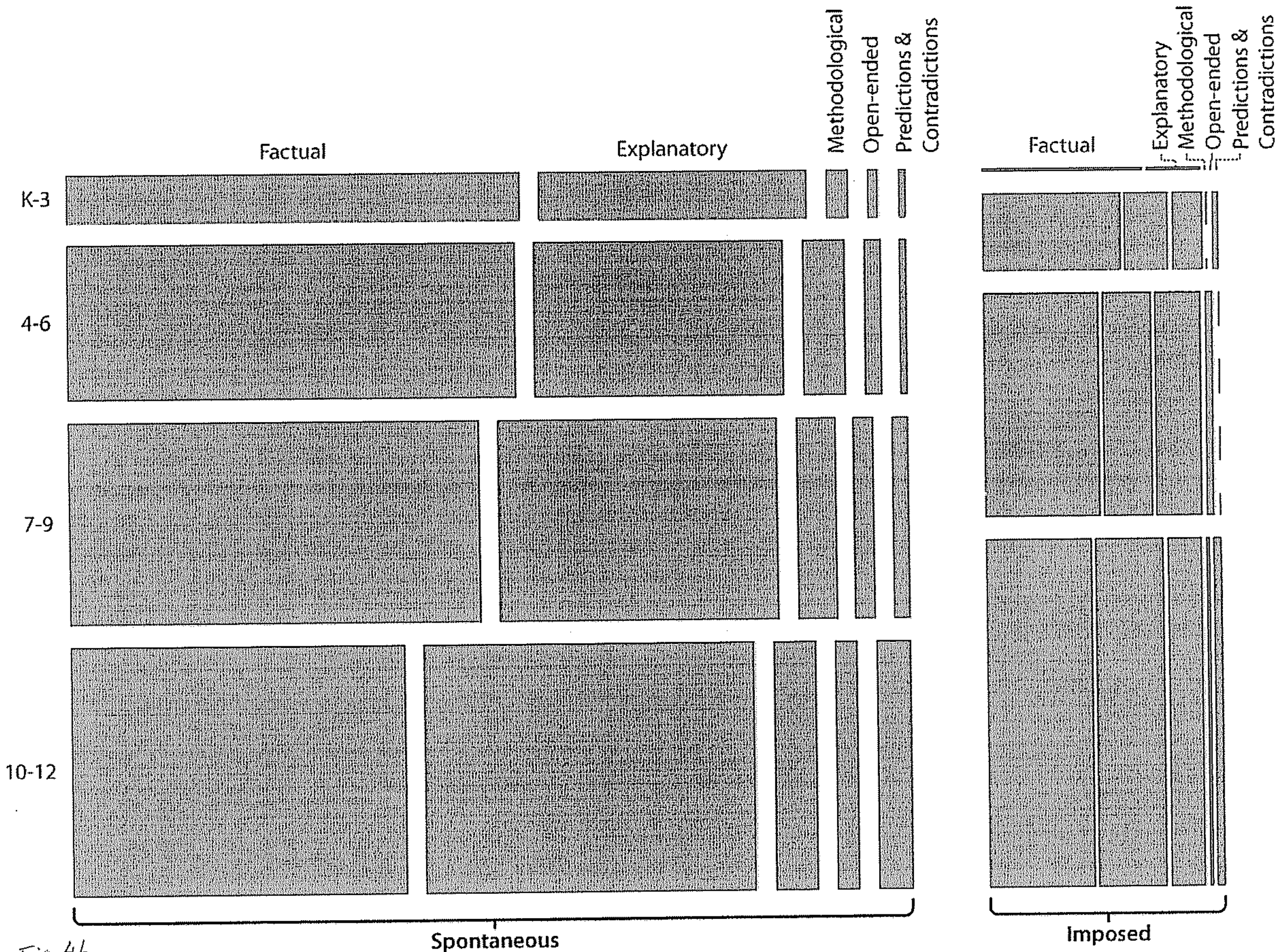

Non-classic
Classic
Non-classis
Classic
K-3
4-6
7-9
10-12
Spontaneous
Imposed

Fig 3.



Properties
Comparisons
Causal relations
Properties
Comparisons
Causal relations
K-3
4-6
7-9
10-12
Spontaneous
Imposed

Fig 4a



Factual
Explanatory
Methodological
Open-ended
Predictions & Contradictions
Factual
Explanatory
Methodological
Open-ended
Predictions & Contradictions
K-3
4-6
7-9
10-12
Spontaneous
Imposed

Fig 4b.

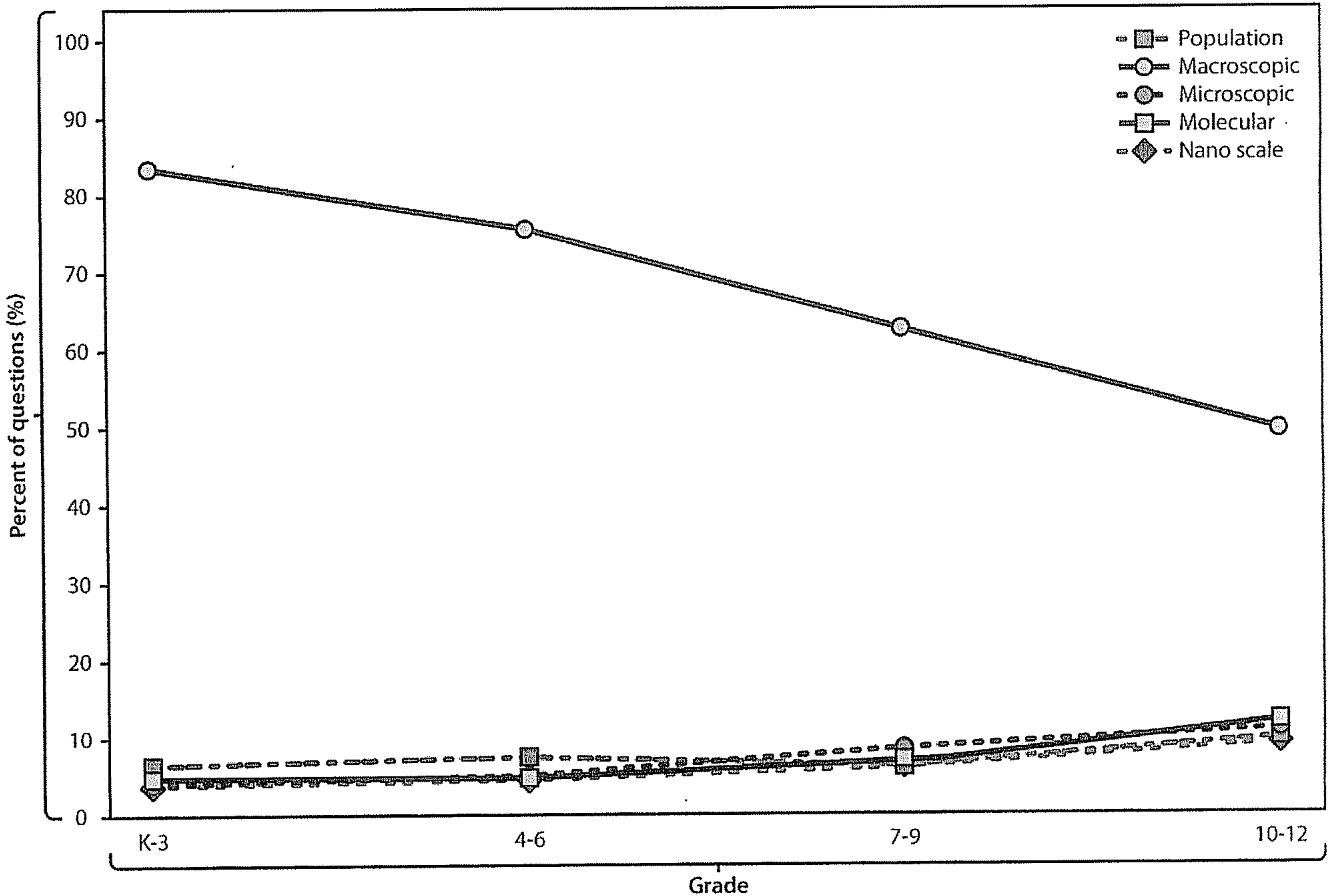

Population
Macroscopic
Microscopic
Molecular
Nano scale
Percent of questions (%)
100
90
80
70
60
50
40
30
20
10
0
K-3
4-6
7-9
10-12
Grade

Fig 5.

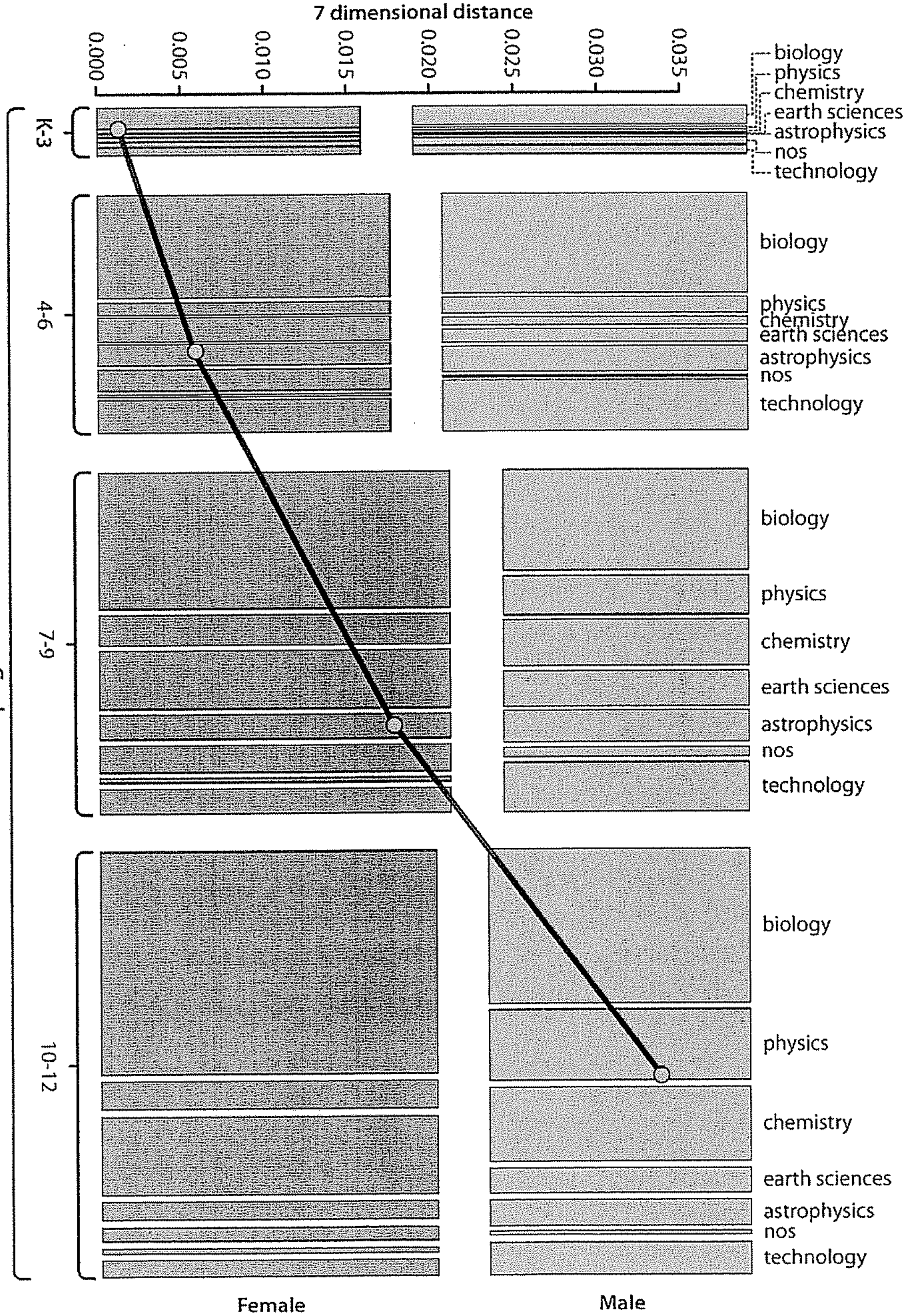

7 dimensional distance
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Grade
K-3
4-6
7-9
10-12
biology
physics
chemistry
earth sciences
astrophysics
nos
technology
Female
Male

Fig 6.

Part III: Discussion

The purpose of this study was to investigate students' interests in science using their self-generated questions. I argue that there is considerable promise in using students' self-generated and primarily spontaneous questions to enhance the attractiveness and relevance of science curricula. The methodology used here may provide a rapid and consistently up-to-date way of assessing children's interests while avoiding adult-generated views.

Some of our results confirm and reinforce what is already known about children's interest, using a different data source and methodology. However, this study provides new insights into issues such as topic-specific differences between spontaneous and school-related interest in science; the higher cognitive-level of children's questions in free-choice settings compared to classroom settings; the females tendency to ask more school-related questions than boys, and the persistence of girls and boys stereotypic interests both among the spontaneous and school-related questions. Other new findings were an increase in the cognitive level of the questions with age, while the psychological distance of the object in question and its order of magnitude decrease; a developmental shift in interest in biology, accompanied by a decrease in interest in zoology and an increasing interest in human biology with age; the dominance of questions asked by females in free-choice science learning environments, and the widening stereotypical gap between girls' and boys' science interests. Finally, six main types of science questions were identified using cluster analysis techniques. Few of these findings will be shortly discussed here.

An important observation of this study is the recurring inconsistency between students' spontaneous (intrinsically motivated) and school-related (extrinsically motivated) interests. There is evidence that intrinsic motivation can promote learning and achievement better than extrinsic motivation (Pintrich & Schunk, 2002). Therefore, it might prove pedagogically beneficial to respond to children's interests by incorporating into school science, topics which are of spontaneous interest to children, such as 'The Solar System', 'Modern Physics', 'Evolution', and 'The Universe', which are currently underrepresented in many science curricula.

Our findings suggest that students can raise questions reflecting a high cognitive level on their own, but may feel less comfortable or encouraged to do so during science class. Another interpretation is that students may have more time to reflect and compose their questions in an online setting than during science class. It should be borne in mind, however, that the student population in our sample may have a higher level of motivation to seek sources outside the classroom for science learning.

Another important finding of this research is that internet-based Ask-A-Scientist sites demonstrated surprising dominance of female contributions among K-12 students, where offline situations are commonly characterized by males' greater interest in science. This female enthusiasm was observed in different countries, and had no correlation to the level of equality in those countries. Learners ask questions when they feel secure, and free-choice science-learning settings on the internet might offer just such a place, where revealing a misunderstanding does not render the student vulnerable to ridicule from his/her teacher or peers. This may indicate that the internet as a free-choice science-learning environment plays a potentially empowering and democratic role which is especially relevant to populations which are deprived of equal opportunities in learning formal science.

However, girls' interest in submitting questions to scientists dropped all over the world as they grew older, and the stereotypically gendered science interests persist in this environment as well. It is important to note, on the other hand, that there are also topics which appeal to both sexes, and arouse spontaneous interest as well. Therefore, it seems possible to teach scientific concepts and ideas in the context of topics which are not profoundly preferred by boys, but rather preferred by girls or equally attractive to both genders (Hoffmann & Haussler, 1998; Krapp, 2000; Sjoberg, 2000). Our study identified few equally attractive topics, such as health issues, atom structure, and chemical bonding and structure; and few science subjects which are very popular among girls, such as ecology, anatomy, botany, nutrition and neurology. Using these topics as the context of science learning could prove beneficial in the process of mainstreaming science education.

Implications

Hofstein & Kempa (1985) distinguished between interest arousal which can be brought about by an appropriate selection and structuring of subject matter included in a curriculum; and motivational enhancement which is brought about by the choice of pedagogical strategies. Students' interests can be used in various ways, since it has to do with the content of the lesson and not with the teaching strategies used by the teacher.

Addressing students' interests in the science classroom

It should prove nearly impossible to adhere to the individual interests of each of the students in a large class. However, there are many ways in which students' interests can be integrated into a standard-based curriculum.

Triggering learning of new content. Having students answer their own questions seem to make it difficult to follow the intended curriculum, but it is common for puzzling questions to embrace topics that the teacher intended to reach sooner or latter (White & Gunstone, 1992). Therefore, students' spontaneous questions may be used for the engaging stage of the learning cycle (Kolb & Fry, 1975). For this purpose, it might prove useful to provide teachers lists of popular spontaneous science questions alongside with their answers.

Reoccurring themes. Where does the fat go when a person loses weight? Why do males have nipples? Can lions become vegetarians? Are dogs color-blind? Some questions are repeated at different ages and in different cultures, and can serve as triggers for standard science-curriculum issues, such as nutrition, evolution, ecology and the senses (respectively). Daiute (1997, p. 329) instructs teachers on how to recognize and use those topics in the classroom: when "topics emerge as recurrent themes underlying children's conversations, it is the optimal time to explore such issues in relation to subject matter in your curriculum." It is sad to note that none of the frequently asked questions, that were reoccurring among Israeli children's questions (Baram-Tsabari & Yarden, 2005) are addressed by the relevant elementary school curricula.

Make room for students' questions. Questions are an important part of the ongoing scientific research process and have an important educational role (Biddulph et al., 1986; Brill & Yarden, 2003; Scardamalia & Bereiter, 1992). Our results indicate that students are able to pose science questions in informal settings, and it would be educationally beneficial if they would use this ability in classrooms as well. Many researchers recommended environments which encouraged question-asking by students, such as discussion (King, 1994), cognitive conflict (Allison & Shrigley, 1986), real-world problem-solving activities (Chin et al., 2002; Zoller, 1987), case studies (Dori & Herscovitz, 1999), biotechnology-focused modules (Olsher & Dreyfus, 1999), use of written questions (Pedrosa de Jesus et al., 2003) and learning using adapted primary literature (Brill & Yarden, 2003). Students' questions enable teachers to be aware of what students are interested in and what they want to know about a given topic (Chin & Chia, 2004). This way teachers can be more responsive to students' needs and interests, and tailor their instruction to cater to these individual differences (Chin & Chia, 2004).

Using the internet to respond to students' interest. Learning using the internet may be a way to cater to the individual interest of all the students in a big classroom, allowing each of them to explore her/his preferred aspect of a subject.

Organization and design of teaching. Students' questions may be used to recommend a design for teaching a certain science topic (Maskill & Pedrosa de Jesus, 1997).

Choice of context. Our analysis identified some scientific topics that appeal to both sexes or predominantly to girls. Therefore, it seems possible to teach scientific concepts and ideas in the context of topics which are not profoundly preferred by boys, but rather preferred by girls or equally attractive to both genders (Hoffmann & Haussler, 1998; Krapp, 2000; Labudde et al., 2000; Sjoberg, 2000; Steinkamp & Maehr, 1984). Haussler *et al.* (1998) identified five domains of interest in physics, only one of which—physics as a scientific enterprise for its own sake—is overwhelmingly dominant in physics classroom. Other domains, such as how science can serve humankind and explanations of natural phenomena which are of more interest to girls, are almost non-existent (Haussler et al., 1998). Girls in particular respond very sensitively to a change of context (Murphy & Whitelegg, 2006). For example, girls are much more interested in learning more about pumping blood by an artificial heart than about pumping petrol from great depths, whereas for boys both are similarly interesting (Hoffmann, 2002). Therefore, human biology, medicinal uses or natural phenomena could be introduced as contexts for physics lessons, topics which would take the interests of girls into account (Hoffmann, 2002). Using such topics, which can be identified using spontaneous questions, as the context of science learning could prove beneficial in the process of mainstreaming science education.

Furthermore, many principles in biology can be taught using different contexts, such as human biology, zoology, botany, and microbiology. It is possible to choose a more engaging context for the target audience, rather than an alienating one. For example, zoology context would appeal more to children, while human biology would appeal more to adolescence and adults (Baram-Tsabari et al., 2006; Baram-Tsabari & Yarden, 2005; Baram-Tsabari & Yarden, 2007c).

Science fairs and project-based learning. Some popular teaching strategies take into account students' interests to some degree. Science fairs and project-based learning, for example, allow students to create their own research questions within a given topic. In a teaching strategy such as K-W-L (know-want-learn), for example, teachers activate students' prior knowledge by asking them what they already know; then students set goals specifying what they want to learn; and after reading students discuss what they have learned (North Central Regional Educational Laboratory, 2006), this way incorporating to some degree students' views and interests in the topic.

Inquiry based learning. Students' self-generated questions can sometimes be used as a starting point for an inquiry based learning. Using student-generated questions has potential in directing students inquiry and guiding their construction of knowledge (Chin, 2001). Question-driven problem-based learning (Q-PBL), which involves students crafting their own problems, generating questions, and investigating related learning issues, is an inquiry based approach, in which learning is based on what the students are interested in and driven by students' need to answer their own questions (Chin & Chia, 2004). However, even teaching strategies which draw upon driving questions to sustain students' interest use questions developed by the teachers (Krajcik & Mamlok-Naaman, 2006), and a context designed to legitimize learning from the students' perspective by making their learning intrinsically meaningful was chosen by the curriculum developers (Bulte, Westbroek, de Jong, & Pilot, 2006). However, for science to be relevant to its practitioners, the origin of the questions which are being investigated are of great importance.

Chin and Kayalvizh (2002) studied the suitability of students' questions for classroom investigation. They found that among the questions that were posed individually, only 11.7% could be answered by performing hands-on investigations. When questions were generated in groups after examples were shown, 71% of the questions that were raised amenable to science investigations but they related to fewer topics. Thus, although there is general agreement in letting pupils investigate their own questions, pupils' 'raw' questions do not seem to immediately lend themselves to practical investigations, and pupils need the teacher's help to translate such questions into testable hypotheses (Chin & Kayalvizhi, 2002).

Question-based lesson. Kwan (2000), an elementary-school teacher, followed a question asked by a student to develop a lesson on constructions, which was based on the child's question and her national science curriculum. Also Yerrick (2000) used lower track students' questions to guide and temper instruction in class investigations.

Question-based curriculum. Gallas (1995) used her elementary-school students' questions to construct a curriculum in human biology. This enabled her to build a community of learners who strive to answer their own specific questions.

Student-centered learning materials. I would like to propose creating student-centered learning materials, which are based on empirical evidence regarding the science interests of different groups of students, as described in the discussion section.

Future research: Student-interest focused learning materials

Asking a question in a free-choice environment does not guarantee willingness to invest time and effort in learning the answer in a school setting. It is not clear what would happen if students' interests were implemented into the school science curriculum. Would free-choice learning lose all of its appeal once it became compulsory? It is an untested assumption that the more that will be known about students' interests, enthusiasms, dislikes, beliefs and attitudes, the more feasible it will be to develop school science curricula that will engage their attention and help reduce long-standing gender and other differentials (Jenkins, 2006). I suggest to put this assumption to the test.

In order to do that, the next step of this research should be to test what are the benefits, if any, of using students' interest focused learning materials. I suggest taking the following steps (fig. 7):

Create an empirically based database about students' interest in science, which includes findings driven from students' self-generated questions collected in free-choice and school settings in the course of this study, findings from international studies (e.g. ROSE (Sjoberg & Schreiner, 2002)) and national based interest studies (e.g. Interest in Biology in Israel (Tamir & Gardner, 1989)).

Use this empirical basis to contextualize and personalize some of the biology formal curricula by developing students' interest focused learning materials. I suggest reversing the traditional process of popularizing scientific research into digestible learning materials, by using students' input as a raw material for a "scientification" process - providing scientific explanations and a basis for learners' concerns and interests. The interests' focused learning materials should not overwrite or ignore the biology curricula - they should serve it better. Many concepts and principles in biology can be thought in different contexts, using different driving questions as an engagement for learning (see implications section). Students' interest-focused learning materials will be based on empirical evidences regarding students' interests and preferences and not merely on the teachers' or curriculum developers' hunch.

In order to test the effectiveness of such learning materials, I suggest applying mixed qualitative and quantitative methodology in a low/average achieving biology classroom setting.

Figure 7. Rationale for developing Student-interest focused learning materials

An empirical basis for supporting
student-centered learning materials

↓

Students-interest focused learning materials

↓ Untested hypothesis

Wish to take part in higher formal and life long science learning

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Appendix

Baram-Tsabari, A., & Yarden, A. (2005). Text Genre as a Factor in the Formation of Scientific Literacy. Journal of Research in Science Teaching, 42(4), 403-428.

JOURNAL OF RESEARCH IN SCIENCE TEACHING VOL. 42, NO. 4, PP. 403–428 (2005)

Text Genre as a Factor in the Formation of Scientific Literacy

Ayelet Baram-Tsabari, Anat Yarden

Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100 Israel

Received 14 January 2003; Accepted 24 August 2004

Abstract: Learning using primary literature may be a way of developing a capacity for scientific ways of thinking among students. Since reading research articles is a difficult task for novices, we examined the possible benefits of learning using primary literature versus secondary literature, particularly with respect to their influence on the creation and formation of scientific literacy. We report on a comparison between four groups of high school students, each with differing degrees of prior knowledge in biology, who read a domain-related text written in either the scientific research article genre (adapted primary literature) or the popular-scientific genre (secondary literature). Although there was no significant difference in the students' ability to summarize the main ideas of each text, indicating that there was no eminent distinction in their content, we found that students who read adapted primary literature demonstrated better inquiry skills, whereas secondary literature readers comprehended the text better and demonstrated less negative attitudes toward the reading task. Since the scientific content of the two texts was essentially identical, we suggest that the differences in students' performances stem from the structure of the text, dictated by its genre.
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The need to create a scientifically literate citizenry is a widely accepted educational goal (American Association for the Advancement of Science, 1990; Laugksch, 2000; Report of the Superior Committee on Science Mathematics and Technology Education in Israel, 1992; Uno & Bybee, 1994). The question of what constitutes scientific literacy, or what a literate person should know or be able to do, is far more controversial (American Association for the Advancement of Science, 1990; Bybee, 1997a; Harlen, Raizen, & deRoo, 2000; Laugksch, 2000; National Research Council, 1996). We chose to use Shamos's definitions for functional and "true" scientific literacy (quotation marks in the original) (Shamos, 1995) as our operational definitions of scientific literacy. Functional scientific literacy is characterized by the ability to converse, read, and write coherently in a nontechnical but meaningful context. This definition should not be conflated with the Biological Sciences Curriculum Study (BSCS) definition of functional biological literacy, which concerns the use of biological vocabulary based on memorized responses (Uno & Bybee, 1994). However, a functional-literate person, according to Shamos, lacks an

Correspondence to: A. Yarden; E-mail: anat.yarden@weizmann.ac.il
DOI 10.1002/tea.20063
Published online 15 March 2005 in Wiley InterScience (www.interscience.wiley.com).

understanding of the fundamental role played by theories in the practice of science and of the unique processes that characterize it. "Scientific habits of mind" such as logical reasoning, the role of experiments, reliance on evidence, the ability to think critically and other elements of scientific investigation are all characteristics of "true" scientific literacy (Shamos, 1995). In addition, the "true" scientifically literate individual has the ability to use those scientific ways of thinking for individual and social purposes (American Association for the Advancement of Science, 1990; Hurd, 1998; Shamos, 1995).

If we want the future citizen not only to be able to possess and use scientific knowledge, but also to take part in decision-making with regard to the application of science to everyday life (Hurd, 1985), we must teach today's students not only what science can do, but also how science is done. Therefore, teaching science should be consistent with the nature of scientific inquiry (American Association for the Advancement of Science, 1990). This includes starting with questions about phenomena rather than with answers to be learned (American Association for the Advancement of Science, 1989).

One possible way of developing this capacity for scientific ways of thinking might be through the use of scientific research articles for learning. Since the scientist who did the research is also the one describing it in the article, this text is also termed "primary literature." The use of primary literature for learning might give the functional-literate person some important elements of "true" scientific literacy. Primary literature not only closes the gap between public knowledge and the frontiers of scientific inquiry, it can also develop the following components of scientific literacy: acquaintance with the rationale of the research plan; exposure to research methods and their suitability to the research question; acquaintance with the language and structure of scientific communication; development of the ability to critically assess the goals and conclusions of scientific research; exposure to problems in a certain discipline and acquaintance with the continuity of the scientific research process (Yarden, Brill, & Falk, 2001). Primary literature may instruct students on the nature of scientific reasoning (Muench, 2000) and help to teach complementary aspects of scientific investigation and writing (Kuldell, 2003). In addition, students may find reading research articles a novelty and a challenge (Epstein, 1970), and may also identify with the researchers' quest. Whereas textbooks concentrate on presenting the conclusions of scientific research, science journals also define problems, as well as describe and justify methods (Norris & Phillips, 1994).

Following this rationale, the new syllabus for high school biology studies in Israel contains a requirement for the comprehension and analysis of research articles by senior biology majors (see Methods). More specifically, as of 2006, all biology majors will be examined on the subject matter they learned through the reading of adapted primary literature, as part of the national matriculation examinations (Israeli Ministry of Education, 2003).

However, learning through research articles is both a challenge and a difficult task for the novice (Janick-Buckner, 1997; Smith, 2001; Yarden et al., 2001). Despite the fact that many scientists would state that a research article is easier for them to follow, and that it is more organized and clearly structured, the research article is much more permissive to information gaps than a popular article and lacks the reader-friendly use of metaphors, analogies and examples.

Scientific research articles and popular-science articles belong to two different genres. Genres are text types defined by function, sociocultural practices, and communicative purpose (Ravid & Tolchinsky, 2002). Two major categories of text genres are expository text, a text whose primary purpose is to expose information or ideas and narrative text, which is usually written to entertain more than to inform, and is easier to comprehend (Grasser & Goodman, 1985). A scientific research article is included in the expository text category, whereas a popular-science article can be considered a mixed text, found somewhere on a scale between expository and narrative text, due to its episodic story-telling parts that include characters and events. One reason genres are important is because they appear to elicit varied processing (Alexander & Jetton, 2000).

Scientific texts, as a subgenre of the expository text, are typically difficult to read because they are written in "scientific language," a "jargon" that has the effect of making the learner feel excluded and alienated from the subject matter (Halliday, 1993). In scientific writing there is much use of the passive voice, of abstract nouns in place of verbs, and of verbs of abstract relation in place of verbs of material action (Lemke, 1990). According to a statistical formula for the objective measurement of readability, scientific magazines achieved the lowest score on the "reading ease" and "human interest" score, ranking them as "very difficult" and "dull," respectively (Flesch, 1948). It also should be noted that the familiar and easy-to-handle structure of the research article is well known to scientists, but not to high school students. Therefore, it is interesting to examine the possible benefits of learning using scientific research articles versus popular-scientific texts, in particular their influence on the creation and formation of scientific literacy.

Although a number of scientific literacy assessment tools are available (Aikenhead & Ryan, 1992; Champagne et al., 2000; Korpan et al., 1994; Laugksch & Spargo, 1996a, 1996b; Schleicher, 1999), none of them deals with comprehension of scientific research articles and most of them do not use high school biology content in their assessment process. We chose to assess scientific literacy through the investigation of students' understanding and interaction with content-related tasks, rather than spelling out the knowledge, skills and attitudes that students should possess as a consequence of their whole school experience (American Association for the Advancement of Science, 1993; National Research Council, 1996).

In the present work, we attempted to determine how adapted primary literature and secondary literature influence the creation and formation of scientific literacy among high school biology students. We hypothesized that secondary literature would generate a better understanding of the text among high school students due to its greater explanatory coherence, whereas adapted primary literature would better convey to its readers a knowledge of the syntactic structure of the discipline, which would help them understand how biological research is done.

Strategy

As a platform for this research, we used a breakthrough research article that strongly correlates to science, technology, and society (S–T–S) issues. The work was carried out as part of an effort to confront students with a current real-world issue impacting society (Yager, 1993), with the understanding that inquiry into authentic questions, preferably scientific topics that have been highlighted by current events, is one of the central strategies for teaching science (National Research Council, 1996).

We chose an article that describes the design of a polyvalent inhibitor to the anthrax toxin (Mourez et al., 2001), as a basis for writing two articles suitable for the high school students' cognitive level. The modified articles were written in two text genres: the first was a research article in which the basic typical structure of the original article was retained, as well as the use of passive voice, as previously described in detail (Yarden et al., 2001). Since we retained the common structure of a research article, as well as the authentic results and illustrations, and since the modifications were only meant to simplify the text, but not to change it significantly, this modified version of the research article is henceforth referred to as "adapted primary literature" (Yarden et al., 2001). The second version was written as a popular-scientific article by one of the authors, who is an active science journalist and has gained a lot of experience in writing and editing in this genre for the print mass media. This version provided easier fluent readability while almost completely retaining the same data; this article is henceforth referred to as "secondary literature."

Biology is one of the most dynamic research disciplines within the natural sciences, and new research discoveries are published almost daily. Most of these discoveries are published in scientific journals in English. Israeli students, for whom English is not their mother tongue, cannot be presented with an authentic English text. Since our goal was to retain the same scientific content in both adapted primary and secondary literatures, we could not use a random popular-scientific article from the available popular press in Hebrew. Therefore, we had to translate the research article that we used into Hebrew and to compose a popular-science article describing it. Appendix A presents paragraphs from both adapted texts and the original article.

Learning from texts is a complex skill that involves complex interactions between the reader's mind and the text (Holliday, Yore, & Alvermann, 1994). Therefore, our group chose to use multiple approaches in order to shed some light on the process of learning from research articles. To obtain rich and in-depth data, we used a qualitative approach to characterize the way in which two high school biology students read a research article, to determine possible reasons for their difficulties, and to identify the reading stages and reading strategies used by the two students (Brill, Falk, & Yarden, 2004).

We decided to use a quantitative approach to this research, although these survey methods homogenize important distinctions (Messer-Davidow, 1985). All Israeli high school students who choose to major in biology (see Methods for details) will have to read adapted primary literature as part of their learning process. Therefore it is important to probe the ways in which the broad population is affected by this new educational effort.

In this research, one group of students received the adapted primary literature text and another group received the secondary literature text. Students' scientific literacy was not assessed in comparison to a particular, predetermined model, but compared with the achievements of the other group. Students' achievements were assessed using diverse paper-and-pencil methods in order to gain a multidimensional perspective (Laugksch, 2000) on the way in which text genre influences the formation of students' scientific literacy. Following the reading of one of the two texts, four types of open-ended items were used as assessment tools:

1. Communication of the main ideas and conclusions that were detailed in the article was assessed in the format of a written abstract. Analysis of what is included and what is omitted in a student's written summary tells us something about what has been understood from the text (Garner, 1982) and provides some valuable insight into what the students considered the most important points in the experiment described in the article.
2. Reading comprehension and acquisition of biological knowledge were tested in the format of content-based True/False (T/F) questions. Students were also required to explain each of their responses. During analysis, the questions were sorted into two groups. Provision of full answers to the first group (which consisted of seven questions) required reading comprehension, while providing full answers to the second group (which consisted of four questions) also required the ability to infer new information. This task demanded the generation of elaborative inferences, not only required inferences, which simply stem from local coherence of the text (Fincher-Kiefer, 1996). The first group of questions can also be described as dealing with the textbase level and the other with the creation of a situation model through the use of prior domain knowledge, as previously suggested by Kintsch (1989).
3. An understanding of the processes and methodology of scientific inquiry was demonstrated in the format of three open questions. Scientific processes which include the collection and interpretation of data, and the derivation of conclusions (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), as well as the combination of those processes with scientific knowledge, use of scientific reasoning and critical thinking abilities

(Bybee, 1997b; National Research Council, 1996), served as the theoretical framework for measuring the scientific inquiry skills in this section.

4. Students' attitudes toward learning using adapted primary and secondary literature were assessed using a series of 11 statements concerning the reading task: four of them were positive and seven negative. Students were asked to rate each of the 11 statements on a Likert-type scale ranging from 1 to 6 (1 = strongly disagree, 6 = strongly agree).

The first and second sections of the questionnaire were aimed at measuring students' functional literacy, while the third dealt with elements of scientific investigation, in order to examine students' "true" scientific literacy (Shamos, 1995). The fourth section accounts for students' attitudes and learning styles.

The full translated questionnaire is presented in Appendix B.

Methods

Subjects

High school biology students ($n = 272$) participated in the experiment for biology class credit. The students were gathered from 11 classes chosen from four different academic urban and suburban-type high schools in Israel. All four schools are attended by a culturally nondeprived population. All subjects learned the same curriculum in biology, since Israel has a centralized education system. We can assume that the students' ability to read and write in Hebrew was similar for all four schools. The schools and classes were chosen according to the teachers' initiative and motivation to take part in what is still an experimental program.

Biology class grades were obtained from the teachers of 6 out of the 11 classes that participated in the experiment. The five remaining teachers felt it would be inappropriate to hand over their students' grades to researchers from outside the school administration. From the grades that we obtained, we learned that the average biology class grade for the males was 81.8 and for the females was 80.6, out of a maximum score of 100. Two hundred-sixty questionnaires out of a total of 272 were gender-identifiable (see questionnaire analysis for details)—180 of them belonged to female students and 80 to male students. This ratio is close to the 1.9:1 female-to-male ratio found in classes in Israel where students major in Biology, according to B. Agrest, Chief Inspector of Biology Education in Israel (personal communication, October 23, 2002).

About one half of the students who participated in the experiment were biology majors. In Israel, at the end of the tenth grade, students choose to major in at least one scientific or nonscientific topic, which is evaluated in a national matriculation examination. The syllabus for the biology-major studies in Israel requires 450 hours of teaching (Israeli Ministry of Education, 1991) and includes, in addition to basic topics, advanced topics that are aimed at reflecting the dynamics of biological research and discovery. The new syllabus also includes the use of adapted primary literature by the students as part of their learning process (Israeli Ministry of Education, 2003).

Biology majors study biology for a period of three years. Therefore, twelfth-graders have more opportunities to acquire diverse biological concepts and principles and to elaborate their knowledge regarding the techniques being used in biological laboratory research during their "hands-on" assignments compared with tenth and eleventh-graders. Prior knowledge can be explained as a combination of the learner's pre-existing attitudes, experiences, and knowledge (Bransford, Brown, & Cocking, 1999); therefore, we can assume that grade level in this research estimates prior knowledge in biology.

To separate the effects of prior knowledge from those of text genre, subjects were divided into four groups according to their estimated prior knowledge in biology: twelfth-grade biology majors

($n = 27$, one class), eleventh-grade biology majors ($n = 115$, five classes), tenth-graders with relatively high knowledge (HK) in biology ($n = 49$, two classes) and tenth-graders with relatively low knowledge (LK) in biology ($n = 81$, three classes). The tenth-graders were classified at the class level: two classes were classified as high-knowledge (HK) and another three as low-knowledge (LK). The classification was initially done according to the biology teachers' estimations and was later verified by Duncan grouping statistical test of the comprehension and inquiry sections of the questionnaire (data presented at Appendix C).

Materials

The two texts were written based on the article "Designing a polyvalent inhibitor of anthrax toxin" that was published in *Nature Biotechnology* the same year (Mourez et al., 2001). The article was translated into Hebrew and adapted into two different versions, preserving most of its content but varying in style: adapted primary literature (1546 words), and secondary literature (828 words). Note that both texts yielded very similar performances on the abstract assignment, where seven main ideas had to be identified and summarized (see Results). This indicates that there was no pronounced distinction between the content of the adapted primary and the secondary literatures. The big difference in word count stems from two reasons: genre-related repetitions in the adapted primary literature (e.g., describing an experiment in the Materials and Methods section, recalling it in the results section, and discussing it in the discussion section of the article), and the omission of one experimental method (selection of peptides by phage display) from the secondary literature text. There was no reference in the questionnaire to that specific method.

The same questionnaire was used for both versions, testing the students for their ability to write an abstract, their reading comprehension and inferential abilities, their inquiry skills and their attitudes toward the reading task (as detailed earlier).

The instruments (texts and questionnaire) were validated by six experts: two high school biology teachers who had already gained experience in the implementation of adapted primary literature, two science teaching researchers at the Weizmann Institute of Science, a biologist, and an experimental psychologist who had specialized in psycholinguistics (since the focus of this study is the use of texts for learning). The reliability of the questionnaire was analyzed using the Alpha Cronbach coefficient and all values appeared to be $\geq .8$. The analysis results are shown in Table 1.

Table 1
Questionnaire reliability analysis

Section	Assessment tool	No. of items	Alpha Cronbach coefficient
A	Abstract writing[a]	7	0.8
B	Content-based T/F questions[b]	22	0.84
C	Open-ended questions[c]	6	0.83
D	Students' attitudes[d]	11	0.86

[a]Abstracts were examined for the presence of seven main ideas appearing in the text.
[b]Students had to explain each of their answers. Analysis was done for all answers and explanations.
[c]Each question was coded first as answer/did not answer and then as relevant answer/nonrelevant answer. The analysis did not include the full scoring scheme ranging 0–5 or 0–4 presented in Table 2.
[d]The scores of the negative attitudes were reversed.

Procedure

Subjects participated in the experiment as part of their regular biology class during the 2001–2002 school year. The two different texts, adapted primary and secondary, were randomly assigned to the students in each class. Teachers were instructed to dedicate two lessons in a row to the task, including the break between lessons (for a total of 95–105 minutes). The task was performed individually and teachers were instructed not to answer questions concerning the information presented in the texts during the activity.

Questionnaire Analysis

The questionnaires were graded in the following manner:

1. The abstracts were examined for the presence of seven main ideas appearing in the text: (i) *Bacillus anthracis* secretes a toxin that has a damaging effect on the body; (ii) the toxin is made up of three proteins; (iii) the researchers tried to prevent/delay the construction of the toxin; (iv) the researchers discovered a peptide that delays the interaction between the proteins that make up the anthrax toxin; (v) from that peptide they built a more effective inhibitor; (vi) the inhibitor was successfully tested in vitro and in vivo; and (vii) as a result of the success, one can hope that the inhibitor or any other substance developed in a similar way will serve as a cure for anthrax. Young adolescents find the production of written expository texts a difficult challenge. Indeed, constructing an expository piece of discourse requires the writer to focus on a clear and explicit discourse topic, and to manifest pre-planning, careful organization of textual information, and extensive common knowledge. Even among well-educated, although nonexpert, adults, narratives are more developed and better constructed than expository texts (Ravid, 2004). Therefore, students' writing literacy, as expressed in their spelling, grammar and rhetorical ability, was disregarded as much as possible during scoring.
2. The answers to the T/F questions and their explanations were graded as either right or wrong.
3. The answers to the scientific inquiry section were graded according to a predetermined scale based on relevance, use of scientific ideas and prior knowledge, detailing, correctness, originality and integration of information from different sections of the article. Scoring schemes and examples of students' responses are presented in Table 2.
4. Attitudes toward the nature of the task were assessed using a Likert-type scale (ranging from 1 to 6).

Gender classification was done using students' answers to the open questions. Hebrew is a gender-defining language, therefore the subjects automatically reveal their gender through the use of verb gender indicators, e.g., "I am checking" will be translated as *ani bodeket* (feminine)/*ani bodek* (masculine).

Statistical Analysis

Unless otherwise indicated, the one-tailed unpaired t test procedure and Pearson correlation statistical test were used. Homogeneity was tested using Bartlett's test for homogeneity of variance (Winer, 1971). Correlation between adapted primary readers' attitudes (see Figure 5A) and learning styles (see Figure 5B) to their prior knowledge was calculated using class averages for the different variables and their prior knowledge group.

Table 2

Scoring schemes and examples of students' responses[a] for the scientific inquiry section

Q1.[b] Which experiments would you conduct now in order to test the medicine's efficiency further?

Score	Indicator[c]	Example
0	Nonrelevant response or no response at all	"It seems to me that the doctors understand this better than me, and they're doing the experiments that should be done" (LK 10th-grader)
1	Illogical idea	"I would inject it into someone who has a similar blood-type to the monkeys" (LK 10th-grader)
2	Logical idea for an experiment, but no details on the variables being tested	"It is very important to verify the result in more animals, not only rats. Maybe in cattle" (11th-grader)
3	A doable idea for an experiment	"I would conduct experiments on other animals, structurally closer to humans–for example, monkeys, in order to test the inhibitor's effect on cells that are closest structurally to human cells" (11th-grader)
4	A detailed suggestion for a doable experiment	"In order to continue the testing of the medicine's effectiveness I would. . .divide the rats into groups. To the first group I would inject the toxin and the inhibitor together. To another group I would inject the toxin and after some time the inhibitor as well. To the next group I would inject the toxin and after a longer time than the second group, I would inject the inhibitor." (11th-grader)
5	Several suggestions for doable experiments	"Firstly, I would test the inhibitor's effectiveness in another animal, additional to the rats, by injecting the inhibitor with the parts of the toxin and checking the inhibitor's influence on the appearance of symptoms. Secondly, I would conduct a similar experiment on rats from the same strain that were used in the research, that are not in normal physical shape, in order to check the inhibitor's effect on their health" (12th-grader)

Q2. Do you have any scientific criticism of the researchers' work? Are there any experiments that you would have conducted differently?

Score	Indicator[d]	Example
0	Nonrelevant criteria for evaluation or no response at all	"I wouldn't use animals in the experiment" (LK 10th-grader)
1	Relevant criteria for evaluation with no explanation	"Maybe they could have checked if the use of the inhibitor has other implications" (11th-grader)
2	Relevant criteria for evaluation with specific reference to the research	"I would do the experiments on animals that have similar cellular structure to humans" (11th-grader)
3	Relevant criteria for evaluation with specific reference to the research and suggestion for rectification	"I have criticism about the dosage of the inhibitor that was used (12 and 75 [nanomoles]) in the trial with the rats, the difference is too big, so you can't tell at what stage the inhibitor prevents the poisoning. Maybe the poisoning is prevented at a dosage of 40 and there was no need to use 75. I would have tried more dosages in order to know when exactly the intoxication is prevented" (11th-grader)

Table 2
(Continued)

Score	Indicator[d]	Example
4	Criticism based on integration of information from different parts of the article or on connection to prior knowledge	"The researchers succeeded in developing an inhibitor that would prevent the toxin's parts to assemble together, penetrate the cell and cause harm to it. However, the toxin that already entered the cell is not affected by the inhibitor. In other words, the inhibitors' activity isn't so much better than the effect of the antibiotic that kills the bacteria but not the toxin that already entered the body" (11th-grader)

Q3. Can you think of any other applications for the technique that was used by the researchers to develop the inhibitor?

Score	Indicator	Example
0	Nonrelevant response or no response at all	"On a dead animal" (LK 10th-grader)
1	An idea with no explanation at all	"Developing drugs for different diseases" (11th-grader)
2	An idea with minimal explanation	"I think this technique can be used in the development of every drug that causes this complication in protein and enzyme binding" (11th-grader)
3	An idea with minimal explanation and connection to prior knowledge	"I think this technique can be used in order to prevent enzymes from binding when a person is infected with the AIDS virus" (11th-grader)
4	A detailed suggestion with explanation of the action mechanism	"In every case. . .that we want to prevent a process in which two substances are connecting to each other in a certain area (some kind of active site) and it is possible to find another material that would replace one of the substances due to molecular similarity and would connect to the active site instead of the original substance" (11th-grader)
5	A detailed suggestion with explanation of the action mechanism and connection to prior knowledge	"In cases where the damage is caused by the binding of two different enzymes and the binding can be prevented by another factor. e.g.: In brain injuries damage is sometimes caused to the memory. . .. The degeneration of the nerve cells worsens because of the binding of metals like Ca^{2+} and Cu^{2+} that are released from the cells with the free radicals. A drug that would absorb the surplus metals would prevent their binding" (11th-grader)

[a]The examples are translated verbatim quotes.

[b]Q1, Q2, and Q3 refer to questions 1–3 in section C of the questionnaire, respectively.

[c]Ethical and moral issues were completely disregarded during answer grading. Scores were given only with respect to the biological and experimental content of the answer.

[d]Only use of internal criteria for evaluation was expected from students who suggested criticism regarding the researchers' work, since students have no knowledge of the standards by which such works are generally judged and are not able to compare the research to other works in the field (Bloom et al., 1956), therefore they can not apply external criteria to their evaluation.

When presented on the same scale, performances in items with different maximal scores were divided by the maximal grade for that item in order to achieve a relative score (see Figures 1, 2, 3 and 4).

Results

Learning Using Adapted Primary Versus Secondary Literature

To evaluate the differences between learning using adapted primary versus secondary literature, we analyzed 272 questionnaires filled in by high school biology students who had read one of the two texts. Although there was no significant difference in the students' ability to summarize the main ideas of each text (two-tailed: $t = -1.46$, $p = .14$), there were significant differences in the students' ability to demonstrate their comprehension and inquiry skills (Figure 1). Students who read the adapted primary literature presented a better understanding of the processes and methodology of scientific inquiry than the ones who read the secondary literature ($t = 1.66$, $p = .049$), while the latter demonstrated better comprehension of the text ($t = -1.63$, $p = .05$) than the adapted primary literature readers. Thus, our initial hypothesis that secondary literature would generate a better understanding of the text, while adapted primary literature would help understand how biological research is done, was indeed verified. To

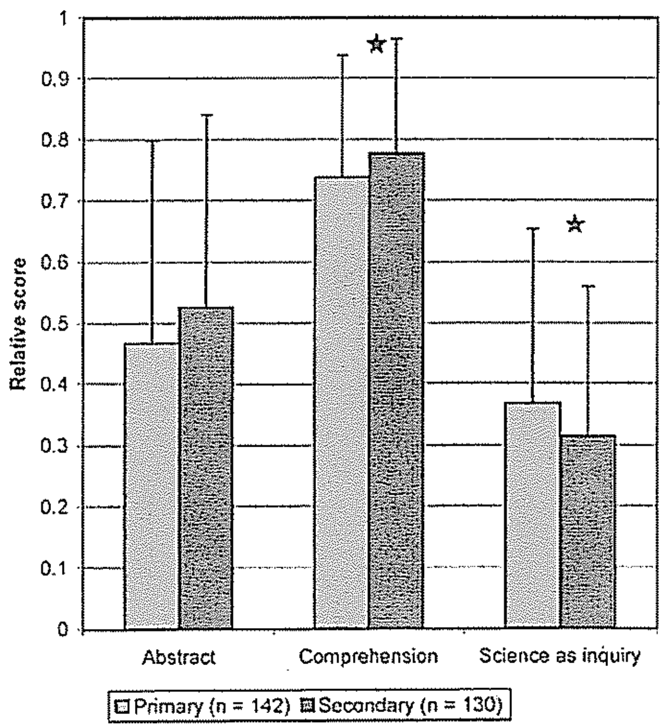

Figure 1. Comparison between learning through a scientific research article and a popular-science article in the 10th–12th grades: 272 high-school biology students were tested for their ability to write an abstract (Abstract), their reading comprehension (Comprehension) and their inquiry skills (Science as inquiry), after reading a scientific research article (Primary) or a popular-science article (Secondary). Significant differences are marked: $^*p < 0.05$. The data were analyzed using a t-test.

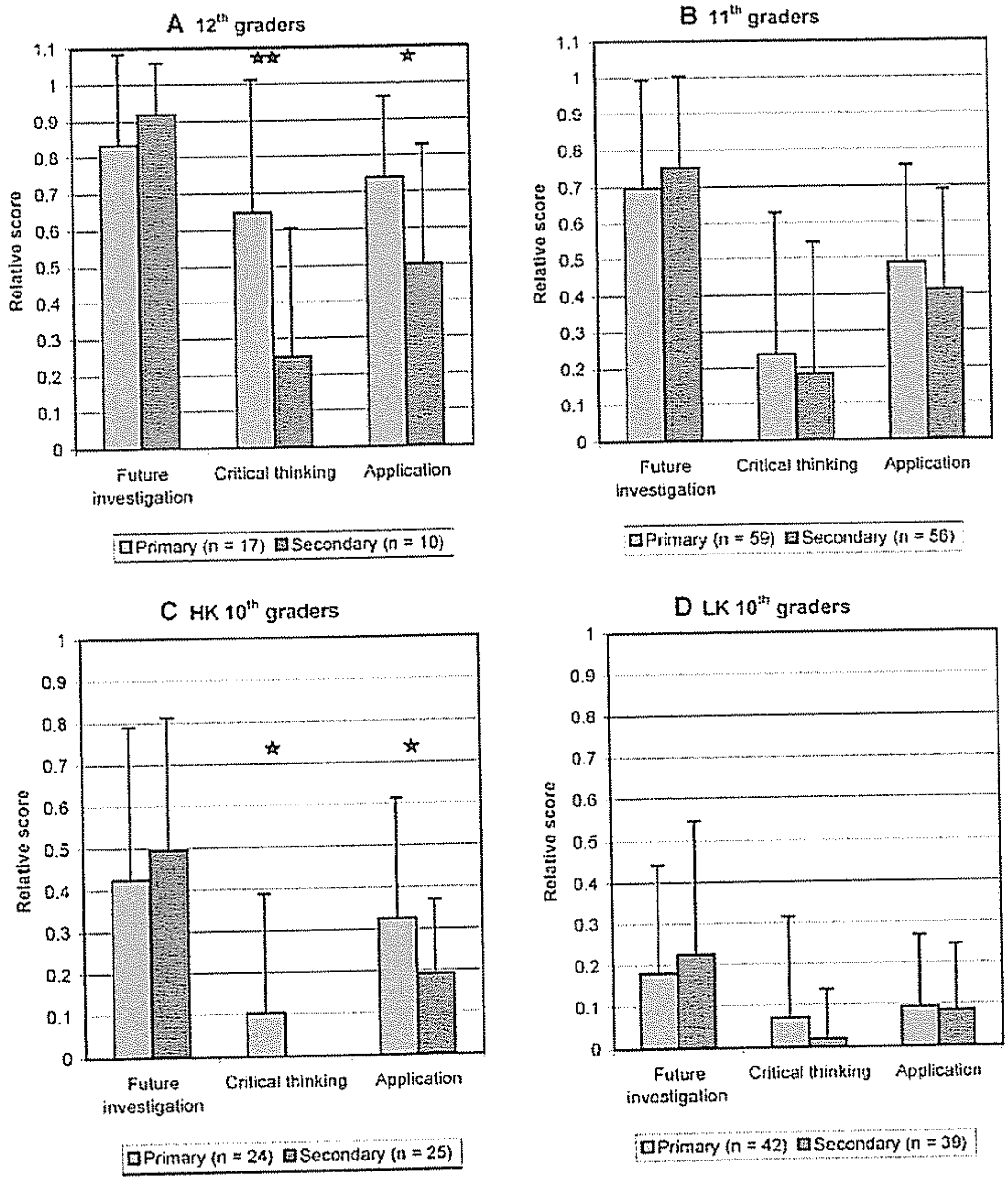

Figure 2. Demonstration of inquiry skills after reading a scientific research article and a popular-science article in the 10th–12th grades: High-school biology students were tested for their ability to suggest what should be the next experimental step (Future investigation), to evaluate the work (Critical thinking) and to offer applications for the technology described in the paper (Application) after reading a scientific research article (Primary) or a popular-science article (Secondary). Significant differences are marked: $*p < 0.05$, $**p < 0.01$. The results of 12th-grade students (A), 11th-graders (B), 10th-graders with relatively high prior knowledge (HK) in biology (C) and 10th-graders with relatively low prior knowledge (LK) in biology (D) are shown. All panels were analyzed by *t*-test. Scales for A and B are higher in order to allow a clear view of the standard deviations.

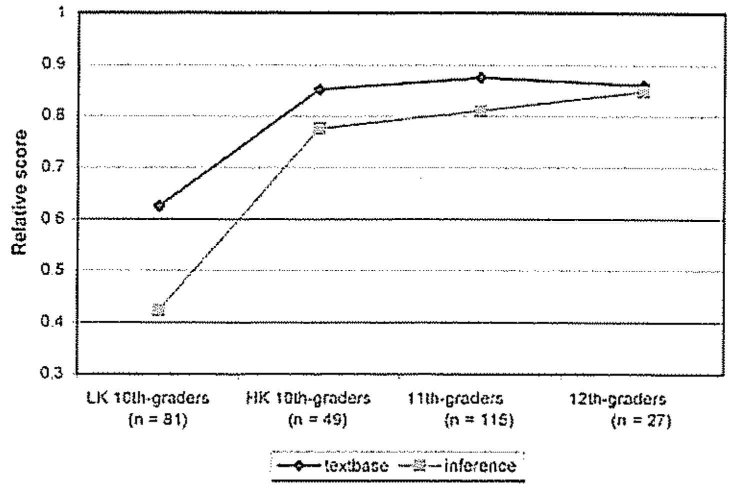

Figure 3. Students' relative scores in textbase versus inference questions. High-school students were divided into four groups according to their grade and estimated prior knowledge in biology. Students responded to 11 items concerning the article they had read: responding to 7 of the items required only reading comprehension (textbase), while responding to the remaining 4 items required analysis and inference abilities (inference).

understand this initial observation further, we performed detailed analyses of each of these components, namely understanding of the processes and methodology of scientific inquiry, as well as text comprehension, among high school students who had read either adapted primary or secondary literature texts.

Understanding Science as Inquiry Using Adapted Primary Versus Secondary Literature

The understanding of the processes and methodology of scientific inquiry was tested using the format of three open questions. In two of the three questions, students who had read the adapted primary literature text did significantly better than the ones who had read the secondary literature text: the former raised more scientific criticism of the researchers' work and methodology ($t = 2.8$, $p = .003$) and suggested more future applications of the technology described in the article ($t = 2.6$, $p = .005$). There was no significant difference in the students' ability to propose the next experimental step ($t = -.97$, $p = .17$).

To examine the effect of prior knowledge on students' inquiry skills, we compared the average scores obtained in that part of the questionnaire by the four prior-knowledge groups. The best scores were achieved by the twelfth-graders, followed by the eleventh-graders and then the HK tenth-graders. Tenth-graders with relatively low prior knowledge in biology were always the weakest (Figure 2).

In two of the three questions, the Duncan grouping test indicated a separate characteristic for each prior-knowledge group. The exception, scientific evaluation of the work, divided the students into three groups, keeping the tenth-graders together (data presented in Appendix D). Note that although the scores obtained in the task are very different among the four prior-knowledge groups, the overall pattern is very similar: the students who read the adapted primary literature demonstrated better critical thinking and application abilities than the students who read the secondary literature, whereas the latter offered more detailed ideas for future investigations (Figure 2).

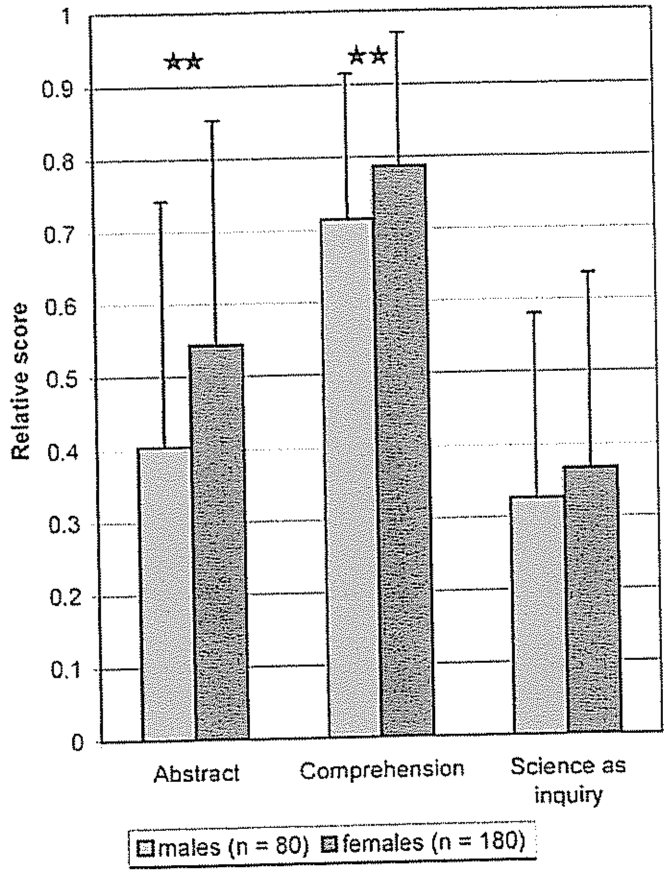

Figure 4. Comparison between male and female performance in a text-based task. 10th to 12th-grade biology students were tested for their ability to write an abstract (Abstract), their reading comprehension (Comprehension) and their Inquiry skills (Science as inquiry), following an individual text-based learning task. Significant differences are marked: $**p < 0.01$. The data were analyzed by t-test.

Furthermore, in all four groups, students found it easier to come up with an idea for the next experiment than to find another application for the technology, and for all of them, raising scientific criticism was the hardest demand (Figure 2).

Grading scales for the scientific inquiry questions and examples of students' responses are presented in Table 2. These examples are translated verbatim from quotes selected from the participants' responses at all prior knowledge and grade levels.

Prior Knowledge and Heterogeneity Within the Knowledge Groups

Homogeneity of the scores within each knowledge group grew with prior knowledge and grade, in all but two items of the questionnaire. The exceptions, in which heterogeneity within the knowledge group increased with prior knowledge and grade, were the critical thinking and application items from the scientific inquiry section (Table 3).

The observed increase in homogeneity can be explained by the fact that among eleventh- and twelfth-grade biology majors, almost all of the students were capable of successfully completing

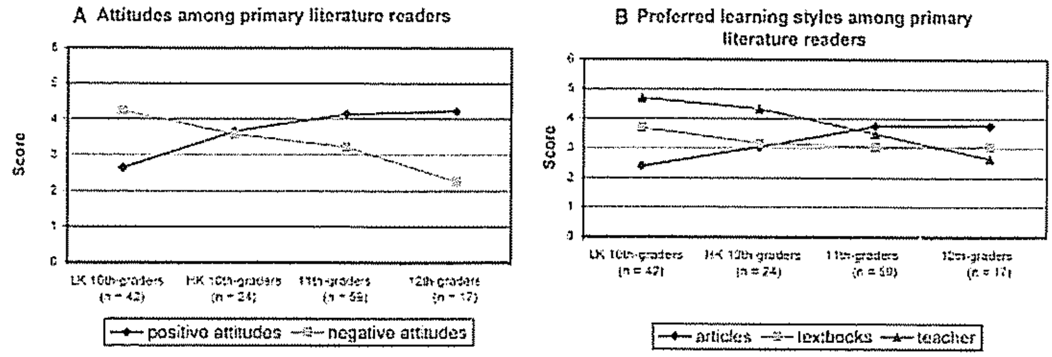

Figure 5. Students' attitudes towards learning using primary literature in the 10th–12th grades. High-school biology students responded to a series of 11 statements concerning a reading task written in the primary literature genre. Students were asked to rate the statements on a Likert-type scale ranging from 1–6 (1 = strongly disagree, 6 = strongly agree). A. Positive and negative attitudes among primary literature readers were analyzed based on 4 positive statements (positive attitudes) and 7 negative statments (negative attitudes). B. Attitudes towards different learning styles were analyzed based on 3 statements: "I would like to learn more subjects using articles" (articles); "I would rather study using a textbook" (textbooks) and "I prefer that the teacher explain, so I won't have to read by myself" (teacher).

the task, while in the tenth grade only a gifted and motivated few broadened the otherwise limited scale of the grades. When the task is a more complicated one (as can be seen in the relative scores of the critical thinking and application items), the situation is reversed: among tenth-graders, almost none of the students were capable of completing the task, while biology majors demonstrated very different degrees of performance and therefore presented high heterogeneity in those performances.

Comprehension: Textbase Versus Inference Questions

Comprehension and acquisition of biological knowledge were evaluated using open-ended content-based True/False (T/F) statements that required either reading comprehension or reading comprehension and inference ability. For LK and HK tenth-graders as well as for eleventh-

Table 3

Prior knowledge and heterogeneity of the scores[a] obtained within the knowledge groups

Item type	LK 10th-graders	HK 10th-graders	11th-graders	12th-graders	Bartlett test
Abstract	4.49	5.64	3.06	2.8	8.84*
Comprehension	4.88	1.75	1.35	0.89	52.85****
Science as inquiry: Future investigation	2.11	2.88	1.91	1.15	6.98
Science as inquiry: Critical thinking	0.6	0.67	2.26	2.62	52.73****
Science as inquiry: Application	0.68	1.5	1.86	2.05	23.75****

Significant at the: * .05, ** .01, *** .001, **** .0001 level.

[a]Variances of the various knowledge groups for different items are shown. Homogeneity was tested using the Bartlett test for homogeneity of variance.

graders, answering textbase questions proved to be easier than answering inferential questions (two-tailed paired t test, $t=8.51$, $p=.0001$; $t=2.61$, $p=.012$; $t=4.07$, $p=.0001$, respectively) (Figure 3). However, differences in the scores decreased gradually, as the level of prior-knowledge increased (the difference in eleventh-graders' ability to answer textbase and inference questions is smaller than HK tenth-graders; however it is more significant due to differences in standard deviations); twelfth-graders were equally capable of answering both types of questions ($t=.46$, $p=.65$).

Gender Equity

Two hundred-sixty questionnaires out of the total 272 were gender identifiable. In the comparison between the two genders, we verified that although there were no significant differences between male and female students' high school biology class grades (see Methods), there were differences in their ability to summarize the main ideas of the text in an abstract and to comprehend the text as expressed in their answers to T/F questions and in their explanations. Female students scored significantly higher in those two parameters (two-tailed: $t=-3.27$, $p=.001$; $t=-2.87$, $p=.005$, respectively), compared with male students (Figure 4). However, there was no significant difference in students' inquiry skills between genders (two-tailed: $t=-1.14$, $p=.25$).

Text Genre and Students' Attitudes

A comparison between students' attitudes toward each of the two texts revealed no significant difference in students' positive attitudes toward the task (two-tailed, $t=-1.71$, $p=.09$), standing at an average of 3.64 (adapted primary literature) and 3.91 (secondary literature) out of 6. However, there was a highly significant difference in the students' negative attitudes: the students who read secondary literature expressed considerably less negative attitudes than the students who read the adapted primary literature (two-tailed, $t=4.65$, $p<.0001$). Negative attitudes like the ones expressed by the adapted primary literature readers may affect future citizens' attitudes toward independent reading of popular-scientific literature later in life.

Students' attitudes toward learning using adapted primary literature in the tenth to twelfth grades are shown in Figure 5A. Note the increase in positive attitudes and the decrease in negative ones correlated to the increase of prior knowledge in biology ($r=.89$, $p=.0007$; $r=-.78$, $p=.008$, respectively). Only among LK tenth-graders were the negative attitudes stronger than the positive ones. Among biology majors—the target audience for learning using adapted primary literature according to the new syllabus for high school biology studies in Israel (Israeli Ministry of Education, 2003)—the average positive attitudes are much more dominant than the negative ones.

Adapted primary literature readers' attitudes toward different learning styles are shown in Figure 5B. The analysis was based on three statements: "I would like to learn more subjects using articles"; "I would rather study using a textbook" and "I prefer that the teacher explain, so I won't have to read by myself" (items 7, 8, and 9 in part D of the questionnaire, see Appendix B). Note that students' preferred learning styles change gradually, in correlation with their increase in age and prior knowledge (Figure 5B). While the importance of the teacher as a source of information decreases ($r=-.73$, $p=.017$), the willingness to learn using articles increases ($r=.69$, $p=.028$). The readiness to learn from textbooks remains quite constant among the knowledge groups, except for the LK tenth-graders who demonstrate a more positive attitude toward this way of learning than the others ($r=-.63$, $p=.05$). The teacher's importance as a source of knowledge appears to decrease with an increase in the students' ability to learn by themselves using adapted primary literature.

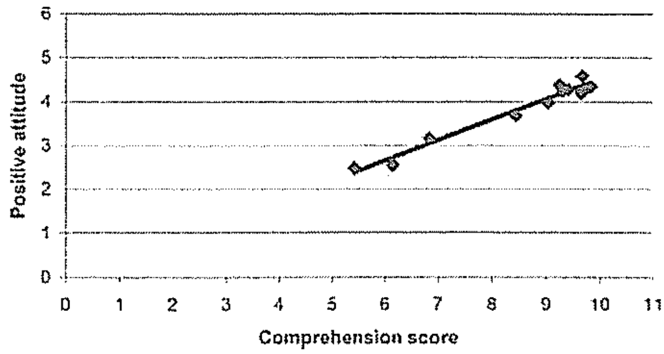

Figure 6. Correlation between average class comprehension score and students' attitudes towards the task. High-school biology students that were tested for their reading comprehension (comprehension score) responded to a series of 11 statements about the reading task, 4 of them positive in nature. Students were asked to grade those statements on a Likert-type scale from 1–6 (1 = strongly disagree, 6 = strongly agree). Each dot represents one class's average score on both axes, $r = 0.98$, $p < 0.0001$.

We found a strong correlation between classes' average scores in the comprehension section of the questionnaire and their average positive attitudes toward the task (Figure 6). The correlation was stronger with the positive attitudes than with the negative ones ($r = .98$, $r = -.85$, respectively). Correlation of positive and negative attitudes with the scientific inquiry scores were a little weaker ($r = .74$, $r = -.73$, respectively), but still very obvious. These findings suggest that the task strictly measured the students' abilities and motivations, regardless of their teachers' mode of instruction.

Discussion

In this study we compared four groups of subjects, each with differing degrees of prior knowledge in biology, who had read a domain-related text written in either the scientific research article genre (adapted primary literature) or the popular-scientific genre (secondary literature). Although there was no significant difference in the students' ability to summarize the main ideas of each text, indicating no eminent distinction in their content, we found that students who read adapted primary literature demonstrated better inquiry skills, whereas secondary literature readers performed better on the comprehension section of the test.

Since the scientific content of the two texts was for the most part identical, we suggest that the differences in students' performances stem from the structure of the text, dictated by its genre. The orderly way in which the theoretical background gives birth to the research hypothesis, the research hypothesis controls the selection of the methods, the methods determine the nature of the results that are obtained in the experiment, the results serve as raw material for the discussion, and the discussion usually yields ideas for future hypotheses, helps the student follow the experiment's internal logic as it unfolds. This internal logic, embedded in the primary literature genre, is not apparent to the student who reads secondary literature, in which the original sequence of the work is omitted for the sake of raising readers' interest.

Our results agree with Epstein's (1970) report of a biology course that was based on learning from a set of research papers which reopened the 17-year-old students' stores of curiosity about how science is done and what a biologist does when he or she is doing biology, with Muench's (2000) statement regarding the unique potential of primary literature to instruct students on the nature of scientific reasoning and communication, and with Schulte's (2003) observation that the similarity in structure of the scientific method and scientific writing can facilitate the understanding of each.

While adapted primary literature has an advantage in conveying knowledge concerning the syntactic structure of the discipline (Schwab, 1978; Shulman, 1986), secondary literature's lack of permissiveness for information gaps (compared with adapted primary literature), permits the students to better understand the article's content. Its greater explanatory coherence allows a better understanding, even for students who lack some of the prior knowledge required (McNamara, Kintsch, Songer, & Kintsch, 1996).

Another possible reason for the tendency of adapted primary literature readers to raise more scientific criticism of the researchers' work might be an outcome of the different source of authority in the two texts. Readers of the popular-scientific article learn of the important progression in the struggle against anthrax that was achieved by a group of scientists from Harvard, while readers of the research article learn about the same breakthrough in a much humbler way. The journal's name is totally unfamiliar to the students, and the work is presented in a scientific genre, which is usually underestimated and modest. Without the press acting as a mediator, the research and its contractors may seem less impressive to nonprofessional readers and be more vulnerable to criticism. The writer of the popular-scientific article equips the readers with the external criteria (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) they are missing, by which they are able to evaluate the work and put it in its proper perspective. Since the significance of the work that is presented to the students is highly impressive, students may be more intimidated by the idea of criticizing it, as expressed in an answer given by a LK tenth-grader who had read the secondary literature text: "They are the researchers, so I can't have any criticism about their work. They are the ones who know because they are scientists."

The two items in which adapted primary literature readers outperformed the secondary literature readers have another unique characteristic in common: in both, heterogeneity within the knowledge group increased with prior knowledge and grade, whereas in all other tasks homogeneity within the knowledge group grew with prior knowledge and grade. These two items were harder for the students to complete, as can be confirmed by comparison of their relative scores, and for that reason heterogeneity was greater among biology majors.

It is interesting to note that although the demands for suggestions of future investigations and for another application in the scientific inquiry section were rather similar, there was a difference between them regarding average scores and text genre-related performances. Since students are quite familiar with the demand for planning the next step of an experiment from their lab experience, they found it easier to complete and no advantage was observed in using adapted primary literature. However, when the task was new to the students, as with the application item, they used the adapted primary literature's unique structure as some sort of a theoretical organizer. In research articles, abstracts usually precede the text itself and thus may act as an organizer of its content (Ausubel, 1963). Similarly, the adapted primary literature's structure, due to the similarity in the structure of scientific writing and scientific method, might serve as an organizer for students' scientific thinking.

The secondary literature readers' tendency to offer more detailed ideas for future investigation was not significant, but was repeated in all four prior-knowledge groups. This anomaly surprised us, and at present we do not understand its origin.

Irrespective of their differences, both adapted primary and secondary texts describe a case study of a current issue. Because of their ability to communicate scientific ideas in a way that makes them memorable and meaningful, they can both be characterized as "explanatory stories" (King, 2002; Millar & Osborne, 1998; Millar, Osborne, & Nott, 1998). Between the lines of the original research article, one can read a hair-raising tale of a world inhabited by heroes and villains: the inhibitor and the anthrax toxin. Both are present in the adapted versions as well. The heroes and the villains appear both at the microscopic level (the inhibitor and the anthrax toxin) and at the macroscopic level (the researchers and the terrorists). Since the macroscopic level is sadly relevant to the students' lives, who fulfill the damsel-in-distress role, they are more motivated to understand the microscopic level as well.

Regardless of the type of literature they read, students showed an increase in their summarization abilities, reading comprehension, inference abilities and inquiry skills with increased prior knowledge in biology. This result agrees well with Chi, Feltovich and Glaser's research on novices and experts (1981). Their work pointed to the importance of the knowledge base as a means of success in problem-solving, due to the different ways in which novices and experts perceive the problems, categorize them, and use their knowledge in order to solve the problems (Chi, Feltovich, & Glaser, 1981). The improvement in achievements, which was correlated with an increase in prior knowledge, might also be explained by findings, which showed that the self-explanations of students with sound vs. low prior-knowledge differs in the extent of using prior knowledge, closely following the given example, and the use of abstract vs. concrete terms (Sandmann, Mackensen, & Lind, 2002).

While understanding stories usually requires causal knowledge about people's motivations, goals and actions (Moravcsik & Kintsch, 1993), reading an account of scientific research requires specific prior knowledge concerning the scientific enterprise, concepts, language, and patterns of argumentation in order to understand it (Yore, Craig, & Maguire, 1998). For example, it was found that limited topic or domain knowledge can have a significant negative impact on students' understanding of a physics text (Alexander & Kulikowich, 1994). Individuals with prior knowledge may process domain-related information differently than those lacking this knowledge. Knowledge differences among the various groups were prominent in the results obtained from all the assessment tools, but they were most notable in the processing of statements that required inference abilities and in the scientific inquiry items. Those questions called for higher cognitive abilities as well as for prior knowledge that was not explicit in the text. Text coherence may play a secondary role in comprehension when knowledge allows for the development of a more enriched conceptual representation of the text at hand (Fincher-Kiefer, 1992).

However, not only factual prior knowledge distinguishes seniors from freshmen. While seniors are highly trained in bringing up testable hypotheses and designing investigations with dependent and independent variables, freshmen are only taking their first steps in the school lab. Skilled evaluation, for example, requires, among other things, knowledge about features of the research that are correlated with its quality, such as scientific methodology, e.g., use of control groups and adequate sample sizes (Korpan, Bisanz, Bisanz, & Henderson, 1997). Knowledge of those features and patterns of the experimental research is more abundant as one spends more years learning science, and this may be why a Duncan grouping test of the different prior knowledge groups' performances for this question indicated a separate characteristic for eleventh- and twelfth-graders, while the HK and LK tenth-graders remained together.

Although there were no significant differences between male and female students' high school biology grades, female students outperformed their male classmates with respect to abstract writing and comprehension. Since the task was text-based in nature, one might assume these differences in achievements stem from gender-related differences in reading ability. However, the reading abilities of Israeli elementary school students were reported to be equally high for both sexes (Gross, 1978) and only small gender differences were reported with regard to American high school students' reading achievements (Hogrebe, Nist, & Newman, 1985). Our results are compatible with those obtained from the biology matriculation exams taking place in Israel during 2002, in which the average grade for the males ($n = 3{,}500$) was 80.8 and 83.8 for the females

($n = 6{,}668$), out of a maximum score of 100 [according to B. Agrest, Chief Inspector of Biology Education in Israel (personal communication, October 23, 2002)].

Empirical data show that for readers with a low level of background knowledge, a text should be as coherent and explicit as possible, while for readers with adequate background knowledge, texts with coherence gaps that stimulate constructive activities are in fact better for learning (McNamara et al., 1996). Following this rationale, groups of readers may be characterized by their knowledge and skills, to help define a set of texts that can serve as the basis for successful learning (Kintsch, 1994). Our results showed a different pattern: students with various amounts of prior knowledge demonstrated better comprehension after reading a coherent and explicit text than after reading a less coherent text. Thus, it seems to us that different text genres promote different educational goals.

This result agrees with Wignell's (1994) findings that applied science and humanities textbooks for junior secondary education in Australia employ a different selection of genres (as demonstrated by using an action-oriented or information-oriented scale), because the curriculum areas themselves have different purposes. Science textbooks are the dominant influences behind most secondary science instruction (Yore, 1991). However, a variety of learning materials written in different genres can be used in science class. Wellington (1991) suggests that science presented in newspapers can be of value in formal science education if used carefully and critically. Incidentally, a great many teachers in Northern Ireland use newspapers to support science instruction in order to highlight the link between school science and everyday life and thus to stimulate interest (Jarman & McClune, 2001, 2002). Norris and Phillips (1994), in contrast, found that even top science students at the twelfth grade did not fully grasp the fundamentals of interpreting popular reports of science: fewer than half of the students interpreted correctly statements that required a semantic or logical connection to other statements, and surprisingly, they attributed to the statements a higher degree of certainty than was expressed by the authors.

Another alternative text that is being used in the science classroom is that of trade books. Fisher (1980) found that the use of literature as a method of teaching science concepts stimulated talk outside class about science, and made students feel that science is a part of their lives. These resulting feelings can be a motivating factor in retaining learning and encouraging further independent study. In a research study conducted among 232 disadvantaged seventh-graders, it was found that texts written either in scientific prose or in a narrative style did not induce appreciable differences in the students' knowledge of the major scientific elements contained in the texts. However, when asked for their opinion, an overwhelming majority of the students preferred the narrative version of the text (Rosenblum & Markovits, 1976). In contrast, Guzzetti, Williams, Skeels, and Wu (1997) state that the inclusion of narrative structures is unnecessary at the secondary level.

Refutational text and conceptual change text, which address common misconceptions as well as scientific explanations, are another alternative to the traditional textbook. Both were shown to be effective for inducing conceptual change in science learning (Chambers & Andre, 1997; Guzzetti et al., 1997; Hynd, McWhorter, Phares, & Suttles, 1994).

Considering all these examples, we suggest that a set of texts in different genres can be defined in order to enhance different intended learning outcomes.

Implications

Although the study described above sheds some light on the advantages of using adapted primary and secondary literatures, caution is needed in identifying any implications for high school biology education, as discussed below. The lack of establishment of construct and content validity and the sole reliance on expert examination of the instrument is one limitation of the study. Furthermore, we recognize that the results were not yet duplicated by a reciprocal experiment or using different set of primary and secondary texts, and plan to replicate and widen the research to include more text genres in the future. Another point to be made is the deliberate removal of the teachers' input from the experiment, while it is clear that in practice the texts will be mediated to the students by their biology teacher using various teaching strategies.

Keeping the study's limitations in mind, the results may have several educational implications. The use of adapted primary and secondary literature in high school biology classes yielded encouraging results among biology majors according to all of the assessment tools used and from a gender-equity perspective. Biology majors expressed much more dominant positive attitudes than negative ones toward the reading task and gave a high rating to the idea of studying more issues using articles (data concerning secondary literature readers was not shown). The use of adapted primary and secondary literature in high school science classes may enrich the variety of instructional strategies with challenging and up-to-date learning materials. The female students' higher ability to summarize and comprehend the texts may call for teaching strategies that include heterogeneous teamwork.

However, three clear differences were found between the results obtained through the use of adapted primary versus secondary literature in high school biology classes: adapted primary literature creates a better understanding of the nature of scientific inquiry, while secondary literature permits better comprehension of the content and creates less negative attitudes among the students. The consequences of text genre selection for high school science teaching should not be overlooked. One of the aims of the science curriculum is the development of will and ability to read and understand newspaper science with healthy skepticism (Wellington, 1991) and to equip the student with the skills needed for sustaining independent and lifelong learning (Bettencourt, 1989; Hurd, 1985). To achieve those goals, students' attitudes toward self-directed secondary literature reading are of the utmost importance. Students' attitudes, as they were demonstrated in this work, were significantly more negative toward adapted primary literature reading than toward secondary literature. These attitudes might have an affect on the future citizens' will to read updated scientific literature later in their lives and should be considered very seriously. In contrast, it seems that of the two text genres, the adapted primary literature equips the student with a variety of tools and skills that a future citizen and decision-maker should possess.

Thus, we are faced with a hard choice between two desirable educational goals. We propose to avoid the dilemma by having the best of both worlds: present high school students with adapted primary literature that is suited to their cognitive level in order to enhance their understanding of the nature of scientific inquiry, but wrap it in a secondary literature package of popular-scientific articles about the same topic. The secondary literature articles may fill some of the information gaps, allowing a better understanding for students who lack parts of the prior knowledge required; equip the readers with the external criteria they are missing, by which they can evaluate the works' significance; and, it is hoped, improve students' attitude toward self-directed secondary literature reading in the future. In this exemplary framework, adapted primary and secondary literature interact together to create a well-informed future citizenry.

The authors thank Mrs. Yetty Varon for her expert statistical analysis and support during the performance of this research. We also thank the teachers and students who participated in the experiment.

Appendix A

Congruent paragraphs from the original article and both adapted texts are presented.

Original Primary Literature

We synthesized a derivative of polyacrylamide that had multiple, covalently linked copies of the P1 peptide. This polymer (polyvalent inhibitor, or PVI) contained, on average, 22 peptide units and ~900 acrylamide monomers per molecule (Mourez et al., 2001).

Adapted Primary Literature

Inhibitor design: A molecule was constructed from many copies of the peptide that were attached to each other by a synthetic material that served as a flexible backbone. On average, there were 22 peptides in every molecule.

Secondary Literature

However, minor disturbance to the toxin's assembly won't save people from death. An effective medication should intensely interfere or even completely prevent the assembly of the toxin. Therefore, the researchers developed an inhibitor, constructed from 22 copies of the peptide, attached to synthetic material that served as a flexible backbone for the molecule.

Appendix B

Questionnaire

A. Briefly summarize the main points of the article.
B. Indicate true or false for each of the statements and provide an explanation:

1. Antibiotics do not have any influence on the anthrax bacteria, and for that reason it is important to develop an inhibitor to the toxin.
2. The toxin is constructed of 22 copies of the protein PA.
3. The inhibitor interferes with the third stage of the toxin assembly, as described in Figure 1.
4. The inhibitor is being investigated because it will be the basis for the development of a drug for anthrax.
5. The researchers added the diphtheria toxin to the cell culture because it is easy to tell if it has entered the cell.
6. A single peptide can serve as a better medicine than the inhibitor, because it binds more strongly with PA.
7. The fact that the inhibitor prevented intoxication, even when it was administered 3–4 minutes after the toxin, has practical significance.
8. Rats injected with a high dosage of inhibitor suffered from side effects.
9. The researchers wanted to find a peptide that would specifically bind the truncated PA and not the whole protein, in order to increase the medicine's effectiveness.
10. The fact that the peptide disrupted the binding of the enzyme LF to PA, supports the assumption that they bind to it at the same place.
11. After the researchers showed that the inhibitor prevents intoxication in cell culture, there was actually no point to the experiment with the rats.

C. Open questions:

1. Which experiments would you conduct now in order to further test the medicine's efficiency?
2. Do you have any scientific criticism of the researchers' work? Are there any experiments that you would have conducted differently?
3. Can you think of any other applications for the technique that was used by the researchers to develop the inhibitor?

D. Attitude questionnaire:

1. I enjoyed reading the article
2. The article was difficult to read
3. The article was difficult to comprehend
4. The article was interesting
5. The article was frustrating
6. I would like to know more about the article's subject
7. I would like to learn more subjects using articles
8. I would rather study using a textbook
9. I prefer that the teacher explain, so I won't have to read by myself
10. The methods don't interest me and they can be skipped in the next articles
11. The article was too long

Other remarks concerning the learning style and the article.

Appendix C

Duncan grouping test for the five tenth-grade biology classes

Class	N	Mean[a,b]	Std	Duncan Grouping
1	25	22.76	3.1	A
2	24	21.04	4.6	A
3	21	15.24	3.9	B
4	31	13.97	6.2	B
5	29	12.52	6.1	B

[a] $F(4,125) = 21.05$ ($p = .0001$).
[b] Maximum score of 36 was calculated for the comprehension and inquiry skills sections.

Appendix D

Duncan grouping test for the inquiry skills section among the four prior knowledge groups

		Future Investigation			Critical Thinking			Application		
Prior knowledge group	N	Mean	Std	Duncan Grouping	Mean	Std	Duncan Grouping	Mean	Std	Duncan Grouping
12th grade	27	4.33	1.07	A	2.00	1.62	A	3.26	1.43	A
11th grade	115	3.62	1.38	B	0.84	1.50	B	2.26	1.36	B
HK 10th grade	49	2.31	1.70	C	0.20	0.82	C	1.29	1.22	C
LK 10th grade	81	1.01	1.45	D	0.19	0.78	C	0.46	1.82	D
F(3,268)		65.56****			17.8****			53.55****		

****$p < 0.0001$.

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