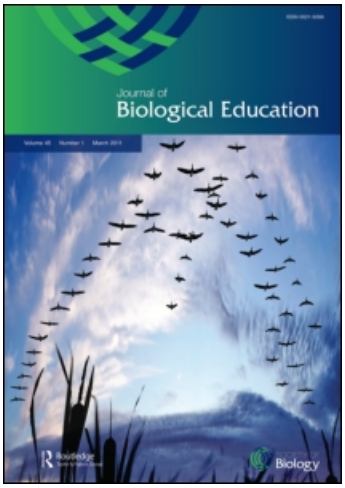

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Tracking invasive birds: a programme for implementing dynamic open inquiry learning and conservation education

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Research paper

Tracking invasive birds: a programme for implementing dynamic open inquiry learning and conservation education

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Among potential topics in the new science of biodiversity, understanding the characteristics and impact of invasive birds is an attractive subject to include as part of junior high school biology studies. Birds are aesthetic and raise curiosity. Curiosity about birds, combined with field observations, can stimulate students to ask authentic questions. As birds are among the few wild vertebrates that one can easily observe, students can easily develop systematic methods to answer their questions and initiate a dynamic open inquiry process. The educational project 'Tracking Invasive Birds', presented here as a case study, is the result of a unique collaboration among conservation biologists, science educators and biology teachers. High school students participated in an open inquiry process facilitated by teachers, ecologists, and science educators. At the end of the inquiry process, these high school students conducted a bird watching tour for junior high school students. This paper shows how investigating a conservation environmental issue – invasive birds – contributes to the development of both dynamic open inquiry skills and environmental literacy among 11th- and 12th-grade students.

Keywords: bird invasion; biodiversity; ecology; environmental literacy; open inquiry

Introduction

Recently, human activity was suggested as an important factor shaping the richness of exotic species in large spatial scales (Taylor and Irwin 2004; Leprieur et al. 2008). Studies show that human-related factors, such as the effort to introduce alien species and the human footprint (an index that includes human population size, land use and infrastructure) are some of the most important factors in shaping the number of alien species established in a new region (e.g. Leprieur et al. 2008; Chiron et al. 2009). The invasion of alien species has been proposed as one of the major risk factors leading to rapid decline in native biodiversity (McKinney and Lockwood 1999; Sala et al. 2000; Dybas 2004). Such an invasion has wide-ranging economic, social, health-related, and ecological implications (Mack et al. 2000; Mooney and Hobbs 2000; Lockwood and McKinney 2002; Simberloff 2004). After the establishment of an alien species, damages can be very difficult and expensive to mitigate (Pimentel et al. 2005). Thus, the process of understanding and preventing such invasions poses a challenge which is a good educational opportunity for conservation biologists, educators and decision makers.

Alien birds, with their ability to fly long distances and cross habitat and topographic barriers, have the potential to invade new areas and expand their range quickly (IUCN 2001). Worldwide, there are many hundreds of bird species now considered alien (Duncan et al. 2003). Despite the popular perception that birds, typically, do not negatively affect native species, several alien bird species rank quite high in the Global Invasive Species

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Program (GISP) list of the 'World's Worst Invaders' (IUCN 2001). The known impact due to alien birds includes the spread of disease (to humans and other wildlife), crop and property damage, noise and nuisance, and reduction in native bird populations (Long 1981; Shirley and Kark 2006, 2009). In such cases, eradication programmes are sometimes proposed (Myers et al. 2000). Nonetheless, programmes for the control of invasive species can be controversial and in some cases have even been stopped due to strong public opposition. Putting more emphasis on education, therefore, will likely prove much more effective in addressing this problem. In addition, the love of nature, 'biophilia' as Wilson (1984) put it, is the seed from which biodiversity conservation can grow. Scientific and environmental literacy can be the soil in which love and appreciation of nature prosper. Conservation education is the water that will nurture it to sprout.

Species invasion: environmental and educational perspectives

Agenda 21, proposed after the Rio Earth Summit in 1992, recommended that educators redirect their efforts to developing curricula programmes that emphasise sustainable development. This, in turn, raises public awareness of conservation and environmental issues towards the development of environmental literacy. Such literacy includes knowledge of the environment, developing attitudes favouring the environment, and taking appropriate action for its protection (UNESCO 1992). The 'Conference of the Parties' in 2006 published additional recommendations calling upon UNESCO, members and organisations to support biodiversity education and to acknowledge the importance of education and public awareness as elements vital to treaty implementation. At the eighth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP8), participants concluded that education must be at the helm of the global trend of conserving biodiversity and minimising harm caused by such threats to biodiversity, such as habitat loss and alien species invasion (Conference of the Parties 8 2006).

Among potential topics in the new science of biodiversity, understanding the characteristics and impact of invasive birds is an attractive subject to include as part of junior high and high school biology studies. Following Roth's (1992) ideas, studying this phenomenon expands knowledge of ecosystems and their interactions, develops an attitude and sensitivity for the environment and what affects it, offers a wide range of inquiry, exploration, and problem-solving activities, and encourages researchers and students to take action and help reduce environmental damage.

Dynamic open inquiry

In recent years, attempts have been made to teach science in general and environmental sciences in particular by emphasising thinking skills and inquiry learning, while cutting down on the mass of information taught. Learning by inquiry can be considered on several levels, defined by the intensity of involvement of the student and teacher in the process (National Research Council (NRC) 2000). Open inquiry is considered to be the highest level. By taking part in such inquiry, the student comes close to experiencing 'real' science. The key to implementing successful open inquiry is involving students in asking questions, as well as involving them in every step of the inquiry process from raising questions to the final stage of conclusions (NRC 2000). Zion et al. (2004) have characterised the dynamic elements as central to learning open inquiry. The main criteria for such dynamic open inquiry are: seeing learning as a process, allowing for changes suggested during the process, procedural understanding, and allowing for affective responses such as curiosity, frustration, surprise, perseverance, and being prepared to cope with unexpected results. A dynamic open inquiry process leads students and teachers to experience inquiry with perspectives of both critical and reflective thinking about the process (Zion et al. 2004; Sadeh and Zion 2009). In open inquiry, the inquiry questions are logically related. Sometimes, more than one inquiry question may be raised simultaneously, resulting in a stimulating discussion (Zion and Sadeh 2007).

Research has shown that among academically talented college students, an open inquiry approach to teaching conservation science and environmental management is effective in improving content knowledge and increasing interest and awareness of environmental issues (Baumgartner and Zabin 2008). In comparison to the success in implementing open inquiry among college students, implementing open inquiry among the heterogeneous high school student population is more complicated, and raises challenges for educators.

Dynamic open inquiry and 'alien bird invasion'

The study of biodiversity and alien bird invasion can inspire high school students to participate in open inquiry learning programmes (Finn et al. 2002). Several factors lead to this conclusion. First, bird studies seem attractive to youths. Curiosity about birds, combined with field observations, may be expected to stimulate students to ask authentic questions. As birds are among the few wild vertebrates that one may easily observe, students, relatively easily, may develop systematic methods to answer their questions and initiate dynamic open inquiry process. This would enable them to develop the disposition crucial for conducting successful scientific studies, i.e. patience, perseverance, open mindedness, and the willingness to engage in problem solving (Trumbell et al. 2005). Trumbell et al. (2005) called for developing bird-based open inquiry activities

that portray science as untidy, involving trial and error, repetition and revision. These activities differ from the prevailing notion of science as a static body of knowledge and a routine entity. Such inquiry may be anticipated to approximate, at an elementary level, the behaviour and thinking processes of scientists who conduct professional scientific studies. In addition, such studies introduce students to some of the complex ecological and behavioural interactions in the world around them.

The educational project 'Tracking Invasive Birds' presented here is the result of a unique collaboration among conservation biologists and education scientists from two universities, two high schools, and one junior high school in Israel. The project focused on the phenomenon of invasive birds. The area used for the study, a large urban park in Tel Aviv (described in more detail in Shwartz et al. 2008) is a hotspot of alien birds. Some of these birds recently escaped from a bird park in the area and are currently establishing populations in the region. This fact may authentically facilitate open inquiry process. Furthermore, as participants in an open inquiry project, students may acquire knowledge on biodiversity and conservation while becoming involved in an academic study and public awareness-raising activities. In view of the above, two goals were set for this paper: (1) to describe the educational model developed for the project; and (2) to study how the participating students developed dynamic open inquiry skills and environmental awareness. The 'Tracking Invasive Birds' curriculum project was accompanied by research. The research aimed to: examine the characteristics of the dynamic open inquiry manifested by the students during the learning process; examine the contribution of the dynamic open inquiry experience to the development of students' environmental literacy; and examine how participating students formulated their inquiry processes with some distance of retrospect.

Tracking Invasive Birds – the educational model

The project was developed taking into account the following four elements: (1) content knowledge – biodiversity, alien bird invasions, and conservation implications; (2) inquiry method – dynamic open inquiry learning process; (3) environmental literacy; and (4) societal and communal learning (see Figure 1).

Content knowledge

Invasion biology has emerged as a leading area of research in recent years (e.g. Simberloff 2004; Shirley and Kark 2006). In a study of Mediterranean climate regions, Kark and Sol (2005) found that invasions of birds into the Mediterranean Basin, including Israel, were both common, and had a higher probability of success compared to other convergent Mediterranean-climate ecosystems (e.g. California, Australia, and the South African Cape region). In the past decade, there has been a huge increase in the rate of bird invasion in Israel (Holzapfel et al. 2006). This increase is attributed partly to a rise in the trade of birds and the recent introduction of bird parks, especially the park in the heart of Tel Aviv's large urban Yarkon Park. Captive birds have likely escaped from the bird park multiple times, and now live in freedom in the Yarkon Park environs. However, decision-makers in Israel have little information on the species, their invasion dynamics and how best to manage these birds. The present ecological team examined the invasion process in Israel and focused especially on the Yarkon Park bird population (Shwartz et al. 2008).

Inquiry learning

As part of the requirements of their practical biology studies and matriculation exam, 11th- and 12th-grade (16–18 years of age) students participated in an open inquiry process. Students accompanied an ecology research team from the Hebrew University in the study of invasive species in the Yarkon Park. This ecology research team guided the students from the important early stages of phrasing inquiry questions, and forming hypotheses and predictions, through decisions about methodology, approaches to data collection, and the final stage of drawing conclusions. In addition, the students' classroom biology teachers facilitated the inquiry process by guiding the students to conform to the requirements established by the Israeli Ministry of Education. An academic research team from the Science Education Center at Bar-Ilan University assisted the teachers and students in coping with pedagogical difficulties. Students presented their findings in the form of a scientific paper. Thus, the students were supported directly by academic research students and by their science teachers. Further scaffolding was provided by senior science researchers and senior science education researchers. These two 'layers' of scaffolding were supported by the Israel Ministry of Education. Figure 1 portrays the educational model developed from the perspective of the supportive array of services available to assist the students.

Environmental literacy

Teachers, scientists and science education researchers who were involved in the project presented the project and its model in professional development workshops for biology teachers. Inspired by the project, teachers developed problem-based learning activities and introduced the subject of biodiversity in general biology courses. Some of these learning activities were incorporated into national matriculation exams in biology and environmental studies.

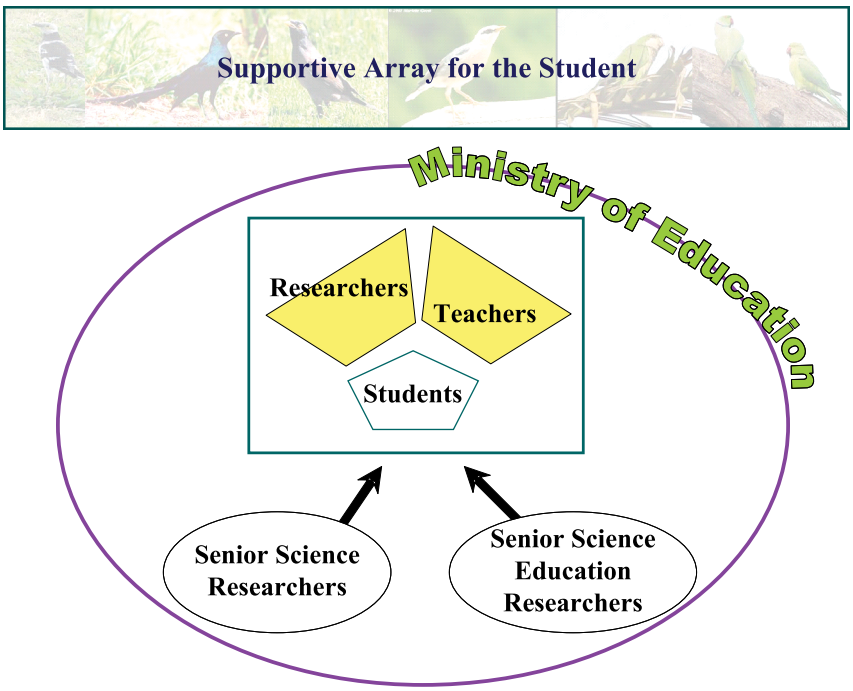

Figure 1. Tracking Invasive Birds – educational model: the supportive array for the students who conduct open inquiry

Notes: The students were supported directly by academic research students and by their science teachers. Further scaffolding was provided by senior science researchers and senior science education researchers. These two 'layers' of scaffolding were supported by the Israel Ministry of Education.

Societal and communal learning

A junior high school student group (ninth-grade) attended lectures by the academic research team on invasive birds in the urban park. These lectures were followed by a learning tour in the park guided by the sample group of 11th- and 12th-grade high school students, who participated in the 'Tracking Invasive Birds' open inquiry project. The high school inquiry participants received special training on how to lead the tour. At the conclusion of the tour, the high school inquiry participants presented their inquiry process and results, and discussed and shared their personal inquiry experiences with the junior high school students. Thus, the junior high school students were able to broaden their knowledge regarding environmental issues in general and local environmental problems in particular. The junior high school students learned how adolescents can be involved in environmental issues by conducting first-hand science work. Figure 2 portrays the educational model developed from the perspective of the different stages of the Tracking Invasive Birds educational project. The high school inquiry participants acquired skills in: content knowledge, inquiry method, and environmental literacy. The next stage was societal and communal learning, in which the high school inquiry participants taught junior high school students about the three elements: content knowledge, inquiry method and environmental literacy.

Data collection and processing

Six high school students from 11th- and 12th-grade biology classes conducted an inquiry process in the urban Yarkon Park over a 12-month period. Two MSc graduate students studying ecology, conservation and invasion biology provided practical guidance. The students frequented the park twice a week, and academic researchers accompanied the students during several observations. In addition, the school teacher met the students once a week, and the science education specialist met the students every month. The participants communicated by email in the interim periods.

The students documented the inquiry process in a work log. One of the researchers met the students in school, accompanied them on observations and conducted occasional interviews. Upon completion of the project, the students submitted a report summarising their inquiry findings in the form of a scientific paper. Four years after completing their inquiry project, the students were interviewed and asked to describe: what they remembered about their projects' content, inquiry processes and experiences, what elements of dynamic open inquiry were expressed in their project, and what skills and what knowledge did they acquire and return to later in life.

A qualitative analysis was made of the scientific paper written by the students, their work logs, interviews with students and teachers and documentation

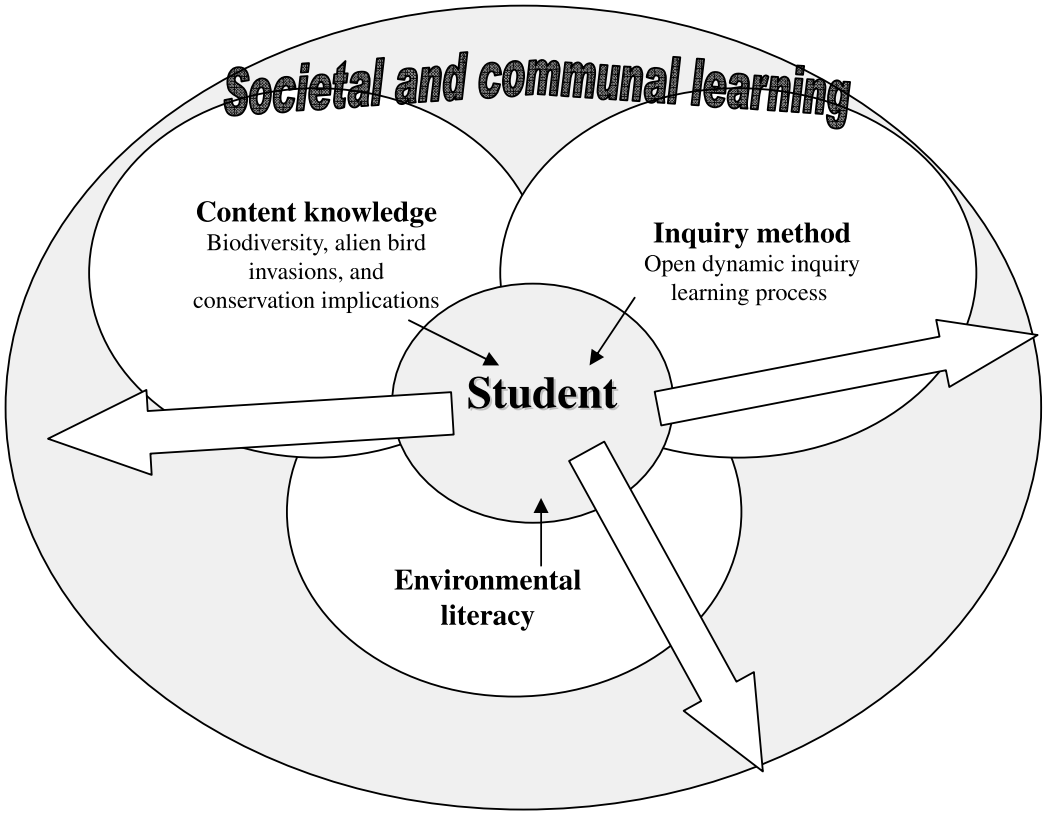

Figure 2. Tracking Invasive Birds: the different stages of the educational model
Notes: The students acquired: content knowledge, inquiry methods and skills and environmental literacy. The next stage was the societal and communal learning in which the students taught junior high school students about these three elements.

of the park tours. The characterisations of dynamic open inquiry, as well as of environmental literacy were used as sensitising concepts for categorising. Research findings were classified by dynamic open inquiry and environmental literacy categories. The current research presents evidence observed in at least two different tools of research; for instance, interviews and work logs. Data collection through triangulation of sources and the rich description of the phenomenon under review contributed to the validity of the analysis. Furthermore, data analysis was confirmed by two educational researchers.

Results

Students' primary inquiry findings

Students conducted authentic research, cooperating with biology researchers. The results of the students' research are summarised in Table 1. The project students found that two species of alien birds, the rose-ringed parakeet and the common myna, have different roosting habits in Yarkon Park. While the parakeet roost site is large and located at one clear area, the myna sites are dynamic and change with time in both space and size. This finding contributed to the wider study of these two alien species and their establishment in a new area (Shwartz et al. 2009).

Characteristics of dynamic open inquiry as manifested by the students' learning process

Our first research objective was to identify characteristics of dynamic open inquiry as manifested by the students.

Learning as a process

The students learned that an inquiry learning process demands ongoing work and effort. They also learned to document the learning process layer by layer. Shahar, a student, wrote: 'every minute and detail must be noted, even the ones that seem irrelevant or incidental, because at this stage we still can not tell how things will turn out'. The inquiry questions were logically related. Sometimes the questions were asked simultaneously; sometimes one question followed another. An example of one question following another can be seen in Shahar and Helena's inquiry regarding how common it is to see different species of birds using the same experimental nest boxes. The inquiry led to information that the rose-ringed parakeet is one of the most common species (both local and invasive) in Yarkon Park. This finding led to an inquiry regarding the connection between the size of the rose-ringed parakeet's population in the park, and the number of active experimental nest boxes used by the species.

Table 1. Primary findings made by project students

- A sleeping site of rose-ringed parakeets[1] was discovered and observed; 600–800 specimens arrived at the site every evening.
- A common myna[2] sleeping site was found; 80–150 specimens arrive every evening.
- It was observed that the myna sleeping site is very dynamic, being extremely populated one evening and desolate on another evening.
- The mynas spent the day at Yarkon Park, but did not necessarily stay the night at the park sleeping site.
- The parakeets demonstrated the opposite behaviour: most were absent during the day, but gathered at the park sleeping site at nightfall.
- Some invasive species share a sleeping site: the common myna and vinous-breasted starling.[3]
- At the final stage of the research, the sleeping site shared by the myna and starling was abandoned. It became known that the starling sleeps at a site outside the park.

Notes: [1]*Psittacula krameri*; [2] *Acridotheres tristis*; [3] *Sturnus burmannicus*.

Although the students managed to conduct the stages of open inquiry, they could not describe or illustrate the entire inquiry process. When asked to illustrate or explain the inquiry process as a flow chart or verbally, they became confused and could not describe it as a continuous process. They only mentioned separate events, unrelated actions, or fragmented processes.

Changes occurring during the process

The inquiry process was dynamic and changed during the course of the study. Tal, the teacher, noted her lengthy discussions with science educators about modifying the students' inquiry questions: 'The discussions were an online teacher-science educator discourse, discussing what to change and how to proceed. The discourse was a succession process, the result was the climax'. Naama, a student, also mentioned that 'things change as work progresses, things that could not be anticipated. I do not think the inquiry process could have occurred without change'. Shahar said:

> I learned to cope with unexpected results. At first we wanted to study the invasive monk parakeet, but couldn't find its roost sites. We were discouraged but did not give up. We found the site of other birds instead (the common myna, rose-ringed parakeet, hooded crow, and house sparrow).

Naama reflected with satisfaction on the uncertainty of the inquiry process:

> We enjoyed every stage of the work. We were glad to discover that some of our hypotheses matched the final results, but even when they did not, it was interesting to try and find alternative explanations.

Procedural understanding

The inquiry process required the application of procedural experimentation skills: maintaining constant experiment factors, repeating tasks, and conducting statistical tests. Shahar mentioned:

> I understand we should only consider existing data and not hypotheses about whatever we want. We must not generalise our conclusions, but must form conclusions only from the specific results of our inquiry.

Irit, the science educator, concluded:

> We could see that the students understood the inquiry procedure. They understood the importance of the reliability of their observations and the importance of maintaining constant conditions and repetition in experiments. Students initially encountered problems they needed to solve, for instance: how to conduct simultaneous observations in distant locations, how to identify specimens/individuals observed, and how to quantify bird activity. These cases demanded a consideration of procedural skills.

Affective points of view

As dynamic open inquiry involves much change and uncertainty, affective aspects such as insistence, determination, disappointment, surprise, and enthusiasm are all part of the inquiry (Zion et al. 2004). We accumulated much evidence about the great enthusiasm students showed in the study project. Shahar said: 'I had a lot of fun. I loved being there, going to the park, counting birds. It is the most beautiful spot in Tel Aviv'. Helena said:

> Yesterday something amusing happened. I was taking a driving lesson while Shahar was out observing in the park. During one of my driving lessons, Shahar called. It was crazy: my instructor was sitting there as I was calling out enthusiastically: You found a nest of parakeets?! Are they going to sleep?!

Maya overcame a moment of despair by exhibiting persistence and determination:

> Persistence and determination are two important qualities because during work we were sometimes on the brink of despair from failing to find roosting sites or complications in defining them. We also received surprising results during work. The number of common mynas in the sleeping site diminished with each count. The researcher working with us said the myna must have noticed our presence and visited the site less often. We had to devise a way of counting the birds without being noticed.

The contribution of the dynamic open inquiry experience to the development of students' environmental literacy

The second objective of the research was to examine the contribution of the students' experience to the development of environmental literacy. Interviews with students supplied evidence for the development of knowledge and positive attitudes toward the environment. Helena said: 'It was truly wonderful to discover that there are 108 species of birds habituating the Yarkon Park, four of which are birds of prey'. Shahar added:

> I suddenly realised that not noticing something doesn't mean it's not there. One hundred and eight species? No one knew there was a European starling there. Suddenly you understand that much more exists in the environment than you'd realised. It's exciting to see that.

The students also improved their awareness of the environmental aspects of species invasion and the threat it poses to the existence of ecosystems. Helena mentioned that 'We learned how aggressive the myna is, and that it has brought diseases. It's something that will stay in our minds'.

The project enabled students to become involved in authentic open inquiry in a new environmental subject. Students were very excited about the subject and about do conducting contemporary science on a 'hot' issue with academic assistance. Maya wrote:

> we chose this subject for our inquiry because it is a new phenomenon both in Israel and around the world. Furthermore, we loved the idea of taking part in professional research whose goals were to save an ecosystem. We enjoyed every step of the work, from the fascinating observations to the processing and analysis of data into exciting conclusions. We were glad to discover that some of our hypotheses raised during work matched the final results, but even when they didn't, it was interesting to try and figure out why, try and find alternative explanations.

Students understood the dynamic element of science and the need for controlled, long term collection of data to achieve reliable results.

The feeling that the work had added value, that the data collected became part of a large academic database, added to the students' pride and interest. Shahar and Helena said:

> First of all we would like to mention that our study is one of the first in its field to be carried out in Yarkon Park and therefore all data gathered are new to science. All the results obtained and the conclusions we came to are to be considered as hypotheses, as field research should be carried out for years and include many repetitions in order to have a reliable basis for conclusions. But our work does open a lot of doors for a lot of future research that can examine different ecological issues in greater focus.

As part of an educational model and towards building a learning community, Shahar and Helena guided ninth-grade students for two-hour learning tours. They taught junior high school students about the issue of the birds' invasion and its problematic outcome in the park – thus, expressing environmental activism. They shared their study results with the younger students and the fascinating experience of assuming the role of scientists during the learning tour. Helena told the young students: 'It's difficult to imagine how I feel. I feel I've just contributed to a governmental decision whether or not to exterminate the common myna'.

The meeting between high school and junior high school students in the actual environment of the study enforced the development of environmental literacy. This meeting of the two groups required the high school students to organise their knowledge, to think about the most important information regarding the phenomena of birds' invasion and deliver this material to the junior high school students. The meeting also required the high school students to take positions regarding the approaches required to solve this environmental problem. These students also had to reflect upon their inquiry process and draw conclusions about ways to improve such studies. Naama and Maya published a letter in a local newspaper that reflected their willingness to share with the general public the important knowledge they gained.

How students perceive the project with distance of retrospect

Four years after the project ended, four student participants were contacted and interviewed. Each participant remembered the project as an exciting learning experience and they still talk about the project when they meet. They fondly remember the field work of gathering data, and the fact that they took part in an

innovative ecological research. Two of the four students interviewed went from high school directly to university biology departments, and are now studying for their master's degrees. These students believed that the project helped them comprehend how scientific research is conducted. Each of the four students were asked to rate the dynamic open inquiry performances in their project between 1 (lowest) and 5 (highest performance). The degree of 'learning as a process' was attributed the highest score (an average of 4.5). Helena, for example, mentioned:

> We had this arrangement that did not allow us to jump ahead of ourselves … only after we'd located birds' nests, and where the birds sleep, could we begin to count them … we would then collect data and only afterward reach conclusions. This is clearly a research process, and this is how research ought to be conducted.

Shahar provides another example:

> We had a work order – we had to come up with some questions, then focus on one. Once we had a question, we planned how to gather information, and only then could we go out to collect data. Then came processing the information obtained, and only after that – conclusions. This is really how we worked.

'Procedural understanding' and 'affective points of view' received the same score: a 4.25 average. The four students mentioned how beneficial the project was to their understanding the importance of defining variables, repetition and comparing research groups. From the affective point of view, all mentioned fun, insistence and challenge, as well as the disappointment and surprise they'd experienced. 'Changes occurring during the process' was the criterion rated lowest, with a 2.4 average. The four students remembered having to modify inquiry questions and collect data from new locations in the field in light of unexpected conditions. All students mentioned they notice birds when they are outdoors. The students recommend giving more students the opportunity for such an authentic experience, for novelty's sake as well as the curiosity born when studying a subject new to science. All students mentioned they worked harder than their classmates, but in retrospect, they say, it was well worth the effort.

Discussion

Research has shown that environmental literacy has a considerable positive effect on students' ability to increase motivation; develop life-long learning skills; develop thinking and inquiry skills; improve a sense of relevance of school studies to students' everyday life; and develop attitudes of respect and responsibility towards the environment (e.g. Hart 2007). In this paper, we demonstrated how investigating an environmental issue of immediate significance contributed to students' development of both dynamic open inquiry skills and environmental literacy. This activity enabled students to experience dynamic non-linear inquiry, with its series of logically related events, changes to the inquiry plan and an understanding of procedural skills that the process requires. The dynamic aspect of the process brought up affective aspects such as determination, insistence, surprise and motivation. Thus, the ecological issue of bird invasions has the potential to encourage and facilitate students in implementing a dynamic open inquiry process.

The results obtained from retrospective interviews with the students show that the project left an impact in three categories of dynamic open inquiry. The *changes occurring during the process* criterion does not appear to be a primary characteristic of the students' inquiry process. This result can be attributed to the fact that the project was part of an academic research effort, already framed and formulated by expert researchers. The students participated in a minor role in this research, with no chance for dynamism on their part. However, the fact that they remember processes of inquiry that were conducted in their projects indicates this project was significant in their acquisition of scientific literacy.

The study demonstrated the feasibility of our educational model. Above all, the study showed the feasibility of cooperation not only between universities and schools, but different faculties among universities, teachers and students. In addition, the study demonstrated the feasibility of our educational model regarding four aspects: content knowledge, open dynamic inquiry learning process, environmental literacy, and societal and communal learning. The guidance of the academic biodiversity researchers contributed to the continued growth of *content knowledge* of the student participants in the project. The possibility to ask questions and receive answers 'on the spot' facilitated the students and elevated their motivation. The fact that the results students collected were used for scientific research emphasised the notion that involving students in authentic research can be fruitful. Our results also showed the growing understanding of the high school students regarding the process of *dynamic open inquiry* and how scientists actually work. This study strengthened the approach that open inquiry is a beneficial learning process. This is an important outcome that should encourage teachers to implement open inquiry as part of the teaching and learning process.

Interviews with the student participants also revealed evidence for the development of knowledge and positive attitudes towards the environment. These are the main components of *environmental literacy*. Knowledge and positive attitudes towards the environment lead to

the willingness to take action in environmental causes. In the 'Tracking Invasive Birds' project, the willingness to take practical action for the environment in communal activity was directly linked to the inquiry project and not to some other, unconnected environmental aspect. Furthermore, in this project the students focused on the framework of conducting explanatory activities and not on direct action or protest. One can argue that if students would have conducted additional voluntary activities on an environmental issue not directly linked to invasive birds, these students would have become more environmentally literate. Nevertheless, *societal and communal learning* that is directly related to the 'Tracking Invasive Birds' inquiry can be seen as an integral part of our model. *Societal and communal learning* was addressed in our approach through guided tours and presentations to younger age groups. We suggest that further research follow the students' future environmental activity. In addition, we suggest that future research examine the effect that the project had on the junior high school students and on family members of the high school students conducting the inquiry, given their second-hand exposure to the issue of invasive birds.

Implications for practice

Implementing this project requires the involvement of an ecology research team, biology teachers and an education research team. As the close support of scientists and education researchers will not be available for most schools, we propose holding workshops to prepare teachers for the task. Advanced study workshops of new subjects in biology can develop teachers' proper pedagogical content knowledge, enabling them to facilitate inquiry learning processes. Workshops should include theoretical lectures as well as practical experience of field research. The personal field work experience is important, indeed crucial, as it will increase the teacher's skills and credibility as a facilitator.

We support the notion that biodiversity education extends beyond an academic study of biological relationships, structural and functional diversity, and the processes of evolution and extinction. In doing so, biodiversity education will become increasingly important for students to consider the impact of human activities on biodiversity, and to learn ways of slowing the increasing rates of animal species' extinction. Beyond gaining an understanding and appreciation of the diversity of living organisms (e.g. birds), students must come to understand the connections between biodiversity and our economy, ecological sustainability, environmental quality and quality of life. There are issues to study, problems to solve, and decisions to make that require an in-depth understanding of biodiversity; and teachers will need to locate sources of information and activities to engage students in this field.

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