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Moving from structured to open inquiry: Challenges and limits

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Abstract

The article provides science educators with definitions of inquiry and its levels, relating them to real-world scientific processes. Such an educational shift entails a fundamental cultural change in the epistemology of science learning in schools, shifting it from 'instructionism' to social constructivist learning. The highest level of inquiry, open inquiry, simulates and reflects the type of research and experimental work that is performed by scientists, and demands high-order thinking capabilities (i.e., questioning, designing an experimental array, critical and logical thinking, reflection). Students who participate in an open inquiry project demonstrated ownership and responsibility for determining the purpose of the investigation and the question to be investigated as a scientist would. We present a model that has been implemented in Israel's high school biology teaching for the past twelve years. The model consists of several components, each of them independently proven important to inquiry teaching by the relevant research literature available. In the article, we present the components of our model, emphasizing the importance of each component. The components (development, implementation, support, and control) at the heart of the model presented here are based on numerous projects and researches from the literature.

***Key words**: structured inquiry, guided inquiry, constructivism, teacher professional development,*

Introduction

Structured, guided, and open inquiry approaches - definitions

Inquiry learning is compatible with the constructivist approach, which emphasizes the idea that knowledge is not transmitted directly from the teacher to the student, but is actively developed by the student. Inquiry-based teaching/learning varies in the amount of autonomy given to students and encompasses a broad spectrum of approaches, ranging from teacher-directed structured and guided inquiry to student directed open inquiry (National Research Council [NRC], 2000).

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In *structured inquiry*, the students investigate a teacher-presented question through a prescribed procedure, and receive explicit step-by-step guidelines at each stage, leading to a predetermined outcome, similar to following a recipe. Students are involved through hands-on investigations in the process of science and develop basic inquiry skills, such as making observations, raising hypotheses, collecting and organising data, drawing conclusions, making inferences and finding solutions. However, students do not acquire the ability to think autonomously because in structured inquiry, questions, processes and results are 'known in advance'.

Obviously, the emphasis in *structured inquiry* is on a *linear inquiry process* that begins with identifying a related question, through data collection, and ends with the drawing of appropriate evidence-based conclusions. However, linear inquiry processes are just one pillar of the scientific inquiry process, which also includes *observation and inference*, *distinction between theories and laws*, and the *coordination of ideas with evidence*. Therefore, structured inquiry, where processes and results are 'known in advance', works well only for developing basic inquiry skills that are inadequate for appreciating the real nature of science.

In *guided inquiry*, students investigate questions and procedures that teachers present to them, but the students themselves, working collaboratively, decide the processes to be followed and the solutions to be targeted. The results are not foreknown to the teachers and students. In guided inquiry, the teacher provides the student with inquiry questions and procedures, and therefore this decreases the level of uncertainty during the inquiry process. The students ultimately lead the inquiry process, are involved in decision-making from the data collection stage, and may come up with unforeseen yet well-conceived conclusions.

In *open inquiry*, the most complex level of inquiry-based learning, teachers define the knowledge framework in which the inquiry will be conducted, but allows the students to select a wide variety of inquiry questions and approaches (student-designed or selected). Thus, students are engaged in continuous decision-making throughout each stage of the open inquiry process, starting from the stage of finding the interesting phenomenon to be inquired. Open inquiry simulates and reflects the type of research and experimental work that is performed by scientists, and demands high-order thinking capabilities (i.e., questioning, designing an experimental array, critical and logical thinking, reflection). Students who participate in an open inquiry project demonstrated ownership and responsibility for determining the purpose of the investigation and the question to be investigated as a scientist would (Reid &Yang, 2002).The student’s functioning corresponds closely to the teacher’s efforts to facilitate the student’s scientific literacy, initiative, responsibility, and motivation. Open inquiry does not separate teaching from learning, but creates a learning community of teachers and students that is crucial to the success of the inquiry process (Zion & Slezak, 2005).

Open inquiry depends on the ability of the teachers to facilitate the students to raise the appropriate, challenging questions that will guide students during their inquiry process, and trigger student-generated investigation and learning. Thus, the participation of students in formulating an appropriate inquiry question in open inquiry is considered crucial, while the teachers scaffold and facilitate their students in every stage so that the students make choices and exercise decision-making for the different stages of inquiry. Open inquiry also depends on the students' cognitive ability. Teachers familiar with the students’ cognitive ability will be able to facilitate them appropriately.

Structured, guided, and open inquiry approaches: advantages and disadvantages

The type of inquiry that is more relevant to the teaching and learning facilities available in schools remains controversial among educators. Some teachers prefer using structured or guided inquiry, whereas others prefer using open inquiry. The structured and guided inquiry proponents claimed that guided inquiry-based teaching helps students learn science content, master scientific skills, and understand the nature of scientific knowledge (e.g. Blanchard et al., 2010; Quintana, Zhang, & Krajcik, 2005; Tabak et al., 1995). Moreover, structured and guided inquiry prevents a 'waste of time,' reduces students' frustration due to achieving undesirable results or experiencing failure, and reduces students' fear of the unknown (Trautmann, MaKinster, & Avery, 2004).

Unlike their colleagues who use structured or guided inquiry teaching strategy, educators who prefer open inquiry claim that this method achieves a higher level of inquiry, in which the students become more familiar with the nature of scientific knowledge, develop greater inquiry skills and practices, and engage in higher-order thinking (Berg et al., 2003; Chinn & Malhotra, 2002; Krystyniak & Heikkinen, 2007). The student’s functioning corresponds closely to the teacher’s efforts to facilitate the student’s scientific literacy, creativity, initiative, responsibility and motivation (Jordan et al., 2011; Zion & Slezak, 2005).

Research evidence clearly indicates that structured inquiry is insufficient for developing critical and scientific thinking and appropriate dispositions and attitudes. Comparing student outcomes during open-inquiry and structured laboratory activity provided evidence that open-inquiry activities can result in more positive outcomes regarding student learning and their perception of the role of experiments (Berg, et al., 2003). Cumulative evidence supports the effectiveness of open inquiry learning in developing cognitive and procedural skills for inquiry and autonomous learning, as well as more positive attitudes towards science and science learning. Guided inquiry constitutes an intermediary level that can help students make the transition from a structured inquiry to an open inquiry. Interestingly, as students move progressively from structured to guided inquiry and then to open inquiry, they develop both critical and scientific thinking, appropriate dispositions in attitudes, and they transform their data into much more complex and abstract forms, such as, graphs and concepts maps ((Lunsford, 2007).

These observations stimulated intensive efforts by science educators to promote the transition of students' learning from structured inquiry to guided and open inquiry. Such an educational shift entails a fundamental cultural change in the epistemology of science learning in schools, shifting it from *instructionism* to *social constructivist* learning. This shift also requires that students experience science in a form that engages them in the active construction and reconstruction of ideas and explanations, so that they can correctly conceptualize the tentative nature of scientific knowledge, the never-ending and continuously renewed process of science, the reciprocal fertilisation between science and technology, and their tremendous impact on our social and natural environment.

For more than 50 years, dynamic changes have occurred in educators' and teachers' conceptions of science, learning, and science learning environments (Grandy & Duschl, 2007). However, research into the development of inquiry-based skills remained focused on concepts of evidence and linear inquiry planning, beginning with one question and ending with a conclusion (e.g. Sandoval, 2005; Roberts & Gott, 1999; Tamir, Stavy, & Ratner 1998).

A recent study compared the influence of open versus guided inquiry learning approaches on inquiry performances among high-school biology students. Sadeh and Zion (2009) compared the students from both groups with regard to their ability to take on a theoretical structured inquiry biology assignment, based on a list of basic inquiry skills, following the work of Tamir, Nussinovitz, and Friedler (1982). Sadeh and Zion (2009) found no significant differences in basic inquiry skills between the two groups in a structured inquiry assignment. In addition, quantitative content analysis of the two groups, using a dynamic inquiry performance index, revealed that open inquiry students applied significantly higher levels of performance in the criteria 'changes during inquiry' and 'procedural understanding.' However, the results of the study indicated no significant differences in the criteria 'learning as a process' and 'affective points of view' (Sadeh & Zion, 2009). Regarding attitudes toward inquiry learning, open inquiry students believed that they were more involved in their project, and experienced a greater sense of cooperation with others, in comparison to guided inquiry students (Sadeh & Zion, 2012). This positive attitude indicates the advantages of open inquiry – stemming from the ability to emphasize the dynamics and discovery involved in methodical scientific research. From all of the above, one can clearly see the importance of leading the student through the different levels of inquiry *gradually*. At each level, the student acquires new skills.

Self-directed and active learning requires a change in approach by both students and teachers. Instead of explaining, demonstrating and correcting, the teacher must place more emphasis on guiding the student's active learning process (Luft, 2001; Rossman, 1993). Particularly, in the guided and open inquiry approaches, the teacher must guide, focus, challenge and encourage student learning (American Association for the Advancement of Science [AAAS], 1993; NRC, 2000; 2012). Descriptors of roles for teachers using constructivist and inquiry-oriented approaches include "teacher as facilitator," and "teacher as guide" (Crawford, 2000, 2007; NRC, 2012). Crawford (2000) widened this scope, and claimed that the teacher in an inquiry-based classroom must assume a myriad of roles. Such roles demand a high level of expertise: the role of motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor and collaborator.

The challenge

A framework is required to support teachers and educators taking up this complex challenge – moving from the structured to the open inquiry teaching approach. We present a model that has been implemented in Israel's high school biology teaching for the past twelve years. The model consists of several components, each of them independently proven important to inquiry teaching by the relevant research literature available. In the text below, we present the components of our model, emphasizing the importance of each component. The model rationale is based on three points:

- The model includes all levels of inquiry up to open inquiry. The transition between levels should be gradual.
- Flexibility of the program allows a teacher to choose the level of open inquiry: full open inquiry or open light inquiry.
- The on-going teachers' professional development stands at the heart of the model:
  - Teachers participate in constructing, implementing and monitoring the program.

- Teachers are offered extensive professional support to enable them to facilitate inquiry teaching.
- Teachers go through advanced professional training covering scientific knowledge, research methods, and comprehension of the nature of science.

The curriculum (the program) is the basis of this model. The model consists of four components: development, implementation, support and control. We will present the model components by their rationale and characteristics. We will then discuss the common features of the model components.

A model for implementing inquiry teaching

In light of the many challenges posted by inquiry teaching, a model must take into account components that would help teachers apply different levels of inquiry in class, from the structured to the open inquiry level.

We have drawn on our 12 years of implementation and research experience to develop a model, which aims to facilitate the shift from structured to open inquiry teaching and learning. The model and its components are detailed in Figure 1.

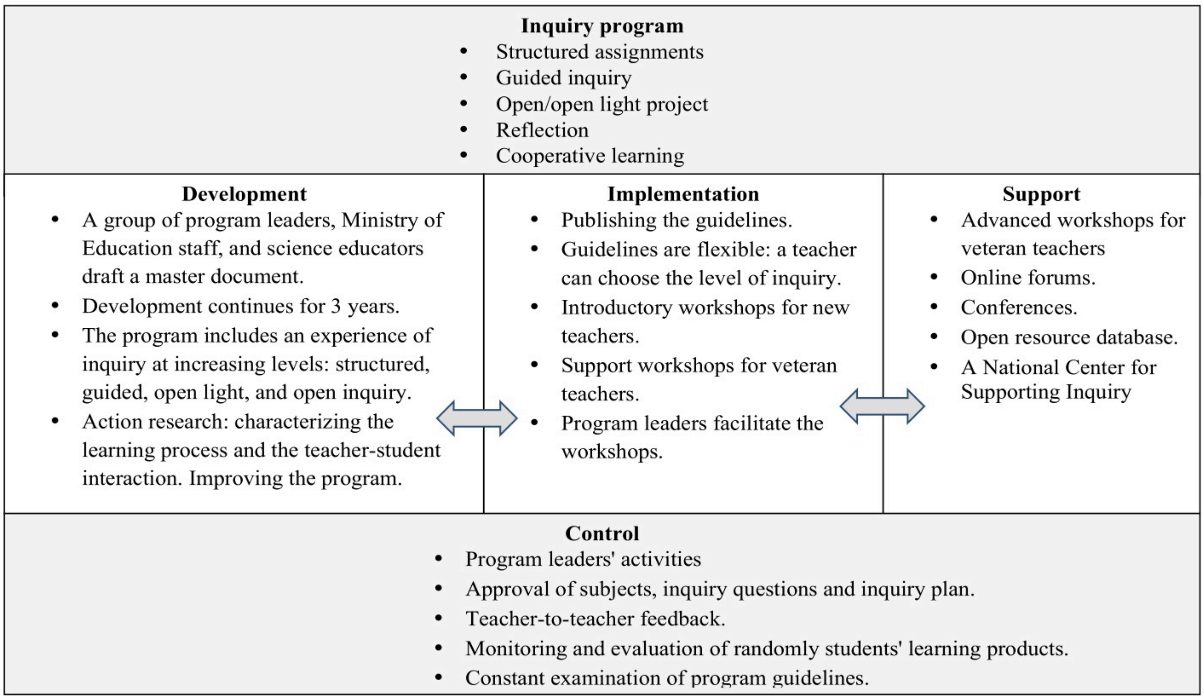

Figure 1. A model for implementing inquiry teaching

Development

Principles of program development:

Teachers, science education professionals and ministry of education staff are all involved in the program's development. This combination of expertise enables the program to be adjusted to the required national standards, and nurtures a commitment to its successful implementation by all contributors involved. The program is implemented experimentally as it is still being developed. As a result of this, and of the fact that open inquiry is a long-term process, the program was in development for three years until it was published.

Defining the program

The curriculum consists of several components, enabling students to advance gradually from structured inquiry, through guided inquiry, and up to the level of open inquiry.

1. The first component includes a series of *structured inquiry* lab exercises. The students are given clear guidelines which they must follow, then turn in an inquiry report. The inquiry report is written in the form of a scientific paper, with a theoretical introduction, detail of methods, tables of data collected by the students and discussion of results. The results of these exercises are known to the teacher but not to the student. Students performing these exercises practice the use of different inquiry skills such as methods for fieldwork and lab work, methods for collecting and analysing data, constructing hypotheses, and drawing conclusions. Students also become familiar with the epistemology of scientific research. The teachers have at their disposal an extensive database of such exercises. They choose the ones appropriate for the course in which they navigate the teaching process for the scientific content knowledge they wish to emphasize. The teachers emphasize the related substantive knowledge in combination with the procedural knowledge (Roberts, Gott, & Glaesser, 2010).

As the assignments are carried out in controlled lab conditions based on previously tested protocols, the teacher knows what results to expect. For this reason, these assignments are considered a structured inquiry exercise. The students are evaluated by their ability to handle such structured assignments by an external evaluation system operated by the Ministry of Education.

2. After developing procedural and substantive knowledge in the structured inquiry stage, the second component of the curriculum includes *guided inquiry fieldwork*. The students are given different assignments, the purpose of which is to methodically identify some environmental aspects (physical, chemical, biological, geological). The teachers supply the students with the inquiry question and the working methods. The teachers also choose the environment to be examined and the time of the year. Teachers are scientifically informed of the results that the students are expected to obtain. However, given that the field is a changing environment, results can be surprising. Although the teachers dictate the method, the student is involved in the process of managing data gathering according to the specific terrain, in the process of drawing conclusions and in discussing the conclusions reached. For these reasons – it is considered a guided inquiry.

3. The third component of the curriculum is an *open inquiry project*. In this project, the students are involved in the inquiry process from the stage of choosing an intriguing phenomenon, and through asking inquiry questions and beyond. The project requires the students ask *two logically related inquiry questions*. The second question follows from the results of the first question. Alternatively, the inquiry questions may lead to understanding different aspects of the problem under review, in parallel. The open inquiry project spans six to twelve months. The project's results are not predetermined – the student and teacher do not know the future outcome. During the inquiry process, students plan the inquiry and make many changes during the course of the inquiry process till the students rich a reliable inquiry setting.

Based on the inquiry level definitions mentioned at the beginning of this paper, we can see how the different levels of inquiry are defined primarily in regards to the stage of constructing the question and planning the inquiry. In order to balance our belief in the importance of an open inquiry experience and the demands of educational reality in class, we must enable the teacher to adjust the level of open inquiry applied to the academic level of the students, the technical resources available at the school and the teacher's own scientific and pedagogical knowledge. When conditions permit – the teacher should lead the students to do full open inquiry. This will enable good students to make the most of their potential, encourage their curiosity, and increase their interest in becoming professionally involved in science. However, when pedagogical conditions do not permit, or when a teacher's pedagogical knowledge of inquiry is insufficient, the teacher can lead the students through an open light inquiry project. An open light inquiry project requires the students participate in making the decisions that will shape inquiry plan. Their involvement in the different stages of inquiry planning moves along a spectrum ranging from full to limited involvement. The number of stages for drawing the inquiry plan also varies: at one end of the spectrum, the students are involved in several stages; at the other end, the students are involved only in one stage (e.g. constructing the question, or devising an experiment or finding relevant literature). Students may also be fully involved in some stages and partially involved in others.

Table 1. A spectrum of student involvement in an open light inquiry process

Stages of inquiry planning	**Level of student involvement**		
	Low	Medium	High
Finding an interesting phenomenon	1	3	2
Constructing Question 1	1	3	2
Constructing Question 2	1	3	2
Organizing manipulation of the independent variable	1	3	2
Finding a technique to examine the dependent variable	1	3	2
Establishment reliable organization of the experiment plan (repetition, control)	1	3	2
Finding a theoretical background	1	3	2
Improving the experiment plan in light of results from a preliminary experiment	1	3	2

Table 1 presents a spectrum of student involvement in an open light inquiry process. The table lists eight categories. A teacher facilitating a student engaging in full open inquiry would grade the process as 8*3=24. A teacher facilitating a student engaging in the lowest level of open light inquiry would grade the process as 1. All intermediate levels are considered light inquiry levels.

The fourth component of the program consists of encouraging ‘metacognitive awareness.’ Research indicates that students, who are meta-cognitively aware, are more strategically oriented and perform better than those who are less meta-cognitively aware (e.g. Garner & Alexander, 1989). Metacognitive awareness, thus, tends to make students more systematic in their thinking, and helps them identify errors before they proceed too far in the wrong direction of the inquiry process (Keselman, 2003). The more accurately students can describe their own thinking, the more effective they are able to self-regulate their learning during the inquiry learning process, and become expert inquiry performers (Loh et al., 2001). In addition, the teachers train their students to reflect upon their learning, while introducing the Regulation of Cognition (RC) - Questionnaire to the students. Following Schraw and Dennison (1994), the questionnaire refers to five categories: planning, process managing, monitoring, debugging, and evaluating. The teachers administer the RC-Questionnaire at the end of each learning stage, and students have to reflect and regulate their learning in writing on the tasks that they completed.

Peer learning is the fifth component of the program. Regardless of inquiry level, it is advisable to enable students to conduct their inquiry assignments in small peer groups. Extensive research has shown that collaborative learning has the potential to develop both inquiry skills (e.g., Crawford, Krajcik, & Marx, 1999; Hofstein, Shore, & Kipnis, 2004; Wu & Hsieh, 2006; Zion et al., 2004a; 2004b). Students can learn from each other, exchange expertise and ideas, and build collective knowledge.

'Content knowledge' is the sixth and final component of the program. An inquiry learning process should emphasize a connection to scientific content (Furtak & Alonzo, 2010), which enables students to internalize the scientific thinking process and experience the practical aspects of this process. This content is emphasized throughout all of the program's components. In the program's *structured part*, the structured inquiry assignments are based on content germinal to the curriculum. Teachers can combine these assignments into their yearly course structure, diversifying their teaching process and enriching the knowledge and understanding of their students. The *guided part* of the program emphasizes ecology and physics contents which are also part of the curriculum. The *open part* of the program emphasizes various science contents throughout the entire inquiry process. The inquiry questions must be based on scientific knowledge – otherwise there would be no basis for hypotheses. Working methods must also be based on scientific knowledge, or they would not be valid. Students who write the discussion section of their inquiry project are required to refer to fundamental principles such as such as evolution, homeostasis, and the conservation of matter and energy.

Action research

The action research made it possible to gather evidence in a controlled and systematic fashion regarding the inquiry teaching process. The action research applied the model of practical-cooperative action research (Elliott, 1997). In this inquiry-based model, collection and analysis of data is performed cooperatively among classroom teachers and university-based academic staff. The teachers participated in the process of planning the research and determining the research goals, conducting the research, and examining the ways in which significant curriculum changes could be implemented (Elliot, 1997).

For example, the inquiry-based teaching program (Biomind) action research characterized the open inquiry as a dynamic inquiry learning process. In open inquiry, learning is a process of continuous and renewed thinking that involves flexibility, judgment, and contemplation, in response to changes that occur in the course of the inquiry process (Zion et al., 2004b). Zion et al. (2004b) found that the main criteria for characterizing dynamic inquiry are: learning as a process, changes occurring during the inquiry process, procedural understanding, and affective points of view such as curiosity, frustration, surprise, perseverance, and having to cope with unexpected results. Characterizing the dynamic inquiry process in the Biomind program has resulted in adding emphases in curriculum guidelines leading students and teachers to experience inquiry with perspectives of critical thinking and change, reflective thinking about the process and affective aspects, such as curiosity, that are expressed in situations of change and uncertainty (Zion et al., 2004b). In addition to the action research contributing to characterizing the inquiry process and improving the Biomind program, it has enhanced participating teachers' understanding of the inquiry process.

Implementation

Guidelines

Following the first years of the inquiry-based program, its official rationale and guidelines were published. The guidelines include student requirements, teacher requirements, schedule, detailed guidelines matching specific inquiry skills for internal and external evaluation, metacognitive guidance questionnaire, appropriate methods of reporting inquiry outcome in one of three versions depending on inquiry level applied (structured guided, open). The teachers' position is flexible: they are allowed to consider which degree of open inquiry to apply, taking into account the scientific content knowledge of the inquiry assignments.

Workshops

Although the spirit and requirements of the program are widely circulated by various documents among biology teachers, teachers' workshops are important for the implementation of the program. To facilitate this aim, two types of workshops have been established. The first type of workshop introduces the program to new teachers. The second type of workshop is designed for veteran teachers. The workshop organizers who lead both workshops, take part in developing the program, and are henceforth referred to as program leaders.

Introductory workshop

The Introductory workshop is intended for teachers new to the program. The workshop takes one or two years. In this workshop, the teachers learn the principles of inquiry teaching and the principles of the new program. The workshop also provides scientific and pedagogical support to assist teachers in facilitating their students' inquiry processes in the laboratory and in the field, and through portfolio construction. Teachers are asked to identify a thought provoking scientific phenomenon, and write a proposal for open inquiry about this phenomenon, similar to the tasks required of their students. Teachers gain practical experience in performing open inquiry in this workshop.

Advanced workshops for veteran teachers

The advanced workshops for veteran teachers are intended for teachers familiar with the program. Most of the work performed in these workshops is collaborative peer review of students' inquiry proposals, examining the scientific basis of inquiry questions and the logical relations hips among them, as well as experimental procedures and their relevance to the proposed inquiry. Participating teachers share scientific and procedural ideas. Involving teachers in such pedagogical support groups is beneficial for several reasons: these groups help teachers in understanding the essence of the inquiry teaching process and provide them with on-going scientific and pedagogical support regarding their students' inquiry projects.

Program leaders

The program leaders are teachers, who guide the different teachers' groups of the program, and who meet several times a year. The National Supervisor of Biology Teaching participates in these meetings. Problems common to all groups were discussed in those meetings. The group of program leaders is actually the administrative body in charge of the program. The leaders monitor what occur in class and decide on appropriate program modifications, as needed. Besides face-to-face meetings, program leaders use a networked discussion group to consult one another on different aspects of program implementation.

Support

Advanced workshops for veteran teachers

Based on the view that a teacher's professional development is an on-going process that occurs throughout their career, especially when faced with a complex constructivist task (Darling-Hammond, 1998; Putnam & Borko, 2000), we find it immensely important that teachers who teach inquiry based methods participate in workshops. These workshops are an important channel for program leaders to convey requirements and guidelines by way of direct experience (See Implementation section). The workshops are also important in the continuous support they offer: teachers share (with peers, with program leaders, with policy makers) the challenges as they encounter them in the field. The workshops also provide teachers with feedback, ideas and morale.

Asynchronous online forums

The implementation of the inquiry-based program is facilitated by an open teachers' forum. This forum is a stage for teachers to consult with colleagues and with the national supervisor on issues regarding the program. For example, it was found that in the teachers' forum, teachers required assistance mainly with technical and procedural aspects of experimentation, bureaucracy, and phenomenon identification in nature (Zion, 2008). In addition, the forum participants raised the following issues: logical progression of the inquiry process, scientific writing, teacher-student interaction, reflective thinking, affective points of view, and administration. Using the forums, teachers from all over the country can ask for each other's advice without having to meet face-to-face. Forum communication is independent of time and place, making support for teachers much more efficient. As this channel of communication is open to all, teachers can benefit from being exposed to ideas that come up in their colleagues' discussions. They may realize, by reading forum messages, that other teachers face similar issues. The forums require neither the full exposure of face-to-face interaction, nor name identification. The forums help to create an open discussion free of prejudice.

Conferences

Conferences are an excellent way for teachers to exchange ideas and opinions. The advantage of a conference over the forum is that a conference brings together all professionals involved in one time and place for a concentrated effort to share insights and information with the inquiry teaching community. The conferences are a good platform for holding lectures and workshops presenting ideas, inquiry projects, guideline pamphlets, and resource databases. Guest scientists who speak at the conferences can enrich teachers' scientific knowledge and give ideas for observations and controlled experiments. Teachers hold workshops and present inquiry processes that occurred in their classes, and students' learning products such as inquiry reports and reflections. Conferences also enable participants to raise concerns and difficulties and suggest solutions. A panel of educators may discuss common difficulties, which were raised in the conferences.

An open, renewable, dynamic database

Teaching inquiry is a complex challenge, and teachers should have a support structure minimizing their uncertainty and supporting their work effort. Different teaching modules have been developed over the years that can be used as a basis for teaching inquiry. These accumulated ideas can be collected to form a resource database. The database would include ideas of scientific knowledge and content: professional scientific papers, digests of professional scientific publications, and popular press articles. The database would also

include references to literature and other databases, and ideas for field and lab experiments. This collection of experiments would serve as a source of reference for techniques and procedures applicable in teaching inquiry. Ideas for inquiry questions and different approaches for their investigation would also be available on the database.
The database can support the different levels of inquiry in different ways: for structured inquiry teaching, the database would offer structured worksheets for the student, with matching assessing sheets for the teacher. For guided inquiry teaching, the database would hold a collection of inquiry questions and techniques. Assuming the guided inquiry would be performed in the field, as suggested here, the inquiry questions will to refer to the dynamics of the changing environment, bringing an element of uncertainty into the results to be obtained.
Such a database is also important for open inquiry teaching due to the high level of uncertainty in this model. Useful database components in these cases would be: ideas for intriguing phenomena, ideas for independent and dependent variables, techniques and methods for measurement. To be useful for open inquiry, the database must also contain advice on how to overcome technical difficulties with experiments and how to plan an experiment producing results of a higher reliability. The database can feature a variety of ideas and technique that are flexible enough to be manipulated and adjusted for a variety of different inquiry plans. The database should also be open to additions by teachers and students, and should contain ideas considering the physical and technical conditions of the school laboratories.

A national centre for supporting inquiry

The Center for Support and Development of School Laboratories supports school pedagogical teams in all practical aspects of the curriculum in the lab as well as in the field. The center supports all levels of the inquiry spectrum, from structured to open; it posts chemical and living material, and provides technical and scientific assistance. The Center develops teaching materials and develops the national laboratory matriculation exams. It also hosts long term professional development programs for pre-service and in-service teachers, and lab technicians. Pre-service teachers are involved in planning and executing a year-long inquiry project focused on scientific core principles, as part of their professional training. The existence of the Center provides teachers with on-going expert assistance, whenever needed, compared with the conference and forum feedback, which is not always available and not always scientifically reliable.

Control

The control component of the curriculum is designed mainly to ensure that the program guidelines and rationale are applied in the field as program designers intended. In addition, the control component can identify program elements of the curriculum that require change. By its very essence, the control keeps the program on its toes, ensuring its vitality.

Program leaders' activities

Program leaders play an important part in real-time control accompanying the teaching process. These teachers serve as facilitators in the novice and veteran teacher workshops. The program leaders are actually a bridge between the central control at the Ministry of Education and teachers in the classroom. The workshops comprised a support infrastructure for teachers, but also acted as an apparatus for controlling curriculum rationale and standardization, which is necessary for the proper implementation of a curriculum in a national-scale program. The existence of such a control aspect, based on the program leaders, contributed to sustainability, and monitored the capacity of the program. Program leaders monitored the teachers' ability to adopt and adapt to implementing the inquiry processes. Program leaders synthesized teaching and learning which evolved through processes discussed in different program workshops, and extracted valuable lessons from these workshops that improved the curriculum.

In order to feel empowered to make changes, teachers need opportunities to reflect on their experiences, beliefs and roles without fear of negative judgments or reactions (Westbrook & Rogers, 1996). For instance, the program leaders play a key role in control of the open inquiry process. In order to conduct open inquiry, the program leaders examine the inquiry subjects, the inquiry questions, and the plans drawn by every student of every teacher under their responsibility. This quality control of helps ensure that implementation actually matches the program's spirit and guidelines.

The fact that teachers are at the forefront of change while officials and academics of science education are in the background, giving the floor for the program leaders, probably enable control, professional development, and openness, and further development of the innovation.

Table 2. Difficulties in teaching and potential solution

Difficulty	Solution
Constructing a focused inquiry question.	Providing teachers with personal feedback.
Proposing a full, reliable inquiry plan.	Topic to be explored with in teacher workshops. Teachers should personally experience inquiry project.
Proposing adequate control in the inquiry. plan	Working with teachers to explain what is a good proposal.
Staging a preliminary experiment.	Topic to be explored in teacher workshops. Teachers should personally experience an inquiry project.
Instructing students in inquiry, especially with unfamiliar topics.	Developing database with examples, and on-line forums to get support through.
Distinguishing results from conclusions.	Topic to be explored in continued education programs for teachers. Teachers should personally experience an inquiry project.
Experiencing difficulty in supporting the student with constructive comments.	Explaining the importance of these comments during teacher workshops.
Defining "a good inquiry" so that students can understand the topic.	Topic to be explored in teachers' continued education programs. These programs will feature presentation of exemplary student projects.
Conducting a student evaluation.	Defining precise guidelines with a detailed index of performances.
Sharing and discussing with other teachers. Maintaining on-going contact with a group of teachers.	Organizing on-line forums and workshops.
Maintaining cooperation with lab technicians.	Providing continued education programs for lab technicians; improving their professional status. Explaining the importance of this cooperation, demonstrated by workshop examples.

Control of the students' learning product

At the end of the Students' learning process, the students submit a portfolio consists of several learning products such as: structured, guided and open inquiry reports, and reflections. Supervisors at the Israel Ministry of Education randomly sample inquiry products for examination with the program's leaders' participation. This complementation enables control over several aspects: teaching quality; constant examination of the relevance of guidelines in light of students' academic abilities; locating the difficulties experienced by students and the difficulties experienced by teachers, and understanding the support mechanisms that teachers require. The control is used to provide teachers with feedback about their work, to reinforce their strengths and work out their weakness points, and to improve the quality of their work. Table 2 presents issues in the control process that have come up in the past 12 years. The table shows difficulties encountered in teaching as they appeared in the examination of products, as well as in attempts to overcome these difficulties.

Discussion

We introduce a model for implementing an inquiry-based curriculum. The model consists of several elements which have enabled students to move from structured to open inquiry. The model is based on students' gradual experience through different levels of inquiry, on cooperation among teachers Ministry of Education staff, and science educators involved in developing, implementing, and monitoring the program.

Teaching inquiry has been a persistent challenge in the field of education for decades. The components (development, implementation, support, and control) at the heart of the model presented here are based on numerous projects and researches from the literature. We have been combining these components systematically over several years. Besides these elements, we would also like to highlight some issues that arose in the model presentation, insights that have proved, in our experience in Israel, immensely important in leading inquiry teaching from the structured to the future open level.

1. The teacher is a key figure in implementing inquiry processes from the structured to the open inquiry level. It is therefore imperative that teachers participate in all components of the model: development, implementation, support, monitoring and evaluation. As teachers participate in the inquiry teaching program, they also develop professionally. A feedback loop is created: teachers' teaching activity encourages their on-going professional development, and this development, combined with the fact that they play a key role in the inquiry program, improves the program on all levels. Then, the program's improvement again encourages teachers' professional development – bringing about further improvement of the program.

2. Massive and systematic support of teachers – A teacher's ability and confidence in leading an inquiry process is the critical element in successful implementation of an inquiry program. Massive systematic multi-faced support is crucial to the success of the program. The model we describe offers varied forms of support: workshops, program leaders, colleagues' feedback, forums, conferences, a digital database, and a national centre for scientific and technical support.

3. Program leaders are key figures in the program.

Parker (1997) explained that leaders should play an important role in educational reforms, especially those reforms that "are long-term, involve many unanticipated surprises, and can often be messy, uncomfortable, and frustrating" (p. 244). As uncomfortable and frustrating events may be part of an inquiry process, especially the open inquiry, the necessity for leaders who drive the implementation vehicle is crucial. These leaders should have a vision that an inquiry teaching process is a dynamic and exciting search for the understanding of patterns.

4. Open light inquiry – We have termed 'open light inquiry' to describe a wide spectrum of levels. Open light inquiry can be used to introduce an open inquiry element to the curriculum.

Open light inquiry can decrease the limitations and difficulties of open inquiry, enabling the teacher to navigate the open inquiry teaching according to the student's level, the technical possibilities available, and the teacher's own pedagogical content ability. Open light inquiry also enables a student to experience inquiry planning and decision making, and feel that they are full partners to the process. The partnership is, we believe, critical in preparing the student to handle the degree of uncertainty defining life in the 21st century. Open light inquiry can be a viable solution for education systems that are not fully implemented, avoiding the open inquiry approach, although they may have been systematically mandated to incorporate open inquiry into their curriculum.

5. Database –Databases for teachers to draw activities and worksheets have been developed in different frameworks. In order to direct an inquiry process toward open inquiry, databases should be organized to point at this basic idea, with examples of possible paths leading to open inquiry. The database should also enable the adoption of different elements from different ideas to form a new combination serving an open inquiry process. The flexible use of the database provides teachers with support and an opportunity for open creative thinking.

6. Monitoring and evaluation alongside dynamic on-going renewal – Monitoring and evaluation as part of the overall program infrastructure helps ensure its reliability and maintains adequacy between its goals, rationale, and implementation. Monitoring and evaluation also enable a strong link between formal state-level control and the teachers and professionals running the program. This official aspect of monitoring and evaluation enables lessons to be learned, guidelines and teaching processes to be altered; thereby, keeping the program fresh and dynamic.

Looking Ahead

In this constructivist age, there is no question that learning by inquiry is a vital step in developing a scientifically literate, critically, logically and creatively thinking citizen. There is also no question about the advantages of experiencing an inquiry process in a protected environment such as the school, as preparation for a modern way of life with its many aspects of dynamism, entrepreneurship, teamwork, and metacognitive thinking. Critical and logical thinking plays an important role in an inquiry process. On the lower levels of inquiry, logical thinking focuses on the linear and logical transition between the inquiry question, hypotheses, the inquiry plan and conclusions. On higher levels of inquiry, logical thinking is of even greater importance, in light of the inquiry process being open to much more uncertainty. In these levels, logical thinking can be expressed in drawing the connections between the inquiry questions comprising a certain inquiry project, in matching the inquiry questions with the inquiry plan, and throughout the entire process of setting up an experiment system.

This defines our future challenge: improving inquiry teaching to emphasize these elements and the gradual experience through all levels of inquiry. Improvements to inquiry learning would benefit from improvements to inquiry teaching. Improvements to inquiry teaching would benefit from the existence of an on-going running, long-term support structure at the teachers' disposal. Catalysts should be maintained to introduce waves through the program once in a while, keeping the creative spirit alive. Such catalysts can include: challenging competitions, conferences for students of different schools presenting their learning products, updates to the curricular requirements based on feedback from the teaching front as well as new inquiry conclusions, teacher conferences, and meetings with colleagues from across the globe. The challenge must remain dynamic – a challenge that never rests.

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