Curiosity and open inquiry learning

Michal Zion and Irit Sadeh

Bar-Ilan University, Israel

Asking questions is an activity central to inquiry learning. This research examined documents created during an open inquiry learning process of the Biomind programme for Israeli high school students. In addition, to understand how students express and develop curiosity in learning, we observed students during a molecular biology lesson, a subject not included in their inquiry project. We performed a grounded theory qualitative approach, based on content analysis. This paper presents four models for establishing logical associations between inquiry questions, and these can serve as a framework for the open inquiry plan. We found that students develop an open inquiry process on the basis of these models. In addition, we found that curious students conduct their inquiries by using the model providing the least degree of certainty, but a high degree of dynamic inquiry.

Key words: Biomind; Curiosity; Inquiry learning; Inquiry questions; Open inquiry

> *"He simply had one of the most penetrating minds I've ever encountered," says the neuroscientist Colin Blakemore, "He was childlike in his curiosity." That curiosity helped Crick secure his place in history 51 years ago when he and James Watson, working at Cambridge's Cavendish Laboratory, cracked the nut that many had been hammering – the structure of DNA (Pincock, 2004, p576).*

Introduction

Teaching students how to learn and how to develop their sense of curiosity are goals of educators in general and science teachers in particular. Biology, concerned with the wonders of life, offers many fascinating natural phenomena that provoke thought and stimulate curiosity. "Students are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses to observe and using instruments to extend the power of their senses" (National Science Board, 1991, p27). Novak (1964) suggested that inquiry involves human beings in the struggle for reasonable explanations of phenomena about which they are curious. In order to satisfy curiosity, inquiry should involve activity and skills, but should focus on the active search for knowledge and understanding of unusual elements in the environment (Haury, 1993; Maw and Maw, 1965).

Teachers vary in how they attempt to engage students in the active and systematic search for scientific knowledge. The National Research Council (NRC) (2000) considers three levels of inquiry, which are mainly distinguished by student involvement at the planning stage of the inquiry process. Structured inquiry is the first level, in which the teacher sets up the problems and processes. The next level of complexity is guided inquiry in which the teacher poses the problem and the students determine both processes and solutions. The third and most demanding level is open inquiry, in which the teacher merely provides the context for solving problems that students then identify and solve.

In recent years, more and more evidence indicates that structured inquiry, systematically guiding the student to solve one predetermined question, is not sufficient in developing critical and scientific thinking (Berg, Bergendahl and Lundberg, 2003; Yen and Huang, 2001). Science educators are searching for ways to encourage students to understand the dynamic and ever-changing nature of the scientific process (Khishfe and Abd-El-Khalick, 2002; Zion *et al*, 2004b).

Since the purpose of inquiry is to lead students to construct their own knowledge, and since questioning is an important skill, developing curricula that emphasise open inquiry learning and questioning during the process is considered an important challenge. Moreover, students motivated by curiosity enjoyed learning in open-ended situations such as inquiry laboratory activities (Hofstein, Ben-Zvi, and Welch, 1981; Hofstein and Lunetta, 2003). The Biomind Curriculum, developed within this orientation, is based on the assumption that coping with three open-inquiry questions related to a given phenomenon has great potential to encourage students' scientific thinking within the timeframe of a single school year.

The Biomind Curriculum

In 2000, a group of Israeli biology teachers created a novel inquiry-based curriculum called *Biomind:* the aim was to develop scientific knowledge through inquiry teaching among 11th and 12th grade students (Zion *et al*, 2004a). This curriculum, in which students must demonstrate self-direction, personal initiative and teamwork, is structured around students' active learning processes. The end-point is an autonomous and authentic inquiry/learning task; open inquiry according to the NRC classification (NRC, 2000). In this, students organised themselves into groups of two or three, and were involved in a dynamic learning process (Zion *et al*, 2004b). This process emphasised critical thinking and change, reflective thinking about the process and affective aspects such as curiosity which were expressed in situations of change and uncertainty (Zion *et al*, 2004b).

The open inquiry task relates to a biological phenomenon that can be observed in the field, and can be checked by both controlled laboratory and field experimentation and observations. Students were instructed to develop an inquiry plan which was based on three inter-connected questions.

Theoretically, four models may serve as the framework for an inquiry plan based on three interconnected questions (Figure 1).

The Sequential Model (SM) requires students to formulate an inquiry question at the beginning of the inquiry process. By performing the inquiry and observing the results obtained during the first phase, a second question is formulated, and an open inquiry plan consolidated. Results of the second question may help to formulate the third question. In this model, the inquiry plan is developed during the progression of the inquiry process. As such, this process provides a low degree of certainty and a high degree of dynamic.

In *the Parallel Model (PM)*, students plan three inquiry questions which may lead to an understanding of different aspects of the problem under consideration, in parallel. In addition, students must ensure that each aspect contributes to an understanding of all other aspects. The PM model presents a situation in which the inquiry plan is known at the beginning of the inquiry process. The process provides a high degree of certainty and a low degree of dynamics.

The third and the forth models integrate the first two models. In the third model, *The Semi-Sequential Model (SSM)*, students initiate the inquiry process by formulating one question. By inquiry and observation of the results obtained during the first phase, students then formulate two new questions.

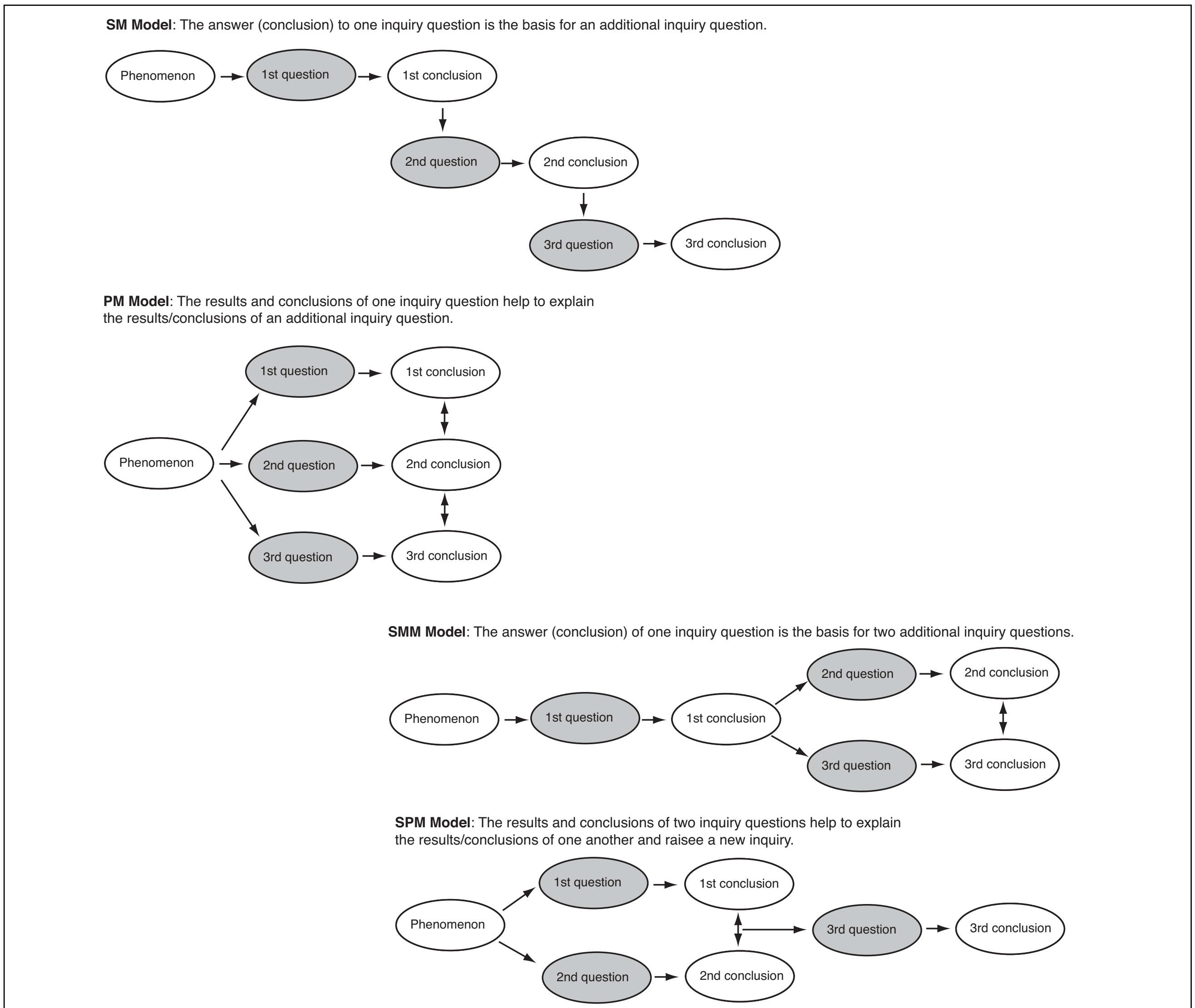
In the fourth model, *The Semi-Parallel Model (SPM)*, students initiate the inquiry process by formulating two simultaneous questions. By inquiry, and by observing and discussing the results obtained from these two questions, students then formulate a third inquiry question.

This paper examines whether these models of logical associations between inquiry questions are relevant to the Biomind inquiry process. In addition, we set out to examine which inquiry model is most popular among curious students.

Method

In this paper, we followed an authentic inquiry process conducted by 12 Biomind students. The students participating in the Biomind programme majored in biology and were guided by a teacher holding a MSc degree in botany. The students whose inquiry plans are presented here are high achievers. They were honoured at the end of the 11th grade for achieving a general grade average higher than 85 (out of a maximum 100). In a test examining inquiry skills independent of content, these students achieved scores averaging close to 90. The students learned three core topics: ecology, human biology and

Figure 1. Models for logical associations between inquiry questions



the cell, following the Israeli syllabus. They did not have biological knowledge specifically related to their inquiry project in advance.

The following documentation was used to characterise the students' organisation of the open inquiry process: a work log for documenting activities and ideas; an inquiry proposal in which students detailed the scientific background of their subject, including the intriguing phenomenon they observed and expected to examine; the rationale for the first inquiry question or questions (depending on the model selected); and the proposed experiments and/or observations. The documentation also included the summaries of the students' inquiries, written as scientific papers together with a personal reflection sheet describing the inquiry process each student performed throughout the project. The students were interviewed to examine features relating to their curiosity at the completion of the Biomind project.

In addition, to learn how students express and develop curiosity in learning, we decided to examine this phenomenon in a non-inquiry learning environment. We observed students during a molecular biology lesson, a subject not included in their inquiry project. In addition, two non-biology teachers (a class tutor and a history teacher) reported how students expressed curiosity in their lessons. The history grades of the students whose inquiry plans are presented here ranged from 90 to 100.

We analysed the research results using a grounded theory qualitative approach. The basis for this is that theory was developed inductively from the data, being generated (or grounded) in a process of continual sampling and analysis of data (Strauss and Corbin, 1990; Pidgeon, 1996). The dynamic relationship between data analysis and data collection was a significant characteristic of our grounded theory approach.

We performed arrangement and construction of information by content analysis in order to interpret and understand the meaning of the data (Pidgeon, 1996). The content analysis concentrated on the students' logical associations between inquiry questions, the students' organisation of the open inquiry process, and the degree of curiosity and initiative they expressed throughout the learning process. Data collection through the triangulation of sources, long-term data and the rich description, contributed to the validity of the research (Anfara, Brown and Mangino, 2002).

Results

The students' inquiry work covers the range of models for logical associations between open inquiry questions. This section also presents evidence characterising the sense of curiosity among students, and explores the model curious students prefer.

Examples of models

The Sequential Model (SM)

In the Sequential Model (SM), the answer to one inquiry question serves as a basis for formulating a second inquiry question. A group of students (Lev, Loni and Rina[1]) examined food preferences among ants. They observed a trail of ants carrying seeds, some of which weighed several times the ants' bodyweight.

The first inquiry question focused on the link between types of plants available around the ants' nest and the ants' preference for specific seeds: "What is the link between the types of plants in the nest vicinity and the types of seeds collected by the ants?" The students discovered a preference for oat seeds regardless of their availability in the vicinity of the nest. After noting this, the students conducted a controlled field experiment examining whether this seed preference prevails when other seeds are available within the same distance from the nest. The students discovered that of all the seeds placed around the nest at equal distances, the ants collected oat seeds more than any other type.

With this finding, the students then examined how distance affects the ants' collection of seeds. Here, the students examined the link between seed preference and the efforts exerted in obtaining seeds, as expressed by the distance the ants travel to obtain them. The seeds were placed at an increasing distance from the nest, with the least preferable seeds closest and the most preferable furthest from the nest. Other seeds were placed between these positions, according to the ants' preference. The results showed the ants' preference is affected by food type, and not by the distance of food from the nest. This conclusion was reached by observing the ants travelling greater distances to obtain the preferred food.

At this stage of the experiment, the students had completed the formal requirements of the Biomind programme. However, the students were curious about the link between the scent of a food substance and the ants' preference for a particular food. The students hypothesised that the ants rely on their sense of smell to locate their preferred food, even when it is far from the nest. Based on this assumption, the students suggested an experiment.

The dynamics of the students' inquiry shows that results of one experiment led to another question. Furthermore, results of previous experiments were considered when conducting later experiments.

The Parallel Model (PM)

In the Parallel Model (PM), results and conclusions of one inquiry question help to explain the results/conclusions of a second inquiry question. A group of students (Nir, Kaly and Tali) noticed a biological phenomenon in the field: bees flying among different flowers, 'searching' for a preferred flower. They noticed many bees and a great abundance of colours, shapes, and scents among the flowers. They decided to examine the characteristics of flowers that attract bees. The students decided to examine in parallel, the effect of colour, shape and size on the bees' preference for flowers. Once the students obtained results, they attempted to construct a specific picture for each flower, explaining which of the three factors was relevant for the bees' preference for a specific flower.

The Semi-Sequential Model (SSM)

In the Semi-Sequential Model (SSM), a group of students (Shelley, Sofi and Lin) noticed an intriguing phenomenon in the field: several plant species were growing without leaves. The students hypothesised that these plants are adapted to a dry habitat and have a low transpiration rate. At the beginning of their inquiry, the students asked how these plants compared with leaf-bearing plants in terms of transpiration rate.

Having discovered that non-leaf plants had the lowest

[1]Students' names have been changed. The real names appear in the research files.

transpiration rate, students decided to examine in parallel the effect of two abiotic variables on the transpiration rate of the non-leaf plants: the degree of luminosity and the variance of radiation wavelengths. The dynamics of the students' inquiry shows that the first question helped them focus on a specific phenomenon. This inquiry led to two parallel experiments attempting to draw an extensive comparison between the two groups of plants.

The Semi-Parallel Model (SPM)

In the Semi-Parallel Model (SPM), a group of students (Miri, Dina and Lili) noticed that less vegetation grew under *Inula viscosa (L.) Aiton* bushes in comparison to other plants found in the same area. These observations occurred in a field located far from the Mediterranean sea. The students hypothesised that allelopathy[2] inhibits plant growth under *Inula viscosa (L.) Aiton*. They also hypothesised that the allelopathy phenomenon increases as the harmful effect of the sea salt diminishes.

Following these hypotheses, the students raised two complementary inquiry questions: one question refers to the effect of allelopathy of the entire plant and the other question refers to the allelopathic effect of a plant's extraction:

1. What is the allelopathic effect of *Inula viscosa (L.) Aiton*, collected at different distances from the sea, on the sprouting of small radish seeds?
2. What is the allelopathic effect of *Inula viscosa (L.) Aiton* extracts, prepared from plants collected at different distances from the sea, on the sprouting of small radish seeds?

The students claimed that while conducting both experiments in parallel, they had good chance to obtain some indication of allelopathy. The usage of a non-crushed plant helped in getting positive results in the first experiment, while the high percentage of an active chemical material in the plant's extract was the advantage of the second experiment. The experimental results confirmed the existence of allelopathic chemicals in *the Inula viscosa (L.) Aiton* extract. The students then raised a third question focussing on the *Inula viscosa (L.) Aiton* bushes which grew further away from the sea, examining the allelopathic effect of different plant organs' extracts on the sprouting of radish seeds.

Evidence regarding student curiosity

Student attitudes to the inquiry model

Despite the similarity in students' learning achievements, the students differed in their attitudes toward the inquiry model, and in the degree of curiosity and initiative they expressed throughout the learning process. Lev, from the SM Group, said in an interview: "It is very interesting to advance from stage to stage, to discover something, or obtain an answer and research deeper into the subject. If I had more time, I would examine more issues regarding ants' food preferences. I would also like to have examined the link between the ants' food preferences and their internal sensory organs. We contacted Dr Ofer, who wrote a field guide about ants, and consulted with him as to their time of activity (Ofer, 2000). Dr. Ofer was skeptical about finding ants in winter. I was really glad we persevered and found ants. It was exemplary of how the expert does not always know everything. We were able to make innovations. This is at least relevant regarding ants living in the Iris Reservation.[3]" Lev's statements show an interest in inquiring further into the subject. His curiosity led him to persevere with his chosen subject and to continue inquiring although he had completed his assignments.

Shelley, from the SSM group, said: "It was quite stressful, talking about the inquiry. We observed so many phenomena on our excursion, and I found it difficult to choose a subject. I wanted to do something original. It seemed that transpiration rates in plants would be a good topic and we had recently conducted laboratory activity about transpiration rates in the celery plant. It was weird seeing these great bushes in the reservation, without any leaves on them. I know some students chose a subject where it was easiest to come up with questions, but we wanted to begin and see where our work would lead us. It was a tough decision how to proceed. So many factors affect transpiration. After observing that light does influence the transpiration rate, we were not surprised, and it was nice delving into the subject. We have not yet completed the repetition of the experiment examining the influence of wavelength, but it is fun that books don't have answers to everything and we would make some sort of discovery. Perhaps high-school students can make a new discovery." Shelley's statements show she had the patience to wait for results relevant to the inquiry question, results which could lead her to the second inquiry question. She enjoyed the unexpectedness of the inquiry process.

Tali, from the PM Group, exhibited an attitude toward the inquiry process that differs from the two students mentioned above. She said: "I wanted to study something that moves. I asked my colleagues if they wanted to do the Biomind project on bees, and they agreed. We knew that we had to come up with three questions, and formulated these questions to meet the requirements of Biomind. The teacher wanted us to begin with just one question and decide how to proceed once we obtain results, but that seemed too risky for us. What if we don't find a way to continue? We might get stuck. We preferred taking a safe approach, knowing exactly what we were doing." Tali's statements show almost no room for curiosity in her inquiry work. Tali preferred to obtain results on which she could base a written report, lacking the joy of discovery.

At the end of their inquiry work, all the students were asked to answer several reflective questions. One of these questions ask students to choose two of the following statements and describe how these characterised their personal experience during the inquiry project:

A. Curiosity increases especially on obtaining unexpected results.
B. Disappointment and surprise occur during the inquiry process.
C. Persistence is important during the inquiry work.
D. I learned to cope with unexpected results.
E. The inquiry process requires great initiative (from both the student and the teacher).

Nine of the 12 students selected C. As for the second statement, the six who learnt according the SM and SSM models selected statement A, concerned with curiosity. None of the six students who participated in the PM and SPM groups selected A. Of these PM and SPM students, five of the six selected statement E, regarding initiative, and stressed in their

[2]Chemically induced growth inhibition affected by a specific plant on other plant species which grow nearby (Kinchin, 1999).

[3]The inquiry location site is situated in Netanya, a city in the centre of Israel.

replies the role of teacher initiative: “The teacher helped us a lot”, “The teacher reminded us that we should…”, “The teacher showed initiative by asking us to a meeting.”

Student activity in the biology classroom

Table 1 presents remarks made by students who studied theoretical biology in a lesson discussing the lactose operon. We discovered that students from the SM and SSM groups raised ‘curious’ remarks regarding both the class curriculum and issues of biology that emerged in the media. These remarks implemented learning topics from other biology lessons, attempting to deduct and expand what was studied in class. Students from the PM and SPM groups also made remarks from time to time. Their comments related directly to the subject matter discussed in class, in an attempt to clarify terms and processes.

Student activity not related to science lessons – impressions of the form tutor and the history teacher

The class tutor, who had guided the class for more than two years, was asked to reflect on the students’ involvement in class and the interests they expressed during class discussions. She stated that all students were involved and contributed to class discussions, except for one shy student (Nir, PM group). Students were willing to assist and respond to her requests. They were all leading students in class.

The class tutor mentioned several differences: the students Lev, Loni, Rina, Shelley, Sofi and Lin (from the SM and SSM groups) often came up with their own propositions, and when the teacher asked a question or suggested an idea, these students would often question her, asking: “Why so and so?” They usually accepted her answers but they also raised additional suggestions and ideas, attempting to suggest improvements. The others (Lili, Nir, Tali and Kaly – from the PM and SPM groups) accepted the teacher’s suggestions without questioning. Miri (SPM) was an exception; she often raised questions and suggested improvements.

The history teacher reflected on the students’ involvement in history lessons. The history teacher said that high-school students tended to ask for information regarding terms during history and civics lessons. Students asked for repeat definitions, explanations of them, and examples of laws passed. Among those were the students discussed in this paper: Tali (PM), Lili, Dina (SPM) and sometimes Lin (SSM). The history teacher reported, however, that students made remarks that indicated a higher level of interest and curiosity. For example, Rina, Loni, Lev (SM), and sometimes, Lin (SSM) asked: “What would happen if …?” “Can this occur in a different place?” A remark by Miri (SPM) could be characterised as curious rather than purely a request for information. She said it would be interesting to consider when a person is responsible for his friends’ actions. Lev and Loni (SM) sometimes brought newspaper clippings regarding the subject discussed in class and asked the history teacher to react to these articles.

In conclusion, the general learning activity of students who adopted the SM and SSM models is characterised by curiosity and initiative. Students who chose to work using PM and SPM models did not exhibit such characteristics.

Table 1. Remarks posed by students in a lesson discussing the lactose operon.

Inquiry Model which served as a basis for the students inquiry process	Students’ Remarks
SM	Lev: ‘So how does the lactose affect the inhibitor, if it is outside the cell?’ And ‘Could there be another inductor affecting the inhibitor in this operon? Is it possible that two molecules that are similar in their spatial structure play a role in this case, just as they do in the case of the competitive inhibition of enzymes?’
	Rina: ‘Could there be some mechanism that demonstrates the reverse effect? Will attaching a protein to a molecule set the mechanism in motion?’
	Loni: ‘Do we also have operon mechanisms?’
PM	Tali: ‘What is the name of the other enzyme?’
	Kaly: ‘What does the third enzyme do? … I don’t get it … what should I write?’
SSM	Shelley: ‘If we take the operon sequence and combine it into the plant genome by genetic engineering, will the plant then dissolve lactose?’
SPM	Dina: ‘What is the inductor? The lactose?’

Discussion

Open inquiry learning is a great and difficult challenge (Germann, Haskins and Auls, 1996). The four models described here, which establish logical associations between inquiry questions, served as an infrastructure for the open inquiry plan. We found that students can develop an open inquiry process on the basis of these models.

Each model expresses the importance of posing several inquiry questions about a chosen phenomenon, and the importance of determining the logical association between these questions. The model type can be adjusted to accommodate both the subject matter and the creativity and curiosity of the student. As noted, the curious student prefers to use the SM and SSM models which are characterised by greater uncertainty during the inquiry process. Due to the small number of students under investigation, it is important to check these claims on a larger scale in the future.

In any case, according to Opdal (2001), there is a need to distinguish between curiosity, conceived as a confident and focussed interest to find something out, and the state of mind called wonder, where one is struck by the strangeness or peculiarity of the things encountered. We may assume that curious students seek the challenge and enjoy modifying their inquiry as they progress throughout the inquiry progress.

Students who used the SM and SSM models expressed their curiosity as the driving force for their inquiry, a curiosity which increased when unexpected results were obtained. Furthermore, unexpected results can fuel their inquisitive passion. A less curious student, requiring a clear predetermined framework, preferred the PM and SPM models. Students who used the SPM model preferred to implement their inquiry process knowing the process in advance. The less curious students began the open inquiry process knowing where the process was headed.

At the heart of inquiry is the ability to ask questions and identify a solvable problem (Main and Eggen, 1991; MacKenzie, 2001). Minstrell and Van Zee (2000) claimed that students need to learn how to question phenomena. We propose to encourage students to ask questions according to the four inquiry models. Curious students are drawn to the SM and SSM models spontaneously. Less curious students can be encouraged through the SPM model, in which the students raise two questions leading to results and discussion. The results and discussion of the first two questions may provide a sense of confidence by which the students can be encouraged to raise a third question based on results obtained.

Furthermore, it is important to focus on how the student copes with the inquiry process and not on the quality of the inquiry results. This teaching strategy will encourage students to cope with SM, SSM, and SPM models, which contain several levels of uncertainty. As such, researchers and educators need to develop a re-thinking of assessment parameters for inquiry learning and rules for successful implementation.

Educational implications

"Our aim should be to develop in students a lifelong thirst for inquiry and independence in learning. To nurture this spirit in students, teachers need to establish clear inquiry priorities and habits of mind so that thoughtful questions are the norm and students become good questioners" (Rop, 2003, p32). The Biomind curriculum and the four models presented here offer programmatic responses to the challenge set by Rop. The notion of a logical association between inquiry questions as the core structure, around which the inquiry plan is constructed, emphasises the importance of questioning, of logical thinking, and of appreciating curiosity as the trigger for formulating questions. But as Rop emphasised, "a good test for the modern curriculum is whether it enables students to see how knowledge grows out of thoughtful questions. … The real test is in the development of a spirit of thoughtful curiosity and the disciplined habits of inquiry to support it" (p32). In addition, Rop claimed that "more attention should be given to the perspectives of the students themselves and the source of the curiosity that drives the scientific questioning" (p17).

The evidence presented in this paper is encouraging, as it indicates that curious students can express their curiosity in open inquiry. Using the models presented here, teachers are able to help students more practically channel their curiosity in planning and conducting open inquiry. Instructing students to follow one of the models can assist students in comprehending both the essence of the open inquiry process and the strategic location of questions in that process.

For future research, we propose to investigate how Biomind students understand the mechanism by which scientific knowledge is constructed. An intriguing path for further research would be to examine the existence of a correlation between the students' preferred model for open inquiry, the development of inquiry skills and the comprehension of the essence of science. Students less curious by nature tend to prefer the PM and SPM models. These students will likely show a greater improvement of their inquiry skills and comprehension of the essence of science once they adopt SM and SSM models. On the other hand, practising inquiry through the PM and SPM models may suffice to develop scientific thinking, at least because these models emphasise the importance of the logical associations between inquiry questions.

The four models and their potential relationship to students' scientific curiosity may serve as a basis for further research. For example, the idea that students use the questioning route offering the least degree of certainty is consistent with some of the literature on neuropsychology and gaming theory (e.g. Atkinson, 1957; Shizgal and Arvanitogiannis, 2003). We look forward to examining the four models for logical association between inquiry questions in terms of neuropsychology.

In another context, Pedrosa de Jesus *et al* (2006) studies how questioning styles fit with students' orientations to learning. From this research it will be interesting to check how does the quality of the individual questions vary and whether this varies with structure. For example, are there questions needed for acquisition, for specialisation and for integration? One might hypothesis that the PM model equates to more acquisitional questions; the SM model might equate to specialisation questions and the third question in the SPM model might be an integration type of question. In order to check these issues it will be better to encourage students to perform their inquiries individually and not as part of a group of students (as currently occurs in the Biomind programme).

Students are not expected to cope with the challenge of open inquiry on their own, as teachers play a critical role in open inquiry learning. This role encompasses facilitating, focussing, challenging and encouraging students to engage in this kind of activity (Zion and Slezak, 2005). Zion, Cohen and Amir (2007) found out that attitudes of teachers to dynamic inquiry teaching are not homogenous and do not consistently reflect the open inquiry principles which are described in detail in the Biomind programme's instructions. Teachers' attitudes to dynamic inquiry teaching cover a spectrum of attitudes, from structured inquiry through guided inquiry to open inquiry. It will be interesting to find out in the future if there is a correlation between teachers' attitudes to dynamic inquiry teaching and teachers' and students' scientific curiosity.

Acknowledgements

We wish to thank Bruria Agrest, Ruth Mendelovici, and Rachel Nussinowitz for their fruitful cooperation. In addition, we would like to thank Ori Stav and Yosef Mackler for their editorial assistance.

References

Anfara V A, Brown K M and Mangino T L (2002) Qualitative analysis on stage: Making the research process more public. *Educational Researcher* 31, 28-38.

Atkinson J W (1957) Motivational determinants of risk taking behaviour. *Psychological Review* 64, 359 – 372.

Berg C A R, Bergendahl V C B, Lundberg B K S and Tibell L A E (2003) Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education* 25, 351-372.

Germann P J, Haskins S and Auls S (1996) Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching* 33, 475-499

Haury D L (1993) Teaching science through inquiry. In *Striving for excellence: The national education goals* Ed. Gronlund L E, vol 2 pp71-77. Washington, DC: Educational Resources Information Center.

Hofstein A, Ben-Zvi R and Welch W W (1981) Some aspects of scientific curiosity in secondary school students. *Science Education* 65, 229-235.
Hofstein A and Lunetta V N (2004) The laboratory in science education: Foundation for the 21st century. *Science Education* 88, 28–54.
Khishfe R and Abd-El-Khalick F (2002) Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders views of nature of science. *Journal of Research in Science Teaching* 39, 551-578.
Kinchin I M (1999) Allelopathy: a neglected aspect of plant biology in schools. *School Science Review* 80(292), 87-92.
Mackenzie A H (2001) The role of teacher stance when infusing inquiry questioning into middle school science classrooms. *School Science and Mathematics* 101**,** 143-153.
Main J and Eggen P (1991) *Developing Critical Thinking through Science*. Book Two. California: Null Critical Thinking Books and Software.
Maw N H and Maw E N (1965) Differences in preferences for investigatory activities by school children who differ in curiosity level. *Psychology in the Schools* 2, 263-266.
National Science Board (1991) *Science and engineering indicators – 1991*. Washington, DC: US Government Printing Office.
National Research Council (2000) *Inquiry and the National Science Education Standards.* Washington, DC: National Academy Press.
Novak A (1964) Scientific inquiry. *Bioscience* 14, 25-28.
Ofer J (2000) *Let's Go to the Ant - A Field Guide to the Ants of Israel*. Jerusalem: Yovel-Ofer. In Hebrew
Opdal P M (2001) Curiosity, Wonder and Education seen as Perspective Development. *Studies in Philosophy and Education* 20(4), 331-344.
Pidgeon N (1996) Grounded theory: Theoretical background. In: *Handbook of Qualitative Research Methods* ed. Richardson J T R, pp75-85. Leicester: The British Psychological Society Books.
Pincock S (2004) Francis Harry Compton Crick: co-discover of the structure of DNA and Nobel prize winner. *The Lancet* 364(9434), 576 .
Rop C J (2003) Spontaneous inquiry questions in high school chemistry classrooms: Perceptions of a group of motivated learners. *International Journal of Science Education* 25, 13-33.
Shizgal P and Arvantitogiannis A (2003) Gambling on dopamine. *Science* 299, 1856-1858.
Strauss A and Corbin J (1990) *Basics of qualitative research: grounded theory procedures and techniques.* California: Sage Publications
Yen C F and Hunang S C (2001) Authentic learning about tree frogs by preservice biology teachers in open-inquiry research settings. *Proc. Natl. Sci. Counc. ROC(D)* 11, 1-10.
Zion M, Cohen S and Amir R (2007) The spectrum of dynamic inquiry teaching practices. *Research in Science Education*. (On line first). Retrieved May 4, 2007, from www.springerlink.com/content/x60570571r1335k2/?p=029138abd37c4f4993505b74f3cb292a&pi=13
Zion M, Shapira D, Slezak M, Link E, Bashan N, Brumer M, Orian T, Nussinowitz R, Agrest B, and Mendelovici R (2004a) Biomind - A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education* 38, 59-67.
Zion M and Slezak M (2005) It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education* 21, 875-894.
Zion M, Slezak M, Shapira D, Link E, Bashan N, Brumer M, Orian T, Nussinowitz R, Court D, Agrest B and Mendelovici R (2004b) Dynamic, open inquiry in biology learning. *Science Education* 88, 728-753.

Michal Zion is a lecturer in the School of Education, Bar-Ilan University, Ramat-Gan, Israel 52900. She is coordinator of the Science Education Programme and the Biology Teaching Programme. Tel: + 972-50-8807365. Email: zionmi@mail.biu.ac.il Irit Sadeh is a PhD student in the School of Education.

Charles Darwin bicentenary special issue

Call for papers

The year 2009 will be the two-hundredth anniversary of Charles Darwin's birth. To mark that occasion, the *Journal of Biological Education* will be producing a special edition. It will be devoted to the impact of Darwin and his theories on biological education. It will also deal with issues concerning the teaching of evolution.

The *Journal of Biological Education* invites submissions to this special issue which will be published in the spring of 2009.

Papers must be produced in accordance with the standard Instructions to Authors which are available on the website of the Institute of Biology (www.iob.org) or direct from the Features Editor (jbe@iob.org). In particular, papers must be no longer than 5,000 words in length. Papers are usually classified into one of *JBE*'s standard categories: reviews, educational research, interactive learning and practicals. However, all submissions will be considered.

In order to ensure that all submissions are fully peer-reviewed in time to meet the issue's production deadlines, papers must be received no later than 31 August 2008. The decision of the editor is final regarding suitability and selection of materials to appear in this issue.

For more information please contact the Features Editor at: jbe@iob.org

Journal of Biological Education