The Future of Biology Education Research

Research in Biology Education

A selection of papers presented at the 10th Conference of European Researchers in Didactics of Biology (ERIDOB)
June 30th - July 4th, 2014
Technion, Haifa, Israel

Organized by:
The Technion, Israel Institute of Technology and **The Weizmann Institute of Science**

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Layout: **Zipi Ovadia**
Cover: **Ziv Ariely**
First published in 2016

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Preface

This volume consists of papers presented at the 10th Conference of European Researchers in Didactics of Biology (ERIDOB) held in June 2014 at The Technion, Israel Institute of Technology, in Haifa, Israel. The theme of the conference was The Future of Biology Education Research that was reflected in a special symposium during the conference, which is elaborated in this volume. The first part of the volume consists of individual papers that were presented in the conference. The second part is the summary of the special symposium.

Before and during the symposium, a few issues emerged, which are summarized in a collection of short papers, written by scholars from various countries in Europe, which appear in the second part of this volume. In those papers, the authors addressed research in biology education from different perspectives and contexts. These summaries of the symposium blend wonderfully with the collection of papers that are presented in the first part of this volume. These papers focus on perspectives of evolution, teaching genetics in real contexts, scientific reasoning, teaching outdoor inquiry, environmental behavior change, model-based learning, student questioning and critiquing while learning biotechnology, sustainability in higher education and scientific inquiry. Taken together, this volume represents the richness of current research in biology education.

All the papers presented at the conference have been double reviewed by scholars from the ERIDOB community. The 10 papers presented in this volume address topics in the areas of student conceptions, reasoning and thinking skills, attitudes, teacher professional development and environmental education.

The family atmosphere of an ERIDOB conference offers possibilities of recognizing and exploring European research cultures with the intention of building a strong and internationally coherent research community.

Tali Tal

Anat Yarden

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1 CAN THE IDEA OF 'BALANCE OF NATURE' BE EFFECTIVELY CHALLENGED WITHIN A MODEL-BASED LEARNING ENVIRONMENT? INSIGHTS FROM THE SECOND CYCLE OF DEVELOPMENTAL RESEARCH

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Abstract

This paper reports on the second cycle of developmental research aimed at designing a learning environment that can support non-biology-major students in (a) challenging the idea of 'the balance of nature' and constructing an up-to-date understanding of ecosystem function, and (b) using this understanding to enhance context-free ideas that underlie systems thinking. Here, we focus on whether and how students' reasoning about ecosystems' responses to disturbance or protection has been altered after their engagement with the second version of our learning environment, and whether the problems identified in implementing the first version of it were effectively dealt with. Considering social constructivism and a problem-posing approach, we developed a CSCL environment to highlight ecosystems' contingent behavior through the idea of 'resilience of nature'. Thirty-four first-year students were introduced to the assumptions of the idea of 'resilient nature' in five 2-hour sessions, by exploring our NetLogo models of protected or disturbed ecosystems with the aid of worksheets. The analysis of students' responses to certain items of the pre/post-questionnaire shows that the idea of unpredictability as a substantial feature of ecosystems was reached by most students, while the problems identified in the first version of our learning environment were handled rather successfully.

Keywords

Model-based learning; collaborative learning; teaching about ecosystems; ecological reasoning; teaching about nature's resilience

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

Research on the ways in which students reason about ecosystems and in particular, ecosystem responses to human-driven disturbance or protection, has revealed a widespread belief in the 'balance of nature' (Zimmerman & Cuddington, 2007). The idea of 'balanced nature' is a long-held, popular assumption about the natural world, which implies a predetermined order and stability, assured by the will of a divine power or nature itself (Cooper, 2001; Cuddington, 2001; Kricher, 2009). This view has been criticized quite strongly as not being representative of natural systems (Cooper, 2001; Cuddington, 2001; Kricher, 2009), but it seems to dominate public perception (Ladle & Gillson, 2008), school science (Jelinski, 2005; Korfiatis, Stamou, & Paraskevopoulos, 2004; Westra, 2008), and students' reasoning about ecosystems' responses to human-driven disturbance or protection (Ergazaki & Ampatzidis, 2012).

It is worth noting that a belief in the 'balance of nature' may hinder environmental awareness. Believing the 'initial-state recovery' assumption of the outdated cybernetic view of ecosystems may lead to an underestimation of the consequences of disturbances to them (Westra, 2008). Moreover, such a belief seems to hinder conceptual understanding as well. It obviously opposes the current idea of 'nature's resilience', which (a) favors contingency over purpose and order, (b) suggests that ecosystems function in multiple alternative states which are self-organized through feedback, (c) assumes that ecosystems shift between these states in abrupt-and not necessarily reversible-ways (Gunderson & Holling, 2002; Holling, 1973; Scheffer, 2009), and (d) seems to offer a promising context for fostering systems thinking skills, which are considered crucial for all aspects of life (Boersma, Waarlo, & Klaassen, 2011).

Thus, our study addresses the question of whether it is feasible to design a learning environment that can support non-biology-major students in (a) challenging the idea of the 'balance of nature' and constructing a meaningful, up-to-date understanding of ecosystems' functions, and (b) using this understanding to enhance context-free ideas, such as interdependent and circular causality, which underlie systems thinking. In this paper, we are particularly concerned with identifying (a) whether and how students' reasoning about ecosystems' responses to human-driven disturbance or protection has been altered within the second version of our learning environment, and (b) whether the modifications we made to the first version of this learning environment, such as introducing the use of 'two-version models', were effective. Therefore, the questions here are:

(a) What kind of predictions do students make about the future of disturbed or protected ecosystems and how do they justify them before and after their participation in the second version of our learning environment?
(b) Are the problems identified in implementing the first version of the learning environment, such as overestimation of the power of balancing loops, effectively dealt with in the second version?

2. Methods

2.1 Study overview

In this developmental research study (Akker, Gravenmeijer, McKenney, & Nieveen, 2006), we drew upon social constructivism (Vygotksy, 1978) and a problem-posing approach (Klaasen, 1995) to design a computer-supported, collaborative learning environment that aims to support non-biology majors in challenging the idea of the 'balance of nature' and replacing it with the idea of 'resilience of nature'. We also developed a pre/post-questionnaire with open-ended items, followed by short interviews when needed, to collect data about the effectiveness of our learning environment. Finally, we analyzed students' responses using the qualitative analysis software NVivo and tested for the statistical significance of their progress using the quantitative analysis software SPSS.

2.2 The participants

The second cycle of the research, upon which we report here, was carried out with some of the 160 first-year students of educational sciences at the University of Patras (aged 18–19 years), who were enrolled in an optional ecology course offered by the second author. More specifically, those students who attended the course classes on a regular basis were asked to consider the possibility of taking part in the study, after they had been (a) thoroughly informed of its goals and time schedule, and (b) reassured that they could pull out at any time for any reason. Thirty-four students volunteered to participate. They (a) had basic ecological knowledge from a university entrance course, (b) were familiar with computers and group work, and (c) were rather active in terms of raising and answering questions in the course's regular classes, thus showing interest in its content.

2.3 The learning environment

The learning environment aims to highlight the contingent behavior of ecosystems through the basic assumptions of the idea of 'resilient nature'. More explicitly, the learning objectives (LOs) have to do with understanding these assumptions (LO1–LO4), and with using them to (a) challenge the notion of balance as an inherent feature of nature and (b) move to the notion of contingency (LO-contingency).

More specifically, the LOs consisted of:

- LO1: Ecosystems may have multiple alternative states.
- LO2: Each state is self-organized through feedback which changes abruptly at tipping points.
- LO3: Shifts between alternative states may be irreversible or reversible based on initial conditions or handlings.
- LO4: Reversing the factor that caused the shift does not necessarily return the ecosystem to its prior state.
- LO-contingency: Natural systems show contingent-and not predetermined-behavior ('resilient nature' vs. 'balanced nature').

Students were introduced to the assumptions of the target idea in five 2-hour sessions of an optional ecology course. The four models that we developed using the NetLogo software (Wilensky, 1999) to pursue the LOs were based on the findings of current ecological research, and they simulated terrestrial or aquatic ecosystems faced with internally or externally triggered changes (NetLogo models-NMs). The models' interface included three elements: (a) a series of boxes depicting population size (i.e. the number of individuals), as well as the level of certain abiotic factors (e.g. nutrients) where called for, (b) a 'simulation window' depicting the individuals of the different populations in different shapes and colors, giving the students a relatively concrete visual representation of what happens in the ecosystem with time, and (c) a 'graph window' depicting the changes in population size and the levels of certain abiotic factors with time, providing the students with a graphical representation of the trajectory of the ecosystem that they are actually required to explore (see Figure 1 from left to right).

The results from the first research cycle, in which we implemented the first version of our learning environment, seemed to underline a rather problematic effect of some models on students' understanding. The model 'NM1-Forest', which simulates a protected forest that undergoes internally triggered changes, may have overemphasized the possibility of recovery to the initial state, while 'NM2-Lake' and 'NM3-Lake', which simulated a lake that undergoes a human-driven disturbance, may have overemphasized the possibility of not recovering to the initial state or facing significant difficulties in doing so (Ampatzidis & Ergazaki, 2014).

Taking this feedback into account, we came up with the 'two-version model' idea: this time, each model had two different versions showing two different trajectories of the ecosystem, depending on its initial conditions or on certain human actions in the recovery plan. Students collaborated in groups of three, and half of the triads explored one version while the other half explored the other version. The two different trajectories simulated by each model were discussed with the whole class at the end of the sessions.

More specifically:

- Session 1 – NM1-Forest: the model simulated the maturation of a tree species in a forest (Gunderson, Allen, & Holling, 2010) that was inhabited by two plant species (spruces and bushes) and three animal species (budworms, rabbits and passerines). In one version, the ecosystem's state did not shift, whereas in the other version, the bushes and rabbits died out. The focus here was on LO1, LO2 and LO-contingency.
- Session 2 – NM2-Lake: the model simulated an inflow of nutrients into a lake (Scheffer, 2009) that was inhabited by phytoplankton, zooplankton, one species of sea plant and two species of fish. In one version, the ecosystem's state did not shift, whereas in the other version, all populations died out apart from the phytoplankton. The focus here was on LO1–LO4 and LO-contingency.

- Session 3 – NM3-Lake: the model (Figure 1) simulated an inflow of nutrients into a lake, their subsequent removal, and the performance of other corrective actions to restore the lake (Scheffer, 2009). The lake was inhabited by two plant species and two fish species. In one version, the ecosystem shifted back to its original state, whereas in the other version, this was not possible. The focus here was on LO1–LO4 and LO-contingency.
- Session 4 – NM4-Meadow: the model simulated the removal and subsequent reintroduction of an animal species (spiders) from a meadow (Schmitz, 2010). The meadow was inhabited by two plant species and three animal species (grasshoppers, spiders and bugs). In one version, the ecosystem shifted back to its original state, whereas in the other version, this was not possible. The focus here was on LO1–LO4 and LO-contingency.

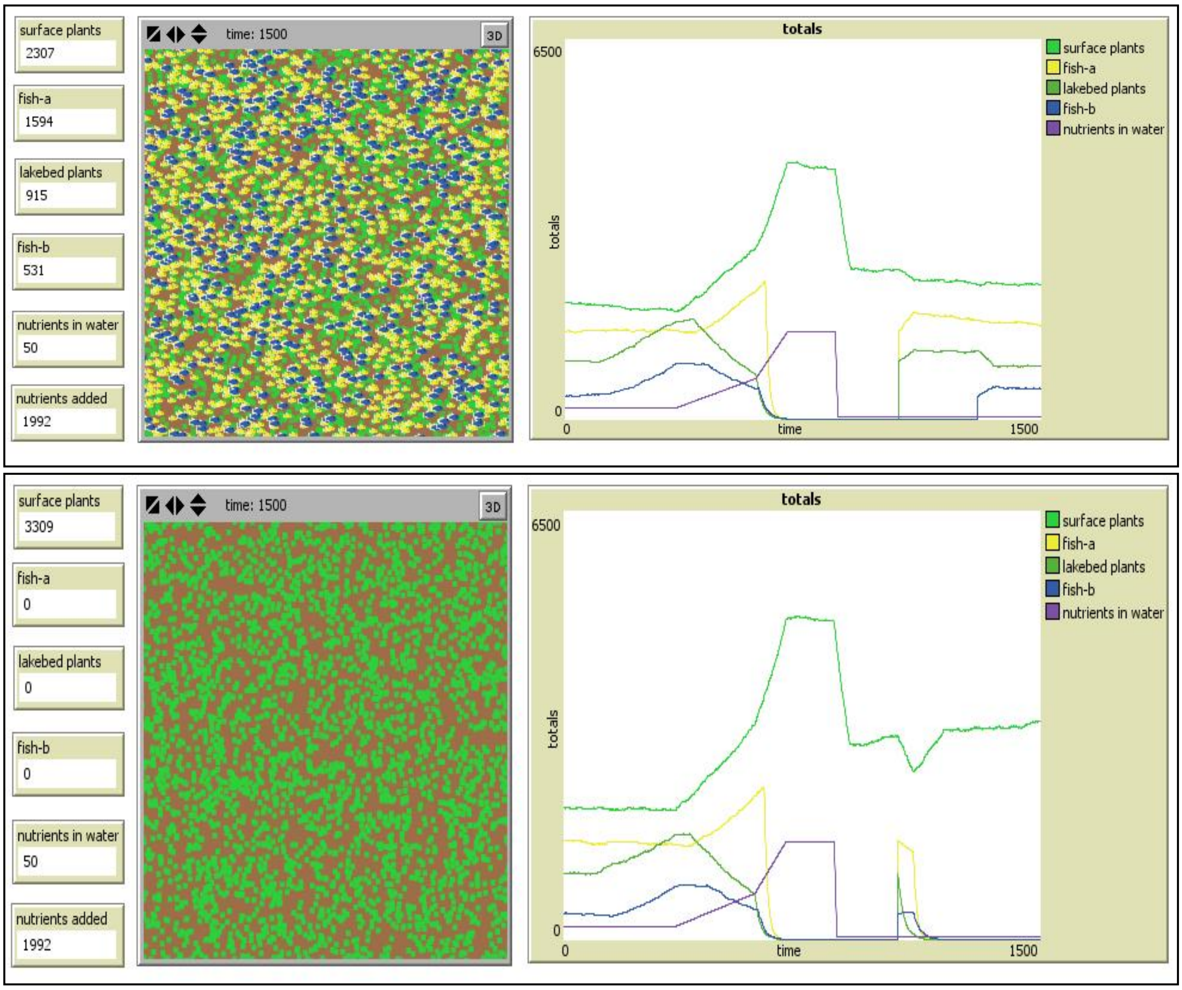

Figure 1. The two-version NM3-Lake model: inflow of nutrients, subsequent removal and additional corrective actions (version 1 at the top, version 2 at the bottom).

Finally, in the fifth session, students were engaged in reasoning about ecosystems' behavior through 'landscape models' made from plasticine cardboard and hands-on activities concerning systems thinking.

2.4 The pre/post-questionnaire

Students were administered a pre/post-questionnaire after it was explained to them that this was not an exam but an opportunity to give us valuable insight into their own understanding of nature. Its first part included five open-ended items on the behavior of protected or disturbed ecosystems. The pre/post items were equivalent and all of them-except for item 2-aimed to probe specific target assumptions as justifications for the contingency ($_{\text{J-contingency}}$) of the ecosystems' behavior (see LO1–4$_{\text{J-contingency}}$).

More specifically:

- Item 1 – 'protected ecosystem': students were asked to reason about the future of a terrestrial/aquatic national park under human protection. The focus here was on LO1$_{\text{J-contingency}}$.
- Item 2 – 'feedback': students were asked to explain the control of population size in a lake/swamp through feedback-mediated self-organization, and the loss of population control through feedback change at a tipping point. The focus here was on LO2.
- Item 3 –'disturbed ecosystem–biotic change': students were asked to reason about the future of a lake/forest where a new population was first added and then removed by humans. The focus here was on LO3–4$_{\text{J-contingency}}$.
- Item 4 – 'disturbed ecosystem–abiotic change': students were asked to reason about the future of a lake where the nutrients in the water or salinity of the water were (a) increased due to human activity, which led to the extinction of an animal species, or (b) restored to their initial value, followed by reintroduction of the extinct species. The focus here was on LO3–4$_{\text{J-contingency}}$.
- Item 5 – 'schemes': students were asked to choose among schemes representing ecosystems that were faced with a disturbance (Gunderson et al., 2010) and explain their choice. The focus here was on LO1–4$_{\text{J-contingency}}$.

The questionnaire was first administered to non-participating students with a 'think-aloud' protocol and elaborated accordingly. Finally, the first author read all of the responses as soon as the students had completed the questionnaire and carried out short interviews with those whose responses needed clarification. In this report, we are only concerned with items 1 and 4.

2.5 The analytical procedure

Students' responses to the pre/post-questionnaires and relevant notes from the interviews, where applicable, were transcribed and coded within NVivo, one of the most widely used softwares for the analysis of qualitative data (Gibbs, 2005). What we actually did was to create a series of data-driven categories by reading students' responses to each task and coding their predictions as well as their justifications. In other words, our coding scheme was derived through 'open coding' (Gibbs, 2005) and it was divided into two parts: (a) students' 'predictions' about the future of the ecosystem in question (e.g. 'full recovery', 'possible full recovery', 'same picture'), and (b) students' 'justifications' for what they had predicted (e.g. 'unpredictable factors', 'possible side effects', 'possible differences in handlings'). The coding was performed by both authors with satisfactory agreement: Cohen's Kappa with regard to items 1 and 4 was estimated at 0.88.

Moreover, to test students' progress and its statistical significance, we developed a scoring grid for their responses to each item of the questionnaire (Table 1). The score of each response was the sum of two sub-scores: one for the prediction about the future of the ecosystem in question and another for the justification provided for that prediction. More specifically, the prediction of an 'unpredictable picture' was assigned the highest score, while the predictions of 'same picture'/'different picture' and 'full recovery'/'no recovery' were scored lowest. Similarly, each justification was assigned a score depending on the level of understanding that it showed (Table 1). It should be noted that the scoring grid was developed so that predictions contributed more than justifications to the total score. Thus, satisfactory predictions with non-satisfactory justifications got a higher score than non-satisfactory predictions with satisfactory justifications. Finally, responses with no predictions were not scored at all and responses with unjustified predictions were scored according to the prediction only.

Table 1. The scoring grid.

Items	Predictions	Prediction score	Justifications	Justification score	Total score
Item 1	Unpredictable/contingent picture	3	Possible tipping point reached	0.5	3.5
			Possible feedback change	0.5	3.5
			Unpredictable factors	0.25	3.25
	Possible different picture	2	Possible changes in population sizes	0.5	2.5
			Possible changes in environmental factors	0.5	2.5
	Same picture	1	Self-regulated populations if not disturbed by humans	0.5	1.5
	Different picture	1	Changes in population sizes	0.5	1.5
			Changes in environmental factors	0.5	1.5
Item 4	Unpredictable/contingent picture	3	Possible tipping point reached/feedback change	0.75	3.75
			Possible tipping point reached	0.5	3.5
			Feedback	0.5	3.5
			Possible differences in recovery handlings	0.5	3.5
			Possible side effects	0.5	3.5
	Possible full recovery	2	Possible recovery process	0.25	2.25
	Full recovery	1	Recovery process	0.25	1.25
	No recovery	1	Changes in populations' relationships	0.5	1.5

3. Findings

Regarding students' reasoning about the future of a protected ecosystem such as a terrestrial or aquatic national park (item 1), we note that in the post-test students found the idea that the protected ecosystems remain unchanged less appealing. More specifically, the prediction of 'same picture' based on 'self-regulation of populations in the absence of human disturbance' became less popular in the post-test (Figure 2). In the students' own words:

- *"Since the forest is protected from human and natural disturbances, some years later there will be no change, because the environmental conditions are controlled and ideal for the well-being of the flora and fauna."* (pre-test)

Moreover, the prediction of a 'different picture' due to changes in 'population sizes' or 'environmental factors' became less popular in the post-test as well (Figure 2). In the students' own words:

- *"There will be more animals and plants in this forest some years later since there are people who check and protect their well-being."* (pre-test)
- *"If the environmental conditions change and, for example, extreme high or low temperatures are recorded, in that case plants won't survive and this will also make the animals leave the forest."* (pre-test)

In contrast, the prediction of a 'possibly different' picture because of possible changes in 'population sizes'/'environmental factors' became more frequent in the post-test (Figure 2). In the students' own words:

- *"As we know, there is no human activity in this aquatic park and all of the organisms live undisturbed. However, some years later, the size of each population may change. My conclusion is that, although the ecosystem is protected from human disturbances, it may be stable or it may change."* (post-test)
- *"Since the aquatic park is protected from human disturbances, there won't be any changes, unless there is a change of temperature or weather conditions, which could cause the water level to get lower, and change the number of organisms."* (post-test)

Finally, some students supported unpredictable/contingent behavior for the ecosystem, justified by unpredictable factors, feedback changes or populations reaching a tipping point (Figure 2). In their own words:

- *"We cannot be sure about the state of this aquatic park some years later. That is because the human activity, which is forbidden, is only one of the factors that could make it shift to an alternative state. Other factors, such as competition among different species, access to sunlight, available oxygen, etc., could also influence its state."* (post-test)
- *"Some years later, the ecosystem will either be in the same state, balanced by balancing loops, or it will have shifted to an alternative state if the balancing loops have stopped functioning and new reinforcing loops have been established."* (post-test)
- *"We cannot be sure about how this aquatic park will look like some years later. Even without human disturbance, there is a chance of changes due to natural reasons. However, we cannot be sure whether these changes will reach a tipping point leading to a shift of the state of this aquatic park."* (post-test)

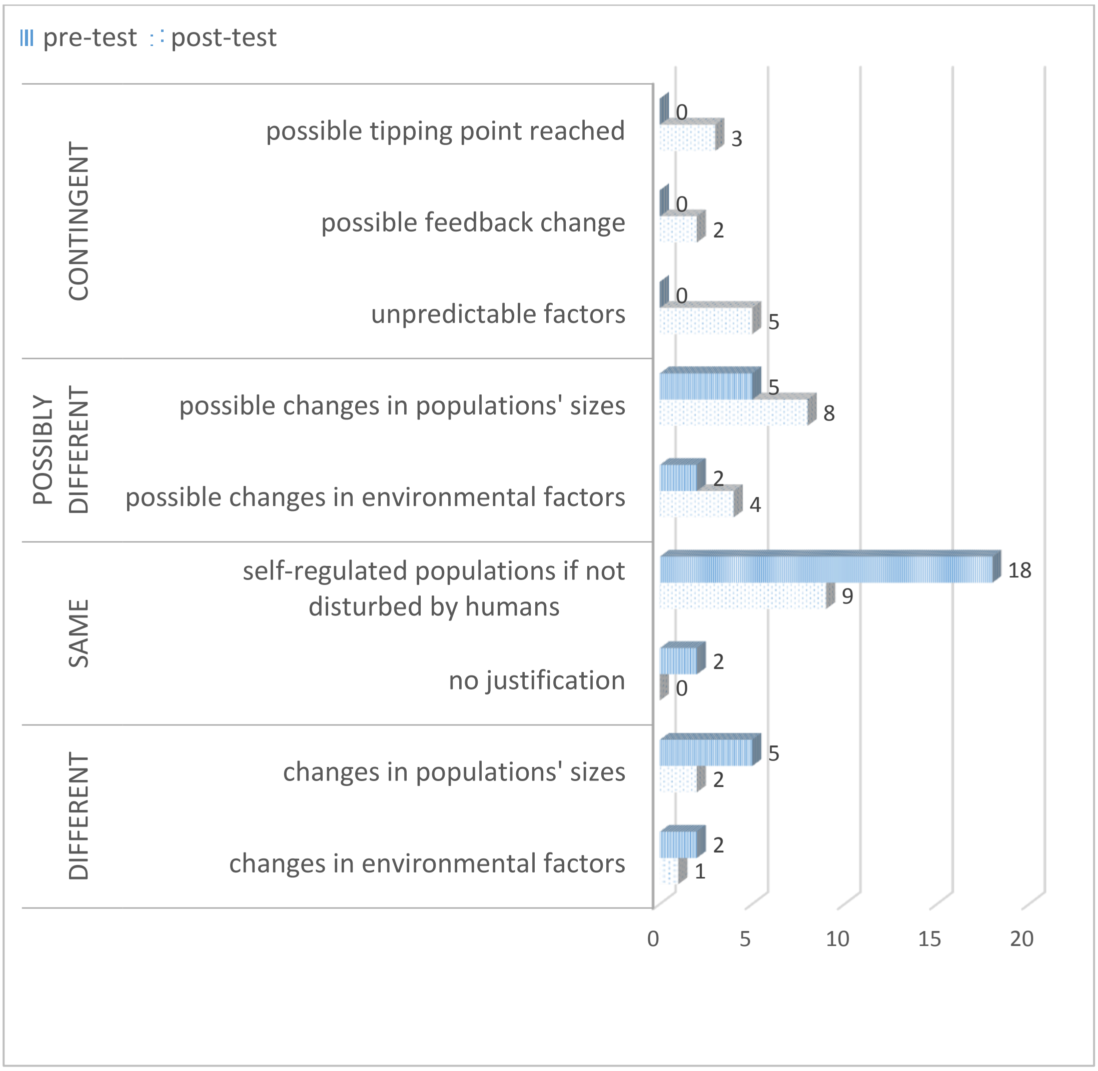

Figure 2. Categories of predictions/justifications pertaining to a protected ecosystem (item 1).

Moving on to students' reasoning about a lake where the nutrients or salinity of the water were increased and subsequently decreased due to human actions (item 4), we note that the prediction of 'full recovery' of the initial state became significantly less frequent in the post-test (Figure 3). In the students' own words:

- *"Zooplankton will feed on phytoplankton. Fish will feed on phytoplankton and sea birds will feed on fish. Thus, the lake will come back to its original condition and the food chain will continue normally."* (pre-test)

Figure 3. Categories of predictions/justifications pertaining to a disturbed ecosystem (item 4).

Moreover, the prediction of 'no recovery' because of 'changes in population sizes' became less popular in the post-test as well (Figure 3). In the students' own words:

- *"The nutrient inflow will cause an increase of the algal population and consequently the balance in the lake will change. When the nutrients of the lake get back to normal, the algae will die out since their now larger population has increased needs for nutrients. Thus, the lake will not recover its original state."* (pre-test)

In contrast, the prediction of a 'possible full recovery', based on a 'possible recovery process' became more frequent in the post-test (Figure 3). In the students' own words:

- *"After the restoration of the salinity of the lake and the reintroduction of the missing fish population, the lake will try to recover, under the function of balancing and reinforcing loops. We cannot be sure that this recovery process will restore the lake to its original state."* (post-test)

Moreover, several students argued that the disturbed ecosystem would have unpredictable/contingent behavior by mostly considering the unpredictable case of a population reaching a tipping point between the disturbance and restoration time (Figure 3). In their own words:

- *"After the restoration of the lake's salinity and the reintroduction of the missing fish population, the lake may recover its original state or not; it depends on whether some population reached a tipping point during the time of the human disturbance which may have shifted the lake's state to a point that does not favor the recovery of the missing fish population."* (post-test)
- *"We cannot be sure whether the lake will show the same picture as at the beginning or not. If during the time we caused the increase of the salinity and the subsequent increase and decrease of populations, some of them reached a tipping point, the lake could shift to an alternative state. On the contrary, if this was not the case, then the restoration of the salinity and the reintroduction of the missing fish population will bring the lake back to its original state."* (post-test)

Finally, a Wilcoxon signed-rank test was performed to determine whether the scores assigned to students' responses in items 1 and 4 according to their level, differed in a statistically significant way between the pre-test and post-test. For both items, the score difference between the pre- and post-test was found to be statistically significant (item 1: $Z = -3.864$, $p < 0.01$; item 4: $Z = -4.294$, $p < 0.01$).

4. Discussion

LO1 served as a justification for the unpredictable/contingent behavior of a protected ecosystem for 10/34 students. Taking into account also those who claimed a 'possible different picture', we may argue that after their exposure to the second version of the learning environment, 22/34 students did recognize a certain degree of unpredictability in the behavior of a fully protected ecosystem. Comparing these results to the ones from the first version of the learning environment (22/34 vs. 9/41), one may claim that our modifications were effective (Ampatzidis & Ergazaki, 2014).

More specifically, it seems that the development of two sub-models for NM1-Forest was effective in supporting students' understanding of the unpredictable behavior of a fully protected ecosystem. During the whole-class discussion at the end of the first session, students had the chance to realize that the trajectory of the forest in their simulations might be contingent on some initial conditions (e.g., the initial size of a plant population). This seems to have helped them move from the idea of a 'never-changing' ecosystem to the idea of unpredictability as an inherent feature of ecosystems.

Furthermore, in an effort to challenge the apparently overestimated power of the balancing loops that was somewhat promoted in the first version of the learning environment (Ampatzidis & Ergazaki, 2014), this time we connected (a) the balancing loops with the *temporal* balance of the ecosystem, and (b) the stopping of the balancing loops and the subsequent initiation and function of the reinforcing ones with the shift of the ecosystem to an alternative state. These modifications aimed to help move from (a) an arguably misleading representation of the balancing loops, and (b) a rather vague idea according to which each stable state is organized through specific balancing and/or reinforcing loops and when these change, the ecosystem may shift to a different stable state, to a more specific and accurate presentation of the role that feedback loops play in ecosystems. As a result, only 9/34 students predicted a 'same picture' of the ecosystem in the post-test with no one drawing on the balancing loops, which was actually the case for almost half of the students in the first cycle of research (Ampatzidis & Ergazaki, 2014).

LO3 and LO4 served as justifications for the contingent behavior of a disturbed ecosystem for most of the students (20/34). Again, it seems that being exposed to the different versions of each model and the whole-class discussions helped students move from the idea of 'always-recovering nature' to that of 'unpredictable nature'.

More specifically, it seems that the development of sub-models for NM2-Lake, NM3-Lake and NM4-Meadow helped students understand the unpredictable behavior of disturbed ecosystems. During the whole-class discussions at the end of the relevant sessions, students had the chance to realize that the trajectories of the simulated ecosystems may be contingent on some initial conditions [for instance, the number of nutrients introduced in a lake (NM-2) or the initial number of plants in a meadow (NM-4)], or to differences in the handlings during the effort to restore the ecosystem (NM-3). Once again, this seems to have helped the students move from the idea of an 'always-recovering' ecosystem to the idea of unpredictability as an inherent feature of ecosystems.

Finally, the introduction of sub-models and whole-class discussions about them in the second version of the learning environment seemed to be effective in dealing with the overestimation of non-recovery in the first version. This time, the idea of never-recovering nature was evidently less appealing than it was in the first cycle of research (1/34 vs. 26/41) (Ampatzidis & Ergazaki, 2014).

In summary, it seems that our modifications of the first version of our learning environment were effective, and the students who participated in the implementation of its second version were efficiently supported to build an understanding of how nature works in the case of protection or disturbance. The third version of our learning environment will be designed in line with these results, and it will be implemented and tested during the third cycle of the research.

Acknowledgments

This study was carried out for the Project 'Constantin Carathéodory 2010' funded by the Research Committee of the University of Patras.

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2 CHARACTERIZING THE DEVELOPMENT OF STUDENTS' ASKING OF QUESTIONS AND CRITIQUING OF PRACTICES IN AN INQUIRY-ORIENTED BIOTECHNOLOGY PROGRAM

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Abstract

Asking questions and critiquing are key practices required from K–12 science learners. Students' abilities to ask research questions and critique are expected to improve in the course of performing authentic scientific inquiry. This research examines the possible development of 11th-grade biotechnology majors' abilities to ask research questions and critique during their participation in an inquiry-oriented program entitled Bio-Tech. The analysis included a comparison between Bio-Tech and non-Bio-Tech students' questions at the beginning and end of the school year, and an in-depth examination of one classroom lesson designed to teach students to formulate their own research questions and that included a peer-critique activity. The results indicate that in the course of participating in the Bio-Tech program, students' ability to ask questions about the experimental process improved. In addition, the peer-critique activity encouraged students to evaluate their peers and their own research questions. Some of these questions were eventually investigated in later stages of the program. We suggest that high-school students' learning to ask research questions and critique may be promoted by employing opportunities for students to perform peer-critique activities.

Keywords

Inquiry; question-asking; scientific practice; critique; biotechnology

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

Inquiry-based teaching, in which students are engaged in active and open scientific investigation, is an essential part of science education (National Research Council [NRC], 2000), and is supposed to increase the students' learning of scientific concepts (Minner, Levy, & Century, 2010). Authentic scientific inquiry should provide an opportunity for developing students' ability to ask questions (Chinn & Malhotra, 2002). Still, suitable means to implement authentic scientific practices in classrooms have not been clarified, and many issues remain unclear regarding the learning goals and strategies for teaching scientific inquiry (Furtak, Seidel, Iverson, & Briggs, 2012). In an attempt to address these challenges, this study aims to characterize the teaching and learning of inquiry in an innovative inquiry-oriented program for high-school biotechnology majors entitled Bio-Tech.

1.1 Asking research questions

The practice of asking questions is a key scientific requirement for K–12 science learners, as it is an important scientific habit of mind, driven by curiosity, the study of a model or theory, or the need to find a solution to a problem (NRC, 2012). The goals of teaching students to ask questions are to direct students' knowledge construction, foster communication, help self-evaluation of their understanding, and increase their motivation and curiosity (Chin & Osborne, 2008).

Research questions, also termed researchable (Cuccio-Schirripa & Steiner, 2000), investigable (Chin, 2002) or operational (Wayne & Shrigley, 1986) questions, are questions that require hands-on, manipulative, operational activities that lead to a process of collecting data to answer those questions. Research questions should be meaningful, interesting and challenging for the students, provide opportunities to demonstrate their skills, help them progress to the next stages of the scientific inquiry, and encourage them to exercise their critical thinking (Chin & Kayalvizhi, 2002). Students are expected to formulate their own research questions while participating in scientific inquiry (Chin, 2002).

Explicit teaching of the asking of research questions in middle and high school improves students' level of research questions (Cuccio-Schirripa & Steiner, 2000). Presenting students with examples of research questions can assist them in formulating their own (Chin, 2002). Harris, Phillips, and Penuel (2012) found that although the teachers displayed a student-centered and dialogic approach while teaching students to ask research questions, they experienced challenges in developing the students’ ideas into investigable questions. Lombard and Schneider (2013) found that high-school biology majors’ ability to formulate research questions appropriate for investigations improved while maintaining their ownership of the inquiry process. Classroom authentic scientific inquiry should develop students' cognitive abilities and understanding, as it provides an opportunity to develop students' ability to ask research questions. In most simple inquiry tasks, the research questions are given to the students, unlike authentic research, where scientists are expected to investigate their own research questions (Chinn & Malhotra, 2002).

Based on these studies, there is a need to promote the teaching and learning of asking research questions in the context of authentic inquiry-oriented programs such as Bio-Tech.

1.2 Critiquing

Critiquing, as defined by Ennis (1987), is "reasonable reflective thinking that is focused on deciding what to believe or do" (p. 10), and is crucial for productive participation in scientific practice and discourse. Students should identify possible weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner (NRC, 2012). Critiquing is considered to be a key part of sense-making and persuasion in scientific argumentation (Berland & Reiser, 2011). The ability to critique makes up an important part of scientific inquiry and consists of overlapping skills and abilities, such as testing hypotheses, designing experiments and drawing conclusions from results (Ford, 2012).

Students usually lack opportunities to develop their abilities to reason out and critique scientific claims (Osborne, 2010) or to be engaged in critiquing and in scientific argumentation (Sampson & Clark, 2011). More activities are needed to develop these abilities in the classroom, mainly by restructuring current science lessons (Berland & Reiser, 2011).

Here, we suggest that a peer-critique activity, specifically designed to promote students' ability to formulate an appropriate research question in an inquiry-oriented program, is an adequate platform for developing students’ ability to critique, and provides them with an opportunity to communicate and evaluate their own and their peers' ideas.

This research set out to characterize the development of students' abilities to ask research questions and to critique during their participation in an inquiry-oriented program entitled Bio-Tech. To this end, we focus on the following questions: (a) How does participation in the Bio-Tech program develop students' ability to ask questions? (b) What are the characteristics of teaching and learning the formulation of research questions in a lesson that includes a peer-critique activity?

2. Research design and methods

This study involves mixed methods, integrating both quantitative and qualitative approaches. The research was designed to evaluate possible changes in students’ ability to ask questions following their participation in an inquiry-oriented biotechnology program, and to characterize the teaching of asking research questions during one lesson that included a peer-critique activity.

2.1 Research context

2.1.1 The Bio-Tech program

The Bio-Tech program is a year-long innovative inquiry-oriented program that allows students to practice a high level of open inquiry while incorporating a co-teaching approach. Students' learning includes reading an adapted scientific article based on the Adapted Primary Literature (APL) approach (Yarden, Brill, & Falk, 2001). The Bio-Tech program at the Davidson Institute for Science Education (hereon referred to as 'the Bio-Tech') is an optional part (1 credit out of a total of 5 credits) of the Israeli matriculation examinations for biotechnology majors during the 11th grade (16–17 years of age). The Bio-Tech program design originates from the Teacher-Led Outreach Laboratory (TLOL) program (Stolarsky Ben-Nun & Yarden, 2009). The Davidson Institute for Science Education began supporting the Bio-Tech program in 2009.

In the Bio-Tech program, students practice high levels of open inquiry and a co-teaching approach is implemented, where teaching is performed by the class teacher, a research scientist, and a science educator. This allows the students to learn up-to-date scientific concepts, practice with technologically advanced tools and methods, and experience a firsthand encounter with authentic science (Bielik & Yarden, 2013).

In the Bio-Tech program, students are expected to formulate their own research question that will lead them to plan and execute their experiments. Therefore, much emphasis is placed on developing the students' ability to ask research questions. In most Bio-Tech classes, the teacher explicitly instructs the students on how to formulate an appropriate research question and assists them in the process of formulating their own research question.

2.1.2 Lesson on formulating research questions and peer-critique activity

In the investigated Bio-Tech classes, the teaching of formulating research questions was facilitated in a lesson that included explanations and examples of appropriate research questions, followed by a peer-critique activity performed with small groups (two or three students). This activity, developed by the authors, gave the students an opportunity to formulate their own research questions, evaluate their peers' research questions, and receive and respond to critique by their peers. The class teachers were instructed by the authors on how to carry out the peer-critique activity and to include it in their lesson plan. One class's lesson was examined in depth and is presented here.

The peer-critique activity included a written sheet given to each group. First, students were asked to write three research questions that they would like to investigate in the Bio-Tech program. Then, they chose one of the questions and formulated it as a research question, according to what they had learned in the earlier part of the lesson. The groups then exchanged their written sheets with those of other groups. The students were asked to critique the other groups' chosen questions, based on the research question characteristics they had learned. They were also asked to rewrite their suggested research questions so that they would be appropriate for the Bio-Tech program. The original groups then got their sheet back, responded to the other groups' critique, and wrote their final research question, which was submitted to the teacher for approval. Overall, this activity gave the students an opportunity to independently formulate their own research questions, and to evaluate their own and their peers' questions.

2.2 Population

The research population was comprised of 11th-grade biotechnology majors from eight classes participating in the Bio-Tech program (the Bio-Tech group), and seven classes not participating in the Bio-Tech or any other inquiry-oriented program (the Control group) during the 2011/12 and 2012/13 school years. The selected classes represented average biotechnology classes, chosen for reasons of convenience and according to the teachers' agreement to participate in the research.

One Bio-Tech class from an average socioeconomic background in an urban high school was chosen for in-depth examination. This class had 19 students. The class teacher, Rebecca (not her real name), with 26 years of experience teaching biology and biotechnology, had received her B.Sc. degree in life sciences. This was her second year of teaching the Bio-Tech program. The class was investigating the topic of expression and function of the paraoxonase1 (PON1) enzyme (Ben-David et al., 2012).

2.3 Tools and methods

2.3.1 Pre- and post-questionnaires

To explore possible changes in students' ability to ask questions, pre- and post-questionnaires were administered to the Bio-Tech and Control classes. The questionnaires were based on similar questionnaires that had been developed to evaluate students' ability to interpret media reports of scientific research (Ratcliffe, 1999), and to explore students' oppositional voice and critical reasoning in response to an arguable claim (Ford, 2012).

In the questionnaires, students were asked to answer open-ended questions after reading a popular scientific article about an experimental study. The article, "Alarm Sounds over Toxic Teething Rings" (The New Scientist, 1997), was the same article used in the previously mentioned studies. It was found to be appropriate for high-school students and contained details regarding the methods and experiments by which the conclusions had been reached. Students' written answers to the question: "After reading the article, write at least 2 new scientific questions that interest you" were taken for analysis.

The pre-questionnaire was administered at the beginning of the school year. The post-questionnaire, identical to the pre-questionnaire, was administered at the end of the school year, following the classes' completion of the Bio-Tech program. A total of 115 Bio-Tech students and 80 Control students filled out both the pre- and post-questionnaires.

2.3.2 Artifacts of the lesson on formulating research questions

To gain an in-depth view of the process of teaching and learning to formulate research questions during the Bio-Tech program, one classroom lesson was examined. In that lesson, the teacher used the peer-critique activity described in section 2.1.2. Students' written questions during the peer-critique activity were collected and taken for analysis. Data from the lesson included classroom observation, audio recordings, and several semi-structured interviews with the teacher following the lesson.

2.4 Analysis

A total of 444 questions from the Bio-Tech students and 299 questions from the Control students were taken for analysis. Students' questions were classified into two categories of relevance to this research: (a) research questions, defined as questions that require a hands-on investigation and data collection, include variables that are specific, manipulative and measurable, and whose answer is unknown to the students (Cuccio-Schirripa & Steiner, 2000), and (b) questions about the experimental process described in the article (examples given in Table 1). Statistical analysis was performed using non-parametric one-sample χ^2 goodness of fit tests to identify significant differences between the groups, and the effect size was calculated according to Cohen's d (Cohen, 1988).

The analysis was validated by four science education researchers. More than 80% agreement was reached between the raters. Debatable terms were further discussed until full agreement was reached among raters. Students' written questions during the peer-critique activity were compared to the final research questions that were investigated by the students during the Bio-Tech program. The transcripts of the examined lesson and interview were divided into episodes and utterances, and analyzed according to Chi (1997). Analysis of teacher's instructional moves and teaching approach was based on Pimentel and McNeill (2013).

Table 1. Classification of students' questions.

Categories		**Examples of students' questions**
Research questions	**Regarding described experiment**	
No	No	"Are there other baby products that may hurt babies?"
Yes	No	"Is there a connection between the amount of toxins and the softness of the toy?"
No	Yes	"Are the results of the experiment accurate?"
Yes	Yes	"Did the experiment duration affect the results?"

3. Results

To investigate the possible development of students' ability to ask questions, their questions in the pre- and post-questionnaires were examined. In addition, an in-depth examination of one Bio-Tech lesson was performed. In this lesson, students were taught to formulate their own Bio-Tech research questions, and a peer-critique activity was included.

3.1 Students' ability to ask research questions

Students' written questions in the pre- and post-questionnaires were categorized as research or non-research to examine possible development of their ability to ask research questions during their participation in the Bio-Tech program.

A significant increase in the percentage of research questions in pre- and post-questionnaires was found for the Bio-Tech students' questions (6.5% and 20.3%, respectively, $\chi^2 = 18.11$, df = 442, $p < 0.001$) and the Control students' questions (4.7% and 18%, respectively, $\chi^2 = 13.12$, df = 297, $p = 0.002$). The effect size between the pre- and post-questionnaire in both the Bio-Tech and Control groups was high (Cohen's d: Bio-Tech = 0.42, Control = 0.41), while low effect size was identified between the Bio-Tech and Control groups' pre-questionnaires (Cohen's d = 0.04) and the two groups' post-questionnaires (Cohen's d = 0.05) (Figure 1).

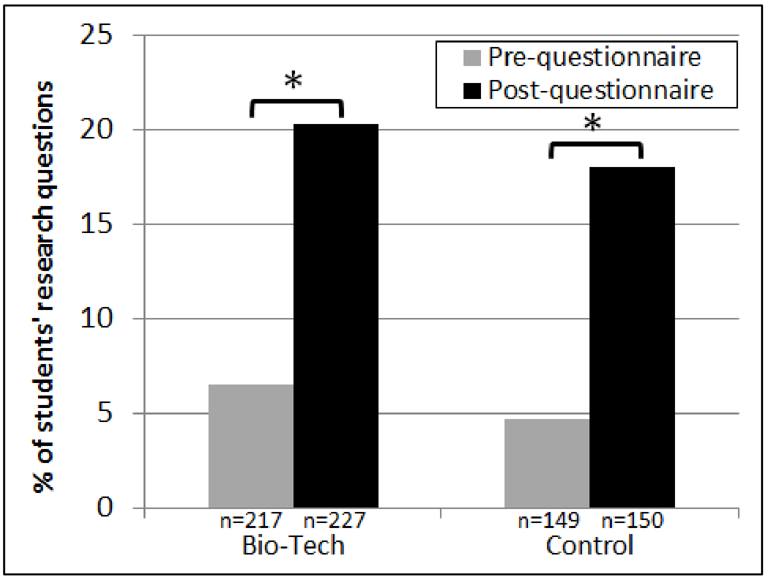

Figure 1. Percentage of research questions out of total number of student questions. *$p < 0.001$, n = number of students' questions.

This result indicates that 11th-grade biotechnology students' ability to ask research questions developed during the academic year, regardless of their participation in the Bio-Tech program. This issue was addressed in the interview with Rebecca, the Bio-Tech teacher. She mentioned that biotechnology students have opportunities to practice their ability to ask research questions in various learning activities, such as laboratory experiments and other projects ("They [the students] receive this knowledge [of asking research questions] not only in the Bio-Tech. We try to provide them with inquiry learning in the school laboratory experiments, the computer laboratory or the bioinformatics project. This means that they have many other opportunities to learn the inquiry approach…We start in the 10th grade. They study this in biology, so this is not the first time they are encountering the formulation of research questions").

3.2 Students' ability to ask questions regarding the experimental process

To identify possible changes in students' ability to focus their questions on an experimental process that has been presented to them, students' written questions in the pre- and post-questionnaires were classified as either about the experimental process described in the article or not. An increase in students' questions focusing on the experimental process may indicate a change in their interest and attention to the scientific process following their participation in the program.

A significant increase in the percentage of students' questions about the experimental process in the pre- and post-questionnaires was found among the Bio-Tech students (11.5% and 16.3%, respectively, $\chi^2 = 2.11$, df = 442, p = 0.007). A non-significant decrease was found among the Control students by the end of the school year (8% and 5.3%, respectively, $\chi^2 = 0.886$, df = 297, p = 0.146). The effect size between the Bio-Tech and Control groups' post-questionnaires was high (Cohen's d = 0.36). Low effect size was found between the two groups' pre-questionnaires (Cohen's d = 0.13) and between the Bio-Tech group's pre- and post-questionnaires (Cohen's d = 0.12) and the Control group's pre- and post-questionnaires (Cohen's d = 0.12) (Figure 2).

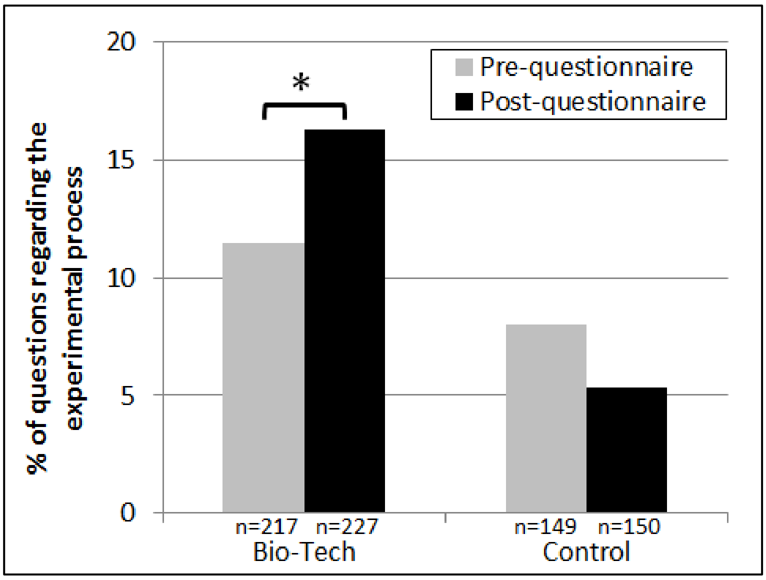

Figure 2. Percentage of questions about the experimental process out of total number of student questions. *p < 0.01, n = number of students' questions.

3.3 Teaching and learning to formulate research questions

To examine the processes of teaching and learning the formulation of research questions in the Bio-Tech program, we examined a classroom lesson of one Bio-Tech teacher, Rebecca, and her students. It is not suggested that this is the only factor that contributes to the development of the Bio-Tech students' ability to ask research questions; however, it is believed to be a meaningful part of the program in influencing the students' learning of this practice.

Rebecca's lesson began with a whole-class discussion in which she reviewed the characteristics and components of research questions appropriate for the Bio-Tech program (40 minutes). The discussion focused on the correct phrasing of research questions and the characteristics of research questions appropriate to the Bio-Tech program. Some of the mentioned aspects were that the questions need to include independent and dependent variables that are measurable and can be manipulated, they should be applicable in terms of the available tools and methods, and they need to be relevant to the Bio-Tech topic. It was also mentioned that the questions need to contribute to the students' scientific knowledge, and unethical experiments should be avoided. Rebecca emphasized that the research questions should lead to a doable experiment under all of the Bio-Tech program's experimental limitations. She also reviewed some of the methods that the students were expected to use in their experiments, focusing mostly on determining protein expression levels. After this, the students were asked to suggest possible variables that might affect the protein expression of PON1 enzyme. The students suggested variables such as temperature, pH, salinity, radiation, substrates, protein-purification techniques and different growth media. The next part of the lesson included the peer-critique activity (38 minutes), and the lesson concluded with another whole-class discussion dedicated to analyzing some of the students' formulated research questions (22 minutes).

The classroom lesson included several opportunities for the students to discuss and share their ideas about asking research questions. During the whole-class discussions, the teacher asked many open questions, allowing the students to express their ideas and thoughts (e.g., "What are the characteristics of a good research question?"). In several cases, the teacher avoided giving immediate feedback to the students' responses and used probing or toss-back questions to encourage the students to further elaborate their ideas. The students also asked many questions, and most of the students were involved in the interactive discourse. Therefore, Rebecca's teaching approach was found to be student-centered and dialogic. This gave the students opportunities to be involved in the whole-class discussions and in the peer-critique activity. An example of Rebecca's student-centered teaching approach is presented in Episode 1.

Episode 1. Teacher–student interactions in Rebecca’s lesson.

Turn	Speaker	Utterance	Teacher’s move
1	Rebecca	*Now, you are asking why it [the research question] can’t be investigated. Give me one idea.*	Open question
2	Student	*Risk.*	
3	Rebecca	*Risk. It could be risky. Give me an example of a risk related to the PON1 enzyme.*	elaborate
4	Student	*Toxic gas.*	
5	Rebecca	*Toxic gas may be a problem. Maybe we shouldn’t ask questions that are related to toxic gas.*	Re-voice

Four out of the five research questions that were investigated in the main experiments at the research institute by Rebecca's' students originated from their questions in the peer-critique activity (e.g., "What is the effect of different bacterial growth media on PON1 enzyme activity?", "What is the effect of different [protein] purifying techniques (ammonium sulfate/dialysis) on PON1 enzyme activity?"). These questions were accepted by the critiquing groups as appropriate for the Bio-Tech program, mentioning in their justifications that the questions were relevant to the Bio-Tech topic and operationally feasible, and that the answers were unknown to the students. This was in line with the characteristics of appropriate research questions taught by the teacher in the previous part of the lesson.

Four out of the nine groups that participated in the peer-critique activity in Rebecca's class did not accept their peers' research questions as appropriate for investigation in the Bio-Tech program. The main issues mentioned in the students' critique were: incorrect phrasing of the question (e.g., "*Your question is not specific, not relevant and not clear*"), the required experiment was not applicable to the Bio-Tech program (e.g., "*The research question requires clinical experiments that are not moral and not appropriate for the Bio-Tech program"*), no clear or specific independent variable in the question (e.g., "*[the question] is not focused enough when you say 'different antibiotics'. There are a variety of antibiotics and you don't have the time or the means to examine all of them*"), and no contribution to scientific knowledge (e.g., *"in this research there will be no difference between the natural gene and the engineered gene since the gene sequence is similar. This question will not contribute to our knowledge*"). In her interview following the lesson, Rebecca pointed out that the peer-critique activity supported her students' understanding and collaborative work ("*This activity is a very good idea. The students are thinking and once you can critique the work of someone else and examine it, I think the students are gaining a lot themselves*"). In the follow-up interview a year later, Rebecca mentioned that she had performed activities similar to the peer-critique activity, where students suggested their ideas for research questions and received critique from other students, but that she did it during a whole-class discussion rather than using the written sheets that were used in the peer-critique activity in this study. This suggests that the peer-critique activity is suitable for the Bio-Tech program students, and that teachers may independently use this activity in their teaching, with some adjustments.

4. Discussion

This study explored the development of students' abilities to ask questions and critique in the course of their participation in Bio-Tech, an inquiry-oriented high-school program for biotechnology majors. Students' written questions before and after their participation in the program were analyzed and compared to questions written by other 11th-grade biotechnology major students that were not participating in any inquiry-oriented program. In addition, a Bio-Tech lesson that focused on formulating research questions and included a peer-critique activity was examined.

Participation in the Bio-Tech program enabled the students to focus their questions on the experimental process. This increase in the Bio-Tech students’ attention or interest in the experimental process can be explained by the fact that during the program, the students had many opportunities to learn and practice the experimental process while learning the APL articles, planning the research, visiting the research institute, collecting the data, and analyzing the results. As recommended by Chinn and Malhotra (2002), the Bio-Tech program provided the students with an authentic inquiry experience, which contributed to the development of their practice of asking questions. The percentage of research questions written by the students at the end of the school year significantly increased in both the Bio-Tech and Control groups. It appears that 11th-grade biotechnology students have opportunities to develop this ability in the course of other curricular activities as well.

The peer-critique activity during the examined lesson encouraged the students to evaluate their peers' and their own research questions, and gave them an opportunity to communicate their ideas and thoughts. These results are in concurrence with those of Ford (2012), who found that students were better able to find flaws and suggest improvements to their experiments after engaging in peer-critique activity. Several of the students' research questions during the peer-critique activity were eventually investigated in the Bio-Tech program. This suggests that the student-centered lesson, which included the peer-critique activity, contributed to the students' ability to ask research questions. This correlates with other studies which concluded that explicit teaching of the asking of research questions improves this student ability (Chin, 2002; Cuccio-Schirripa & Steiner, 2000).

The peer-critique activity supported the students' knowledge and understanding of asking research questions, as they were able to implement their previously learned knowledge about formulating appropriate research questions in their critique. This is in line with previous studies that called for providing students with more opportunities to critique during classroom learning (Lombard & Schneider, 2013; Osborne, 2010; Sampson & Clark, 2011). In accordance with those studies, our results indicate that 11th-grade biotechnology majors' ability to formulate research questions improved following a lesson that included a peer-critique activity.

One limitation of this study is that it examined only one inquiry-oriented program and focused on one classroom lesson. Other Bio-Tech lessons and other inquiry-oriented programs need to be examined to strengthen the conclusions and to expand our understanding of students' development of question-asking and critiquing practices while participating in inquiry-oriented programs.

This research may contribute to the understanding of students' process of learning to ask research questions, as recommended in the latest NRC (2012). We suggest that the practice of asking questions may be promoted by employing opportunities for students to perform self- and peer-critiquing activities in student-centered lessons. We encourage science educators, inquiry-program designers and practitioners to consider using inquiry-oriented programs and peer-critique activities as a platform for promoting students' practice of asking questions.

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3 THE KNOWLEDGE – BEHAVIOR GAP: TESTING THE MEDIATING ROLE OF ENVIRONMENTAL EMOTIONS

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Abstract

The knowledge–behavior gap has been extensively researched and the notion that imparting knowledge is not enough to promote transformative action is gaining acceptance. Studies show that emotions play a central role in behavioral decision-making. The present study tested the hypothesis that environmental knowledge can drive environmental behavior only if it arouses environmental emotions, i.e., only if that knowledge's effect on behavior is mediated by emotions. Using a structural equation modeling approach, we tested the direct and indirect (mediated) effects of knowledge on behavior and assessed the mediating role of environmental emotions. We found that knowledge is an important but distal variable, the significant effect of which is fully mediated by emotions. The high explanatory power and good fit indices of the model support and validate the important role of emotions in the learning process.

Keywords

Environmental behavior; environmental education; environmental emotion; environmental knowledge; knowledge-behavior gap

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

In the end, we will protect only what we love. We will love only what we understand. We will understand only what we are taught.
Baba Dioum (1968)

1. Introduction

The Tbilisi Intergovernmental Conference on Environmental Education defined the objectives of environmental education: to help social groups and individuals acquire awareness, sensitivity, knowledge, and understanding of environmental problems, pro-environmental values and concern, and skills to identify and solve environmental problems, and finally, to provide an opportunity to be actively involved (UNESCO/UNEP, 1977). This definition describes a schematic model of transforming environmental knowledge and understanding into action, and highlights the importance of environmental emotion as a mediator. Today, the notion that knowledge is not enough to motivate environment-friendly behavior and that the key entry point for instilling values and attitudes associated with environmentally conscious behavior is the affective domain rather than knowledge, is gaining acceptance (Iozzi, 1989; Hungerford and Volk, 1990; Coppola, 1999; (Pooley & O'Connor, 2000; Kollmuss & Agyeman, 2002; Frick et al., 2004; Wiek et al., 2011). Finally, Schultz (2013) referred to the effectiveness of providing more knowledge to promote environmental behavior, and noted that "the changes that do result are typically limited to people who already cared about the topic" (p. 59). Freely interpreted, this means that knowledge can only drive environmental behavior if it arouses emotion and if the individual assimilates and internalizes that emotion. The purpose of the present study was to test the hypothesis that people who are more knowledgeable of environmental issues will be more inclined to behave in an environmentally responsible manner only if they have stronger environmental emotions.

The present study was based on the premise that emotions mediate the translation of knowledge acquired about environmental issues into environmentally responsible behavior, and was aimed at exploring the mediating role of environmental emotions in this process. We tested the model depicted in Figure 1 by structural equation modeling (SEM) to assess direct as well as mediated influences. Knowledge was treated as an entry variable (as accepted and used in many models) and a predictor of environmental behavior (EB) (Hungerford & Volk, 1990; Kollmuss & Agyeman, 2002; Frick et al., 2004; Carlson et al., 2009; Levine & Strube, 2012). The term "knowledge" included objective and subjective knowledge, as described in section 2.2. "Environmental emotions," consisting of several accepted measures, was used as mediator. The dependent variable, EB, represented various aspects of indoor and outdoor behavior and therefore we relied only on self-report data. To reduce the potential bias of social desirability that accompanies self-reports, we included this construct (social desirability) in our model.

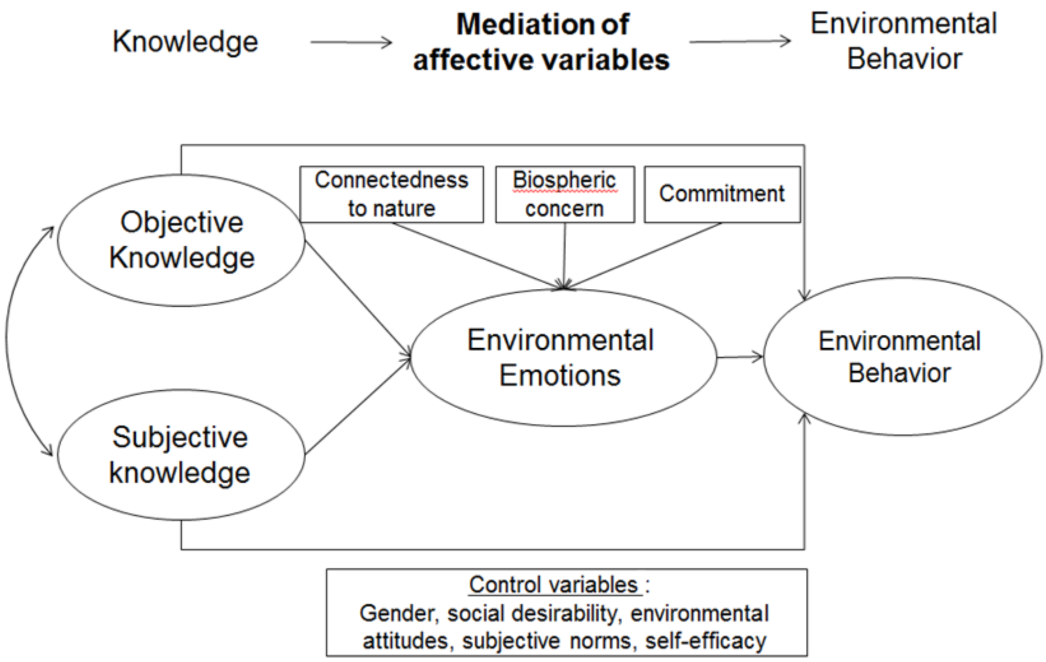

Figure 1. Schematic model of the mediating role of emotions in the knowledge–behavior relationship. Covariances are represented by curved lines and regression weights by single-headed arrows. Latent variables are represented by ellipses and observed variables by rectangles.

2. Method

2.1 Sample and procedure

This study was conducted among a sample of 1014 students from the Faculty of Sciences and Technology and the Faculty of Humanities and Social Sciences in Tel-Hai Academic College at the beginning of the 2012/13 academic year. The research was conducted with a computerized questionnaire (Qualtrics), and was designed so that each student had to answer all of the questions, resulting in no missing data. At the beginning of the 2012/13 academic year, we selected a stratified quota sample of about 25% of the students in each year of study. Gender and ethnicity (Jewish and Arab) were also proportionally represented. The sample comprised 681 (67.2%) females and 333 (32.8%) males, ranging in age from 18–56 years (mean = 24.7, standard deviation = 3.14 years). Most of the students (84%) were Jews and the rest were Arabs, Druze or Circassians.

2.2 Study Measures

2.2.1 Knowledge

We operationalized "knowing" by testing the students' ability to achieve a high score on a test of knowledge, and termed this "objective knowledge". The respondents were presented with 18 yes/no questions (see Table 1 for the items) and received one point for each correct answer. The option “I don’t know” was coded as zero. Since the total number of objective knowledge items was 18, the knowledge scale ranged from 0 (minimal knowledge) to 18 (maximal knowledge).

Table 1. Environmental Objective Knowledge questionnaire (α = 0.78).

1.	Carbon dioxide contributes to the creation of the greenhouse effect (T) (28.9%)[a]
2.	Natural gas is a greater source of air pollution than fuel oil (F) (20.7%)
3.	Global warming is caused by the hole in the ozone layer (F) (7.8%)
4.	The hole in the ozone layer is caused by a rise in the amount of carbon dioxide in the air (F) (5.4%)
5.	In Israel, plastic bottles can be recycled (T) (62.5%)
6.	It takes a soft drink can 200–500 years to decompose in nature (T) (18.8%)
7.	An electric car will significantly solve our dependence on gasoline, coal, and gas (F) (9.1%)
8.	When I drive a car, materials are emitted which destroy the ozone (F) (2.1%)
9.	From an environmental standpoint, drinking mineral water from bottles is preferable to drinking water from the tap (F) (55.1%)
10.	An interurban trip at 90 kph is more economical and uses less gasoline than driving at 110 kph (T) (39.7%)
11.	Today in Israel, you may receive a refund for recycling a soft drink can but not for bottles of 1.5 liters (T) (46.5%)
12.	Reusing bottles, for example, is preferable to recycling (T) (27.9%)
13.	The amount of water wasted during cooking and drinking is greater than the amount of water wasted in the toilet (F) (34.8%)
14.	It is environmentally preferable to build new communities rather than expanding existing ones (F) (35.5%)
15.	A drop of ground water can become part of a cloud in the future (T) (28.0%)
16.	Some of the components of rock may have been animals in the past (T) (37.7%)
17.	Gases emitted from a car in China may reach anywhere in the world (T) (22.8%)
18.	The quantity of water in the ocean has increased in time as a result of the addition of rain water (F) (33.7%)

T – true; F – false.
[a]Percentage of correct answers.

2.2.2 Subjective knowledge (understanding)

This scale included two items. It was adopted from the International Social Survey Program that assesses people's subjective knowledge (see Table 2).

Table 2. Scales[a] and items of understanding of environmental issues, environmental emotions and environmental behavior: means ± standard deviations and factor loadings.

	Mean ± SD	λ[b]
Subjective knowledge ($\alpha = 0.69$)		
I feel that I understand the reasons for various environmental problems	2.5±1.19	0.82
I feel that I know the solutions to environmental problems	2.2±1.21	0.65
Environmental emotions		
Connectedness to nature subscale (a single-item graphical scale)	4.3±1.39	0.58
Biospheric environmental concern subscale ($\alpha = 0.88$)	4.1±0.79	0.46
Commitment to the natural world subscale ($\alpha = 0.79$)	3.7±0.72	0.85
Environmental behavior ($\alpha = 0.73$)		
I save water at home (i.e., closing the tap while brushing my teeth or rinsing dishes)	4.0±0.98	0.51
In my daily life, I try to behave in a way which does not harm environmental quality	3.8±0.92	0.65
I usually save electricity when using light bulbs, air conditioners, and other electric appliances at home	3.7±1.01	0.57
When I go out for a walk in nature and see trash which others have left behind, I pick it up and put it in a bag	3.2±1.11	0.47
I make sure to gather newspapers and other used paper and to bring them to the recycling bin	2.9±1.30	0.63
I buy products only after I check the extent of harm they cause to the environment	2.1±0.95	0.55

[a]All of the scales' and subscales' ranges are 1–5, except for connectedness to nature which uses a 1–7 scale.
[b]λ = standardized factor loading on latent variable.

2.2.3 Environmental emotions

These were operationalized by adopting Schultz's (2002) concept of inclusion in nature, which includes three components, each of which comprises a distinct construct: (a) the integration with nature scale, considered as implicit and existing outside of conscious awareness (Schultz et al., 2004). This is a single-item graphic construct designed to measure the extent to which one feels a part of nature (for details on its construction, development and applications, see Schultz, 2002); (b) the second construct refers to the degree to which one feels concern for the biosphere. Schultz et al. (2004) defined the term “concern” as an affect associated with beliefs about environmental problems. In the present study, we focused on one of the factors that constitutes environmental concern-biospheric environmental concern-which describes the concern and value ascribed by the individual to non-human species or all living things (for details on the construct's development, see Schultz, 2000; Stern & Dietz, 1994). The biospheric concern scale is comprised of four items. Respondents were asked to rate how concerned they were that the state of the environment would negatively affect each of these items, on a scale of 1 (not concerned) to 5 (extremely concerned): plants, animals, marine life, and birds. The reliability of this construct in our sample was $\alpha = 0.88$; (c) the third component refers to the commitment one feels to the natural environment. To operationalize this construct, we used Davis et al.’s (2009) scale. Respondents were asked to rate their level of agreement with each of the statements on a scale ranging from 0 (do not agree at all) to 8 (completely agree). We used the following 4 of the original 11 items: “I feel committed to keeping the best interests of the environment in mind"; "I feel strongly linked to the environment"; "When I make plans for myself, I take into account how my decisions may affect the environment," and "I believe that the well-being of the natural environment can affect my own well-being." The students were asked to rate their level of agreement with each statement on a 5-point scale ranging from 1 (do not agree at all) to 5 (strongly agree). The reliability of this construct in our sample was $\alpha = 0.79$.

2.2.4 EB

EB was assessed with items that were relevant to the students' lifestyle and reflected different degrees of environmental commitment (for the scale and items, see Table 2).

2.2.5 Control variables

There are a few other variables, in addition to those included in the model, which may contribute to the explained variance of EB. In addition to gender (0 = male, 1 = female), variables such as social desirability may be confounding due to the methodology used in this study, i.e., self-report measures. Social desirability refers to the normative conformity motivations to behave in a manner that matches the norms of significant others, in order to gain their social approval. In this research, social desirability was measured by four questions, in accordance with the conformity tendency measurement used by Zhou, Horrey, and Yu (2009). The questions were rated on a 5-point Likert scale. Two examples are "When I consider how to behave I consider what my friends will think about me," and "I don't care what others will think about me; I always behave according to what I think is the right thing to do" (the reverse statement). The social desirability index had a reliability score of $\alpha = 0.74$ (identical to that reported by Zhou et al., 2009). Other variables, such as environmental attitudes, subjective norms, or perceived behavioral control are theoretically important, but for the sake of testing the hypothesis, we measured them only to control for their effects (description of the item selection and validation of environmental attitudes, subjective norms and perceived behavioral control are detailed in Carmi et al., 2015). All of our results presented in the following sections represent effects after controlling for the effects of the aforelisted variables.

2.3 Testing the model

In light of the research hypothesis that knowledge affects EB indirectly through environmental emotions, we employed SEM. We constructed a structural equation model (Figure 1) and treated each of the variables in the model as latent. Throughout this article, we represent these effects with the standardized β. So as not to overload Figure 1, errors of endogenous variables are not drawn. Also not appearing in the figure but included in the analyses: (a) the correlations between the control variables and knowledge and emotions, (b) the correlations among the control variables, and (c) the arrows indicating the effects of the control variables on EB.

3. Results

3.1 Knowledge

The percentage of correct answers for each of the 18 items and the reliability of the objective knowledge index are listed in Table 1. The average proportion of correct answers per respondent for the objective knowledge scale was 32%. In other words, on average, the students knew the correct answers for 5 or 6 of the 18 questions. The means, reliability, and factor loadings for subjective knowledge items are presented in Table 2.
There was a significant and strong correlation between objective and subjective knowledge (r = 0.63). Table 3 presents the direct, indirect, and total effects of knowledge and emotions on EB. Neither objective nor subjective knowledge had any significant direct effects on EB. However, the indirect effects of subjective knowledge on behavior were significant. In other words, the influence of knowledge on EB was completely mediated by emotions.

Table 3. Direct, indirect and total effects[a] of the structural equation modeling components, depicted in Figures 1 and 2, on environmental behavior.

Effect source	Direct effect	Indirect effect	Total effect
Knowledge	-0.037	0.022	-0.014
Understanding	0.100	**0.222**	**0.322**
Affect	**0.545**	-	**0.545**

[a]Numbers are standardized β's. **Bold numbers** designate statistically significant effects on EB for *p* (2-tailed) < 0.01.

3.2 Environmental emotions

The means, standard deviations, Cronbach's α, and factor loadings for the three constructs comprising the latent variable "emotions" are presented in Table 2. The standardized loading coefficients of commitment to the natural environment, connectedness to nature, and biospheric concern were 0.85, 0.58, and 0.46, respectively. The direct effect (standardized β) of emotions on behavior (after accounting for the effects of the control variables listed in section 2.2.5) was 0.54 and environmental emotions accounted for 29.7% of the variance in EB.

3.3 Control variables

So as not to overload Figure 2, the correlation coefficients among the control variables and among the study variables were not drawn. Table 4 presents these data. None of the values exceeded 0.8, the minimal limit for considering multicollinearity.

Table 4. Standardized regression and correlation coefficients among the study variables and control variables, calculated with the structural equation model.

	Study variables				**Control variables**			
Study variables	1	2	3	4	5	6	7	8
1.Environmental behavior	-							
2. Emotions	**0.54[a]**	**-**						
3. Objective knowledge	-0.04[a]	0.04[b]	**-**					
4. Subjective knowledge	0.10[a]	**0.41[b]**	**0.63**	**-**				
Control variables								
5. Gender	0.06[a]	**0.10**	**-0.37**	**0.24**	**-**			
6. Social desirability	-0.01[a]	-0.02	**-0.11**	0.02	0.05	**-**		
7. Attitudes	**0.28[a]**	**0.68**	0.09	**0.24**	0.08	0.02	**-**	
8. Subjective norms	0.09[a]	**0.36**	0.09	**0.21**	-0.04	**0.15**	**0.34**	-
9. PCB	**0.19[a]**	**0.15**	0.03	0.09	0.08	**-0.13**	**0.15**	0.02

[a] Standardized effects (β's) on environmental behavior.
[b] Standardized effects (β's) on emotions.
Bold numbers are significant for α = 0.01.

3.4 The model

Figure 2 presents the results of the SEM and Table 4 presents the relationships between its components. The correlation coefficients provided some initial evidence that emotions are strong predictors of EB and knowledge is not.The hypothesized model explained 81% of the variance in EB. Fit indices were: $\chi 2 = 950$, DF = 293; CMIN/DF = 3.245; CFI = 0.888, GFI = 0.930, NFI = 0.848 and RMSEA = 0.047, thus supporting and validating the hypothesized structure of the causal knowledge–behavior relationship and the mediating role of emotions hypothesized in this study. As recommended by Schreiber et al. (2006), no modifications were made to improve the fit of the model. Knowledge, or more precisely, subjective knowledge, had a significant total (standardized) effect on behavior (0.32), of which most (0.22) was indirect, or due to its effect on emotions.

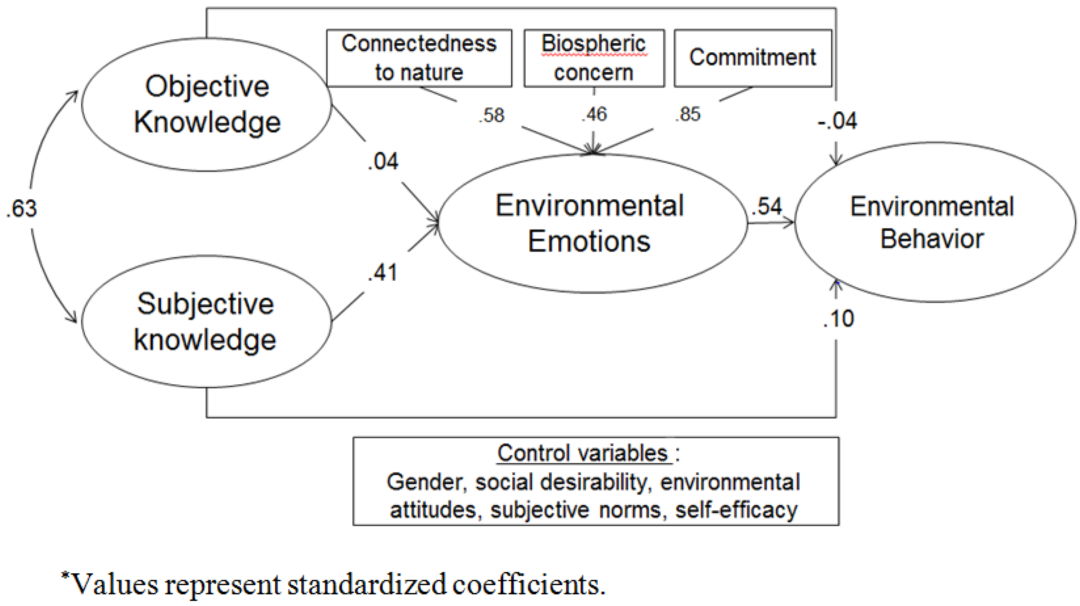

Figure 2. Structural equation modeling path results. Values represent standardized coefficients.

4. Discussion

4.1 The prediction model of EB

The prediction of EB most often entails the inclusion of mediators (Kaiser & Gutscher, 2003; Kaiser et al., 2005; Levine & Strube, 2012), because many EB predictors are indirect. In the present research, even after accounting for various theoretically important variables, we found that emotions were a strong and significant predictor of EB and an important mediator of the effect of knowledge on EB. Many models have been suggested to predict EB (for a review, see Bamberg, 2003; Kollmuss & Agyeman, 2002; Sipos, Battisti, & Grimm, 2008). These models do not necessarily contradict or exclude one another, but all of them include some reference to cognitive and emotional components. Sipos et al. (2008) proposed a tripartite framework of transformative sustainability learning: cognitive (the head), affective (the heart), and physical skills (the hands), which in some ways parallels the model we tested.

4.2 Affective influences

Similar to our model, Sipos et al. (2008) highlighted the important role of environmental emotions. Schultz (2013) also noted that if any improvement in EB results, it is due to those individuals who care about the topic. Our conclusions resonate with other ideas that come from the fields of cognitive science and linguistics. In a discussion of the difficulty of recruiting people's motivation to act, Lakoff (2010) claimed that the key strategy is to frame the (environmental) information in a way that triggers their emotions. According to Lakoff (2010), since humans think in terms of typically unconscious structures called “frames” (p. 71), and since many of these frames have direct connections to emotional regions, it may be fruitful to address environmental issues in a way that activates people's emotional frames.

Adopting this perception, we suggest that environmental programs should be more emotionally than cognitively based.

4.3 Cognitive influences

Our finding that the variance in subjective knowledge accounted for less than 20% of the variance in environmental emotions suggests that knowledge influences environmental emotion, but not exclusively. Thus, environmental understanding is not easily or simply translated into emotion that generates action. One explanation for this may be the "non-immediacy of many ecological problems" (Kollmuss and Agyeman, 2002, p.253), the gradual rather than dramatic nature of the deterioration, the complexity of the problems, and the fact that they do not necessarily relate to the individual alone (Weber, 2006). This cognitive barrier, which compromises our ability to generate an emotional response and makes preventive actions less probable, can be challenged in several ways, for example, by concretizing environmental implications so that they are perceived as more vivid, imminent, and personal (Kollmuss & Agyeman, 2002; Weber, 2006), or by linking environmental implications to personal daily life using self-audits (Savageau, 2011). Hungerford and Volk (1990) already noted that for educators, developing environmental sensitivity "is particularly troublesome" (p. 264), because its precursors are often not associated with formal education. Therefore, they suggested that stimulating environmental sensitivity can be achieved through *non-formal educational settings* and teachers who act as positive environment-sensitive role models. Finally, in light of our results that subjective rather than objective knowledge predicts EB, equipping learners with the former type of knowledge is no less important than with the latter. Our message is that knowing per se does not naturally lead to environmentally friendly behavior but once the affective system is activated, a behavioral response is much more probable.

4.4 Transforming environmental knowledge into behavior

In discussing the urgent change needed in human behavior, the primatologist and environmental activist, Jane Goodall, described the knowledge–emotion–action sequence beautifully: “Only if we understand can we care. Only if we care will we help. Only if we help shall we be saved" (Denys & Holmes, 1998, p. 106). Her vision also included the head, heart, and hands, or in other words, the notion that the road from knowledge to action travels through the heart.

Acknowledgments

This work was supported by the Ministry of Science, Technology and Space, under Grant 3-8083.

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4 JUNIOR HIGH SCHOOL SCIENCE AND TECHNOLOGY TEACHERS' ATTITUDES TOWARD MENTORS AND THEIR CONTRIBUTION TO THE ASSIMILATION OF CURRICULUM CHANGES

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Abstract

The science and technology (S&T) curriculum in Israel was changed in 2009. Since school mentoring may influence teachers' practices in Science Education Reform, school mentors were appointed to implement the curriculum changes. The purpose of this study was to examine S&T teachers' attitudes with regard to mentor characteristics and mentor contribution to the assimilation of curriculum changes. We examined 59 junior high school S&T teachers' attitudes toward mentors' characteristics using Hudson & Skamp's five-factor mentoring model (personal attributes, system requirements, pedagogical knowledge, modeling, and feedback). We also studied teachers' attitudes toward mentors' contribution to the assimilation of curricular changes using a quantitative questionnaire that included 47 statements (Cronbach's $\alpha = 0.8$). Positive attitudes ranging from 2.96 to 4.11 (scale of 1–5) were found for all mentoring-related factors. The attitude toward mentor feedback was lowest, while that toward system requirements was highest. Significant and statistically robust, positive correlations were found between the examined factors. However, no distinction was found in the examined factors between demographic sector or degree of seniority. It seems that training programs for mentors should address how to provide oral and written feedback on lesson plans and practical teaching. It is advised to align the mentoring with assessment, curricular learning materials, and teachers' professional development to create a well-coordinated process of educational change.

Keywords

Mentoring; in-service teacher; science education; mentor

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

1.1 Rationale

Science Education is the focus of many reform efforts aimed at improving teaching and learning. Although researchers and educational leaders recommend reform measures, these measures may not succeed if professionals do not see the value of implementing them (Hudson & Hudson, 2011). Teachers are valuable resources in education, and high-quality performance in teaching is an essential ingredient of educational improvement or reform. Researchers consider mentoring a valuable process for teachers in educational reform (Ganser, 1996; Hudson, 2007). Mentoring is typically described as a way to develop teaching practices involving a close relationship between a less experienced person and one who is more experienced, the latter providing guidance, advice, support, and feedback (Haney, 1997). The two key players at the center of the mentoring process are often the mentee (pre-service teacher) and the mentor (supervising or cooperating teacher) (Hudson, Nguyen & Hudson, 2009). However, this definition can be extended to the in-service teacher as mentee and the didactic-expert leader or collaborating teacher as mentor.
In these relationships, mentoring requires mentors to understand how ideologies, rituals, belief systems, and behaviors play out in mentoring interactions among various participants coming from different cultural and educational orientations. It is important, for example, to understand how the cultural features of a mentoring context might affect the types of dilemmas encountered by mentors in their work, and the types of strategies and actions that they will implement to manage them in practice (Orland-Barak, Kheir-Farraj, & Becher 2013). Thus, there has been a recent growing interest in examining mentoring as rooted in the context of multicultural settings (Orland-Barak, 2010).

However, in the field of education, the mentoring process is not always clearly understood. Researchers are becoming increasingly cognizant of its complexity (Koki, 1997). It is generally accepted that a mentoring teacher leads, guides, and advises another teacher, who is more junior in experience, in a work situation characterized by mutual trust and belief (Wang & Odell, 2002). The literature suggests that mentoring involves five factors that clearly define the mentor's role and characteristics (Hudson, 2004): personal attributes, system requirements, pedagogical knowledge, modeling, and feedback (Hudson, 2010).

Mentors need to exhibit a number of *personal attributes* to foster their mentees' teaching. These include being supportive of the mentee, feeling comfortable talking about teaching practices, and listening attentively to the mentee. The mentor's personal attributes also affect the mentees' reflection on their own teaching practices. Mentors may also link teaching practices and *system requirements* that are an essential aspect of educational reform. Thus, the mentor needs to clarify the aims, policies, and curricula required by an education system. However, difficulties in the implementation of system requirements may be attributed to the mentee's lack of *pedagogical knowledge*. Therefore, mentors must be able to communicate principles for effective teaching by explaining how to plan for teaching, by scheduling lessons for the mentee, and by discussing needs, preparation, teaching, and assessment strategies (i.e., pedagogical knowledge). Expert mentors can provide perspectives on effective teaching practices that link curriculum, pedagogy, and assessment. The mentees' teaching skills are acquired more effectively by observing their mentors' *modeling* of teaching practices. The mentor also needs to model appropriate classroom language for student learning, effective teaching, well-designed lessons, classroom management, and hands-on lessons. Lastly, *feedback* allows mentee teachers to reflect on and improve their teaching practices in specific subject areas. A mentor teacher reviews the mentee's lesson plans and observes the mentee teaching in the classroom, then provides oral or written feedback on the mentee's teaching and the learning environment (Hudson, 2010, 2004). These five factors provide an overall definition of a mentor's role and characteristics, and are particularly valid during a change in curriculum.

1.2 Context of the study

To understand the importance of this study, some related information about the relevant educational context is required. Israeli student achievement on international science assessment measures (e.g., the TIMSS) has proved disappointing, leading to calls for nationwide reform efforts in science and technology (S&T) education.

Zohar (2008) described a model for the implementation of large-scale changes. Implementing a national-scale reform or change (e.g. "Pedagogical Horizons for Learning") requires simultaneous work on three levels: (a) curriculum, learning materials, and standards; (b) professional development, and (c) assessment. Thus, in 2009, the Israeli Ministry of Education established a reform program that included:

1. an update of the curriculum (knowledge and skills) according to the suggestions of the professional subject committee
2. construction of resource materials for teaching and assessment
3. implementation of in-service training courses and mentoring to assimilate the updated curriculum. Every mentor was responsible for five schools, and met the mentee teachers once every 3 weeks. The mentors also participated in in-service teachers' training courses.

According to the Israeli Ministry of Education (MOE, 2009), teachers were obligated to participate in a professional development program and a mentoring period to implement the updated curriculum. The Ministry of Education views the mentoring agenda as reform-driven, with a focus on changing teachers' attitudes and practices related to the implementation of innovative teaching methods in schools, toward raising pupils' academic achievements (Rubinshtein, 2000).

Since the Israeli MOE constructed a continuous mentoring framework for professional development, we thought it reasonable to examine teachers' attitudes to the mentors' role, and to the mentors' contribution to the assimilation of the curriculum changes. Moreover, for large-scale educational reform to be sustainable, and for the benefit of its implementation, one should account for policy, culture, and assessment (Avargil, Herscovitz, Dori, 2013). Since teachers in the Israeli-Arab demographic sector are usually more traditional in their teaching (Abed and Dori, 2013), we examined how their attitudes differed from those of their Jewish counterparts. Lastly, the motivation for attaining knowledge, and the interest in participating in professional development programs may be influenced by the life-cycle phases through which teachers commonly pass during their careers. Therefore, we asked the following research questions:

1. What are the attitudes of junior high school S&T teachers toward the five factors that characterize the mentor's role, and toward the mentor's contribution to the assimilation of the curricular changes?
2. What is the difference between the attitudes of teachers in Israeli-Arab and Jewish demographic sectors toward the five factors that characterize the mentor's role?
3. What are the correlations between the five factors that characterize the mentor's role, and the mentor's contribution to the assimilation of the curricular changes, as presented by S&T teachers?
4. Does the teachers' seniority influence their attitudes regarding the five factors that characterize the mentor's role, and with regard to the mentor's contribution to assimilation of the curricular changes?

2. Research design and methodology

A validated survey instrument was used to explore the S&T teachers' views of their mentors. The quantitative questionnaire included 47 statements, and was based on the five-factor mentoring model questionnaire of Hudson (2010) and Hudson and Skamp (2003). For instance, the feedback factor included statements regarding the observation of teaching for feedback ("the mentor watched my science lessons"), providing oral feedback ("the mentor assessed my teaching process"), etc. Table 1 lists additional statement categories that were used in the questionnaire to explore the other factors in the mentoring model (personal attributes, system requirements, pedagogical knowledge, modeling and the mentors' contribution to the assimilation of the curriculum changes). Responses to questionnaire items were on a 5-point Likert scale (i.e., strongly disagree = 1, disagree = 2, uncertain = 3, agree = 4, strongly agree = 5).

The sample included 59 junior high school teachers (41% Jews, n = 24, and 59% Israeli Arabs, n = 35) after a 3-year-long mentoring experience. Teachers' ages ranged from 25 to 66 years (M = 41.66, SD = 9.27), and their teaching experience ranged from 1 to 38 years (M = 15.61, SD = 8.82). Mentoring sessions were held once every 3 weeks.

Huberman's (1989) study of a teacher's professional life cycle provided an initial framework for this study. Using this model, we divided the teachers into three seniority-based groups: (a) stabilization, (b) experimentation and activism, and (c) mid-career crisis. Stabilization (6 years of teaching) is the stage at which a decision is made about one's teaching career, accompanied by feelings of belonging, contentment, and security in the role. In our experience, this stage is characterized by high motivation to attain knowledge, and teachers often show an interest in participating in various professional development programs. Experimentation and activism (7–18 years of teaching) is the stage at which feelings of security allow the teacher to try new things, such as learning materials, teaching methods, teaching sequences, etc. Having more influence on what happens in the classroom may lead to one or more of the following outcomes: resistance to changes at the system level; awareness, accompanied by the desire to make changes, at the school level. The mid-career crisis stage (19 years and more) is characterized by doubts as to the continuation of the work, with the teacher maintaining a sense of monotony.

3. Results

The study addresses a five-factor mentoring model (i.e., personal attributes, system requirements, pedagogical knowledge, modeling, and feedback). Each factor has associated attributes and practices that were derived from the research literature about mentoring. A sixth factor was added, to examine the mentor's contribution to the assimilation of changes in the curricula.

3.1 Teachers' attitude toward mentor characteristics

We asked the junior high school S&T teachers what their attitudes were toward the five factors that characterize the mentor's role, and toward the mentor's contribution to assimilation of the curricular changes. To compare the teachers' attitudes toward all of the mentoring-related factors, means, standard deviations, and percentage of teacher agreement were calculated for each factor, as well as for the general attitude (Table 1).

Table 1. Means and standard deviations for teachers' attitudes toward the mentor's manifestation of the various factors (n = 59).

Factors and topics (based on total number of statements)	Percentage of teachers who agreed greatly and strongly	Mean (1–5) (standard deviation)
Personal attributes (based on 10 statements regarding: was supportive, felt comfortable talking, instilled positive attitudes, listened attentively, instilled confidence, etc.)	74.57	3.96 (0.78)
System requirements (based on 4 statements regarding: discussed aims, discussed policies, outlined curriculum, etc.)	76.25	4.11 (0.78)
Pedagogical knowledge (based on 10 statements regarding: discussed content knowledge, discussed science problem-solving, assisted with teaching and assessment strategies, assisted with timetabling, etc.)	75	3.92 (0.73)
Modeling (based on 10 statements regarding: used syllabus language, modeled a well-designed lesson, displayed enthusiasm, modeled effective science teaching, etc.)	64.73	3.59 (0.82)
Feedback (based on 6 statements regarding: observed teaching for feedback, provided feedback, reviewed lesson plans, etc.)	51.11	2.96 (0.88)
Mentor's contribution to the assimilation of changes in the curricula (based on 7 statements regarding: helped to implement innovations and changes in the curriculum, frequency and atmosphere of the meetings, and seriousness in promoting teaching, etc.)	72.87	3.89 (0.68)
Total attitude (based on 47 statements)		3.75 (0.70)

The overall attitude of the 59 teachers regarding their mentors' role and contribution to the assimilation of changes in the curricula was a mean scale score of 3.75 (SD = 0.70). Cronbach's α for each key factor—personal attributes (74.57% greatly or strongly agreeing with mean scale score = 3.96, SD = 0.78), system requirements (76.25% greatly or strongly agreeing with mean scale score = 4.11, SD = 0.78), pedagogical knowledge (75% greatly or strongly agreeing with mean scale score = 3.92, SD = 0.73), modeling (64.73% greatly or strongly agreeing with mean scale score = 3.59, SD = 0.82), feedback (51.11% greatly or strongly agreeing with mean scale score = 2.96, SD = 0.88), and contribution to the assimilation of changes in the curricula (72.87% greatly or strongly agreeing with mean scale score = 3.89, SD = 0.68)-was 0.87, 0.73, 0.87, 0.89, 0.76, and 0.71, respectively. The attitude toward the element of feedback (i.e., observed teaching for feedback, provided feedback, reviewed lesson plans, etc.) was lowest, with the lowest percentage of teachers who agreed greatly or strongly. However, the attitude toward the system requirements (i.e., discussed aims, discussed policies, outlined curriculum, etc.) was highest, with the highest percentage of teachers agreeing greatly or strongly (Table 1).

3.2 The attitude of teachers from different demographic sectors toward mentor characteristics

There is growing interest in examining mentoring as rooted in the context of multicultural settings (Orland-Barak, 2010). Since scholarly discourse usually regards teachers in the Israeli-Arab demographic sector as more traditional in their teaching (Abed & Dori, 2013), we examined the difference between the teachers' attitudes in Israeli-Arab and Jewish demographic sectors toward the mentors' characteristics in relation to the factor model. A t-test was performed for two independent samples (Table 2).

Table 2. Means, standard deviations, and t-test difference values between Jewish and Israeli-Arab teachers' attitudes regarding the mentor's manifestation of the various factors (n = 59).

Factors	Sector	N	Mean	Standard deviation	t(57)
Personal attributes	Arab	35	3.89	0.80	-0.795
	Jewish	24	4.06	0.75	
System requirements	Arab	35	4.07	0.77	-0.407
	Jewish	24	4.16	0.81	
Pedagogical knowledge	Arab	35	3.90	0.72	-0.234
	Jewish	24	3.95	0.77	
Modeling	Arab	35	3.59	0.87	-0.052
	Jewish	24	3.60	0.75	
Feedback	Arab	35	2.98	0.83	0.194
	Jewish	24	2.93	0.97	
Mentor's contribution to the assimilation of changes in the curricula	Arab	35	3.98	0.65	1.216
	Jewish	24	3.76	0.73	
Total attitude	Arab	35	3.74	0.71	-0.084
	Jewish	24	3.76	0.70	

$p < 0.05$

There were no significant differences between the Jewish and Israeli-Arab teachers in their attitudes toward the mentor's work and contribution to assimilation of the curriculum change.

3.3 Correlations between the factors characterizing the mentor's role

Our third research question was related to the correlations among the five factors that characterize the mentor's role, and the mentor's contribution to the assimilation of the curricular changes, as presented by S&T teachers. A Pearson's correlation coefficient was calculated (Table 3) to detect differences between the teachers' attitudes regarding the various mentor characteristics in relation to the five factors.

Table 3. Pearson's correlation between teachers' attitudes regarding the mentor's manifestation of the various factors.

	System requirements	Pedagogical knowledge	Modeling	Feedback	Mentors' contribution to the assimilation of curriculum change	General attitude
Personal attributes	.820***0	.864***0	.859***0	.657***0	.702***0	.927***0
System requirements		.869***0	.857***0	.622***0	.682***0	.894***0
Pedagogical knowledge			.899***0	.739***0	.743***0	.959***0
Modeling				.725***0	.736***0	.957***0
Feedback					.507***0	.793***0
Mentors' contribution to the assimilation of curriculum change						.806***0

$^{**}p < 0.01$, $^{***}p < 0.001$.

Significant and statistically robust positive correlations were found between the examined mentoring-related factors. Namely, teachers who were more likely to believe that mentors have positive interpersonal communication skills were also inclined to believe that mentors are familiar with the new curriculum, and that they are experts in pedagogy. Furthermore, these teachers tended to believe that mentors use modeling, provide feedback, and make a positive and substantial contribution to the introduction of change into the curriculum. Overall, the teachers showed positive attitudes toward the mentors' work and contribution, as well as toward the remaining mentoring-related factors.

3.4 Influence of teachers' seniority on their attitudes toward mentor characteristics

The fourth and final research question related to the impact of the teachers' seniority on their attitudes toward the five factors that characterize the mentor's role, as well as toward the mentor's contribution to the assimilation of the curricular changes. We first examined the correlation between the teachers' years of experience (seniority) and their attitudes toward the mentor's performance and contribution to implementing change. To investigate possible correlations between seniority and teachers' attitudes regarding the mentioned factors, a one-way ANOVA was performed. The range of teacher seniority was divided into three categories. The first category included teachers with 1 to 6 years of teaching experience, the second, 7 to 18 years of experience, and the third, 19 or more years of experience (Table 4).

Table 4. Means, standard deviations and F-test for the teachers' attitudes on the mentor's manifestation of the various factors according to their seniority (n = 59).

Factors	**Seniority (years)**	**N**	**Mean**	Standard deviation	**F**
Personal attributes	1-6	11	3.89	0.91	1.718
	7-18	32	3.83	0.81	
	19 and over	16	4.26	0.54	
	Total	59	3.96	0.78	
System requirements	1-6	11	4.02	0.83	2.078
	7-18	32	3.97	0.87	
	19 and over	16	4.44	0.42	
	Total	59	4.11	0.78	
Pedagogical knowledge	1-6	11	3.87	0.77	0.580
	7-18	32	3.85	0.81	
	19 and over	16	4.09	0.53	
	Total	59	3.92	0.73	
Modeling	1-6	11	3.67	0.91	1.951
	7-18	32	3.42	0.86	
	19 and over	16	3.89	0.58	
	Total	59	3.59	0.82	
Feedback	1-6	11	3.08	1.24	0.524
	7-18	32	2.85	0.81	
	19 and over	16	3.09	0.74	
	Total	59	2.96	0.88	
Mentors' contribution to the assimilation of curriculum change	1-6	11	3.99	0.65	0.908
	7-18	32	3.78	0.70	
	19 and over	16	4.04	0.68	
	Total	59	3.89	0.68	
General attitude	1-6	11	3.76	0.82	1.379
	7-18	32	3.63	0.72	
	19 and over	16	3.98	0.53	
	Total	59	3.75	0.70	

The findings presented in Table 4 indicate a lack of significant difference between teachers' seniority and their attitudes toward the various mentoring-related factors displayed by the mentor. The teachers' attitudes regarding all factors were positive, regardless of seniority.

4. Conclusions and discussion

This study investigated the views of in-service junior high S&T teachers regarding mentoring practices involving five factors (personal attributes, system requirements, pedagogical knowledge, modeling, and feedback), as well as mentor contribution to the assimilation of curriculum changes, since mentoring may have substantial potential to bring about reform.

Two limitations of the study were the relatively small sample of teachers (59), and the closed-ended questionnaire that did not allow for more flexible responses. However, the results showed that most mentee teachers had positive attitudes toward the mentoring, with differences in percentages for the various mentoring-related factors, as well as for the contribution to the assimilation of the changed curricula. All mentoring-related factors were rated from a moderate to high level, and the average attitudes toward various parameters ranged from 2.96 to 4.11 on a 5-point Likert scale (1, strongly disagree, and 5, strongly agree). Thus, the research supports previous studies regarding teachers' perception of the mentor's role and the fact that mentoring can be a valuable process in educational reform (Hudson, 2007).

We hypothesized that positive correlations would be found among the mentoring-related factors. The hypothesis was confirmed, and it was determined that S&T teachers are generally positive about the mentoring-model factors that we investigated: personal characteristics, system requirements, pedagogical knowledge, modeling, feedback, plus the mentor's contribution to the assimilation of changes in the new curricula.

A search for correlations between teachers' background variables (seniority or demographic sector) and their attitudes toward the mentor's manifestation of the various factors and contribution to assimilation of curricular changes did not reveal any significant differences distinguishing teachers from their peers. Namely, there was no distinction according to demographic sector (Jewish and Israeli Arab) or seniority (a new teacher and an experienced one).

Avargil, Herscovitz, and Dori (2013) declared that to be sustainable and implement large-scale educational reform, one should account for culture. In addition, Orland-Barak et al.'s (2013) study supports the contention that the cultural features of a mentoring context do indeed play a crucial role in determining what the practice looks like. They reasoned that preparation programs for mentors should highlight awareness of the mentors' own culture as well as that of their mentees, to implement a culturally responsive practice. In contrast, we refuted this hypothesis, as we found no distinction based on demographic sector (Jewish and Israeli Arab) regarding attitude toward mentors' characteristics. Although according to Abed and Dori (2013), Israeli-Arab teachers are usually more traditional in their teaching, it seems that the different cultures or demographic sectors do not play a crucial role when mentoring is viewed as reform-driven (i.e., focused on changing teachers' attitudes and practices related to the implementation of innovative teaching methods at schools, and seeking to raise pupils' academic achievements).

Moreover, we hypothesized that S&T teachers would have different attitudes, based on their seniority, toward the mentor's manifestation of the various factors. Based on Huberman's (1989) study of the professional life cycle of teachers, we assumed that mentee teachers have diverse motives for participating in a mentoring program, where they attain knowledge from the mentor during the various teaching stages of stabilization, experimentation–activism, and mid-career crisis. The findings refute this hypothesis, and suggest that all teachers, regardless of their seniority and teaching experience, have the same attitude, whereby the mentor is perceived as being functional and contributing to the assimilation of curricular changes.

These findings reinforce the argument that teachers, as adult learners, are favored with andragogic learning characteristics expressed as a readiness for learning, focusing on the problem situation, directing oneself toward effective learning, and having motivation as a driving force (Rahimi-Shafran, 2001). Specifically, in the case of educational reform, all S&T teachers focused on the problem situation and were involved with the assimilation of the curricular change, which led them to seek learning opportunities. Consequently, the mentor was important for all of the S&T teachers in the study, regardless of seniority. In other words, the mentoring was a valuable process in educational change, not only for the new teachers, but also for the experienced ones. Support for new teachers' practical teaching will contribute to the stability of the school's teaching staff, and will also create new spheres in the professional development of experienced teachers (Ganser, 1996 in Koki, 1997). Many studies indicate that in-service training activities can improve teacher efficiency (Brinson & Steiner, 2007). The mentee S&T teachers indicated that mentoring during the period of curriculum change improved their efficiency. Suitable teacher training combined with mentor-led teacher participation in dilemmas created during curricular decision-making may improve overall teacher performance, and create a work environment that deepens the teachers' commitment to the school, and assimilation of curricular change.

This may indicate that the mentors' training provided them with pedagogical and organizational knowledge and skills which contributed greatly to their suitability for their role. However, mentors need to improve the feedback factor to develop their mentoring and enhance their teachers' professional development. In other words, mentors need to help more in preparing lesson plans/tests, demonstrate ways to develop a good relationship with students during science lessons, observe lessons, and give feedback. Mentors need to improve and strengthen these aspects of their training.

The model in which each mentor was responsible for the teaching staff in a specific school, district, or demographic sector, and met with the school staff on a monthly basis during the in-service training (built in to the mentor's work week), produced good results in terms of the mentees' experiences. This model provided the mentor and mentee teachers time to discuss and debate relevant issues, such as ways to assimilate curricular change. Moreover, since the mentors were in regular contact with the Ministry of Education supervisors, their monthly mentoring sessions at the schools helped bridge the teachers' immediate needs with the set of policies that were had been handed down. In this way, the mentors contributed to the assimilation of curricular change. However, in addition to the mentoring processes, the framework of in-service professional development courses also needs to deal with the preparation of lesson plans and tests.

To sum up, the goal of this study was to examine S&T teachers' attitudes toward their mentor's performance, and toward the mentor's contribution to the assimilation of curriculum changes. The study also explored whether teachers' backgrounds affect these attitudes. The findings indicate that the S&T mentors have a valuable role in introducing and implementing curriculum changes, particularly regarding the top-down change required by the Ministry of Education. These research findings suggest that there may be implications for policy-makers, especially when it comes to curriculum change in a specific subject area, directed by a top-down change process, and with limited teacher resistance to the required change.

Since S&T mentors may be the link between curricular change design and its assimilation in the field, i.e. functioning as reform-driven, we propose to add mentoring to Zohar's (2008) model of implementation of large-scale educational reform. We argue that the model of implementation consists of introducing simultaneous, large-scale, ongoing changes in the following four domains: (a) curricula, standards, and learning materials, (b) extensive professional development, (c) assessment, and (d) mentoring. This implementation model seeks to align the mentoring with assessment, curricular learning materials, and teachers' professional development to create a well-coordinated and consistent change process (Figure 1).

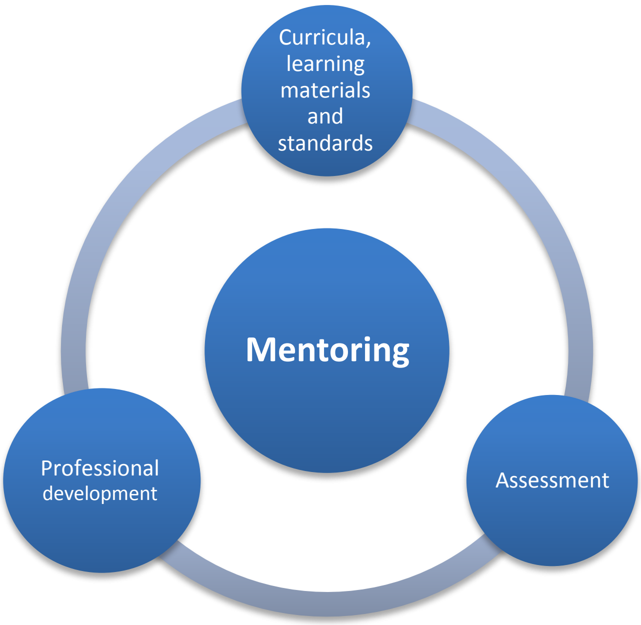

***Figure 1*:** Mentoring as a central component in a model for implementation of a large-scale education change.

We recommend using the model illustrated in Figure 1 for the implementation of a large-scale education change. Nevertheless, more research is needed to examine whether using this specific model will limit teachers' resistance to change, and contribute to the success of the introduction and assimilation of change.

In addition, researchers and mentoring program designers need to further their understanding of teachers' perception regarding mentoring practices, to provide professional development for mentors, and highlight the potential of mentor–teacher relationships, especially when assimilation of a reform or changed curriculum is necessary. Future research should be conducted to examine the impact of this mentor-training plan on teachers' professional development, given the worldwide trend to reform the S&T curriculum.

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5 DEVELOPING AN INTERACTIVE METHOD TO MAP STUDENT PERSPECTIVES ON EVOLUTION

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Abstract

This paper reports the development of a new diagnostic tool for student conceptions in the field of evolution theory. The tool combines open-format and closed-format data sampling to provide an effective, but still accurate picture of student conceptions. The open phase is a writing assignment, where students are asked to explain an evolutionary phenomenon in a free text. Then, the text authors categorize 24 pre-formulated explanations as either 'contained' or 'not contained' in their text, or as 'not in my text but potentially true'. We report results from an in-depth usability test (n = 9, age 10 to 17 years) indicating a big gap between our open- and closed-format data on student conceptions. This may partly be due to language aspects. Furthermore, the students categorized a high number of explanations as 'plausible', even if they had not written them in their text. This indicates that in the sample group at least, evolution was not linked to a static conceptual framework, but rather to a 'space of possibilities' opened up by the tool. Therefore, this new way of mixed-method sampling seems to be sensitive to what diSessa (2002) calls the learner's 'conceptual ecology'.

Keywords

Evolution; explanation; mixed method; conceptual change; construction in interaction

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction and theoretical background

In the field of evolution theory, students tend to stick with their own non-scientific explanations, especially teleological ones (e.g. Halldén, 1988; Wandersee, Good & Demastes, 1995). Many researchers have developed tests to depict learners' conceptions. One of them is the CINS (Conceptual Inventory of Natural Selection) (Anderson, Fisher & Norman, 2002), a multiple-choice 20-item test which has been modified for use from middle school through college (Evans & Anderson, 2013). As Nehm and Ha (2011) pointed out, conceptions depend on the context of the assessment. The ACORNS (Assessing Contextual Reasoning about Natural Selection) instrument (Nehm, Beggrow, Opfer & Ha, 2012) takes this into consideration. It can also be used online to evaluate written explanations automatically (Moharreri, Ha & Nehm, 2014). However, the classical view on conceptual change has been challenged by the idea of a more complex and more flexible 'conceptual ecology' (diSessa, 2002). Geraedts and Boersma (2006, see also Boersma & Geraedts, 2012) questioned the widespread idea of stable and consistent 'Lamarckian' conceptions. They introduced a 'construction-in-interaction framework' which suggests that explanations are context-dependent and instantaneously constructed.

In sampling data on learners' conceptions, researchers are faced with a methodological dilemma: quantitative methods tend not to be accurate enough, as closed items do not allow students to express their own ideas. Open sampling formats, on the other hand, only allow small sample groups, which makes them impossible to use as an everyday diagnostic tool in the classroom. Therefore, we are developing a new type of mixed method to depict student perspectives in a quick and easy way on a classroom scale. Our diagnostic instrument is designed to measure prominent (stable) as well as potential (consistent) explanations through a mixed-methods design (Tashakkori & Creshwell, 2007). The idea is based upon 'Darwin's landscape' (Zabel & Gropengiesser, 2011), a method of mapping content-specific learning progress within a mental landscape, entirely based on free texts. To save time without losing the necessary level of precision, our strategy is to combine open- and closed-format sampling methods. Learners formulate free texts and then evaluate those texts themselves by comparing them to pre-formulated explanations. One objective of this combined method is to sample a broad range of learner conceptions, both prominent and potential, while using only a single context. Furthermore, as the test procedure encourages the students to reflect on their own explanations and thoughts, it is potentially suitable for the initiation of learning processes. It might therefore serve, in the course of evolution instruction, as a good base for further classroom discussion.

2. Key objectives

Our principle objective is to develop a new type of mixed-method test to depict student perspectives on a classroom scale, in order to improve the effectiveness of teaching the biological topic of evolution theory. For this purpose, we created a two-phase diagnostic tool. In phase 1, students formulate their own explanation for a given evolutionary phenomenon. In phase 2, they choose among a given set of explanations, thereby referring to what they wrote in phase 1. In addition, they can label pre-formulated explanations that they did not consider in phase 1, but nevertheless hold to be 'potentially true'. With the help of an in-depth usability test, we intend to evaluate this diagnostic instrument in terms of how the students handle it and which parts or items should be modified, and also to assess its innovative potential for classroom use. Our study includes the following research questions:

1. To what extent is a combination of open- and closed-format tests able to measure prominent (stable) and potential (consistent) explanations?
2. To what extent are students able to categorize their freely formulated texts, using pre-formulated explanations in a closed format?
3. How homogeneous are the three pre-formulated explanations of each explanation pattern in the students' view?
4. What indications can be found for the potential use of the diagnostic tool as a formative assessment tool, or as a teaching tool for evolution?

3. Research design and method

The diagnostic tool itself in its 'classroom version' consists of only two consecutive phases (Figure 1). For our own evaluation purposes, we added another two phases (3 and 4, see section 3.2) as a usability test (n = 9). We chose pupils from different types of schools and of different ages (10-17 years) to get a first impression of the applicability of our diagnostic tool. The setting for the data collection was a one-to-one situation at the students' school or home. The whole test was audiotaped.

3.1 Diagnostic tool (phases 1 and 2)

Phase 1 is a writing assignment, in which students are asked to explain an evolutionary phenomenon in a free text: the evolution of modern whales from their terrestrial ancestors (Zabel & Gropengiesser, 2011). Three naturalistic drawings are provided: a contemporary blue whale and two extinct whale ancestors, one terrestrial and one semi-aquatic. No other information, except for the age of the fossil species (50 million/45 million years), is given to the students. In phase 2, the text authors are asked to categorize a total number of 24 pre-formulated explanations as either 'contained in my text' or 'not contained in my text'. A third category allows them to classify an item as 'not in my text but potentially true'.

All 24 items were formulated based on eight empirically found explanation patterns of 13-year-old students (n = 214 texts). For detailed explanations of these categories, and anchor examples, see Zabel and Gropengiesser (2011). We designed 3 items for each of the explanation patterns and all 24 items were presented to the students on separate cards. Table 1 shows all items. The explanation patterns were:

- Environment causes evolution (ENVI)
- Need causes evolution (NEED)
- Intentional adaptation of individuals (INT-I)
- Intentional adaptation over generations (INT-G)
- Usage of organs (ORGA)

- Evolution through interbreeding (BRED)
- Evolution by variation of a type and natural selection (SEL-T)
- Evolution by full variation and natural selection (SEL-P).

3.2 Usability test (phases 3 and 4)

We performed an in-depth usability test (n = 9, grades 6 to 12, ages 10 to 17 years) to evaluate our diagnostic tool (Figure 2). In phase 3, students were asked to form eight groups from the 24 items, with each group containing up to three items. Items could also be categorized as 'not assignable'. The purpose of this procedure was to assess the homogeneity of the three test items within each explanation category, and consequently the discriminatory power of the eight categories. During phases 2 and 3, students were asked to express their thoughts and difficulties while working on the task (thinking aloud, audiotaped). In phase 4, all of the students were briefly interviewed directly after the test procedure. All interviews were individual and semi-structured, focusing on the handling of the test instrument and the student's motivation to work with it. The whole testing procedure was audiotaped to supplement the researcher's notes in case anything was unclear. As a peripheral data source, these audiotapes were not transcribed verbatim.

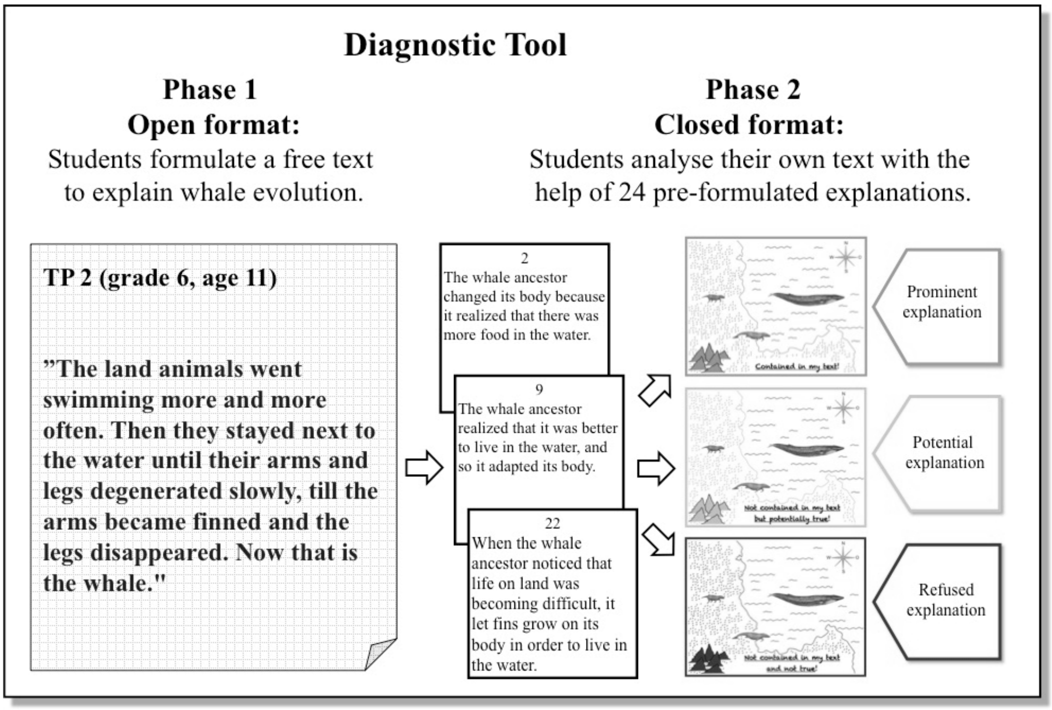

Figure 1. The two phases of the diagnostic tool. In phase 1, students formulate their own explanation for a given evolutionary phenomenon. In phase 2, they make a choice within a given set of explanations, thereby referring to what they wrote in their text in phase 1. In addition, in phase 2, they can label pre-formulated explanations that they had not considered in phase 1.

Table 1. All 24 items of the eight explanation patterns.

Environment causes evolution (ENVI)	
1	Due to contact with its environment, the whale ancestor changed over generations.
2	The stay of the whale ancestor in the water provoked the change.
3	The long time period made the whale ancestor change.
Need causes evolution (NEED)	
1	Nature provided the change in the whale ancestor.
2	Nature made sure that the whale ancestor had the attributes it needed to survive.
3	Nature instigated the change in the whale ancestor.
Intentional adaptation of individuals (INT-I)	
1	The whale ancestor changed its body because it realized that there was more food in the water.
2	The whale ancestor realized that it was better to live in the water, and so it adapted its body.
3	When the whale ancestor noticed that life on land was becoming difficult, it let fins grow on its body in order to live in the water.
Intentional adaptation over generations (INT-G)	
1	The whale ancestor adapted to life in the water, and made its offspring inherit its aquatic traits.
2	The whale ancestor changed its body so that it could swim better. It handed down this advantage to its children.
3	The whale ancestor chose the best genes for its descendants so that they could live in the water.
Usage of organs (ORGA)	
1	The whale ancestor changed by using some organs more often than others.
2	As the whale ancestor swam a lot, its tail changed to a fin.
3	The whale ancestor's legs degenerated, as it was not using them anymore.
Evolution through interbreeding (BRED)	
1	A whale ancestor cross-bred with an aquatic animal, and so it had children that could live both on land and in the water.
2	The whale ancestor bred with an aquatic animal. This allowed its children to live better in the water.
3	The whale ancestor reproduced with a water animal. Therefore, its children got fins.
Evolution by variation of a type and natural selection (SEL-T)	
1	By chance, one whale ancestor was better adapted to the water than the others. Thus, it could find more food and have more children.
2	In a group of whale ancestors, by chance, one was different. It could swim much better and therefore it found more food.
3	By chance, a whale ancestor was born with fins. It survived in the water, while the others starved on land.
Evolution by full variation and natural selection (SEL-P)	
1	No whale ancestor in a group was similar to another. Some could swim better by chance. So they found more food and proliferated more.
2	In a group of whale ancestors, everyone had slightly different features. Some could already find their food in the water, while the others died out on the land.
3	All whale ancestors in a group were a bit different from each other. As the food on land got scarce, those individuals which were better adapted to the water survived.

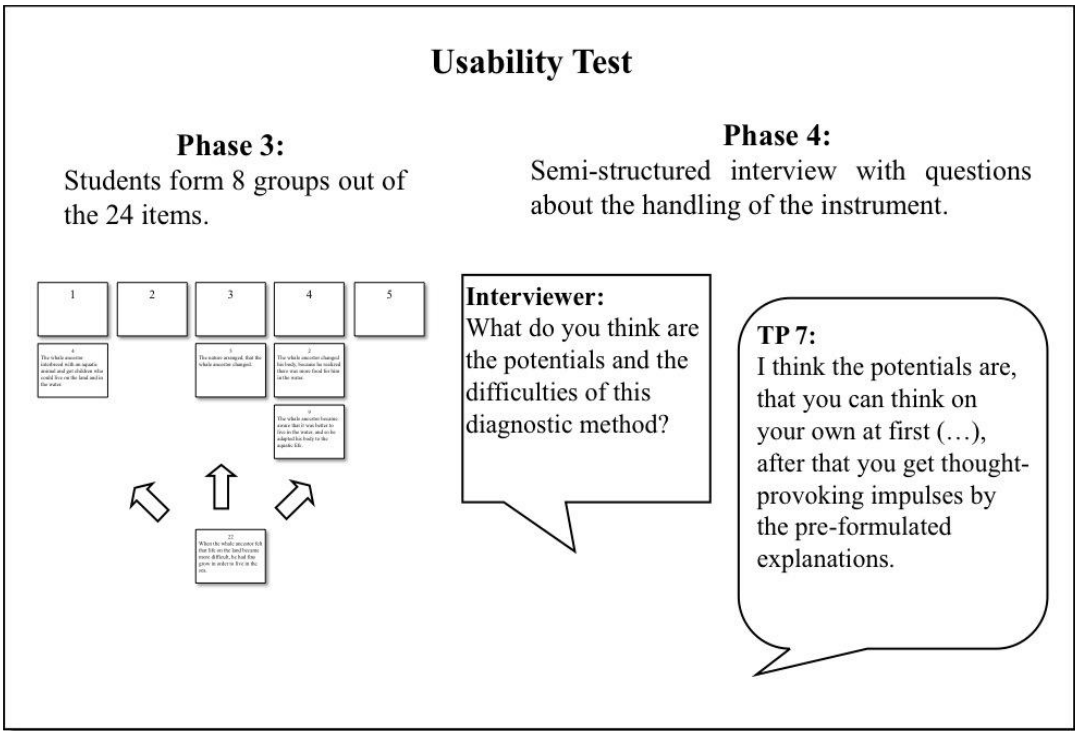

Figure 2. Usability test. Phase 3 was designed to assess the homogeneity of the three test items within each explanation category. Students were asked to form eight groups from the 24 items, with each group containing up to three items. Items could also be categorized as 'not assignable'. Phase 4 is a short individual interview.

3.3. Data analysis

3.3.1 Phases 1 and 2

We used Qualitative Content Analysis (Mayring, 2007), based on eight explanation patterns documented in the literature, to analyze the students' texts for explanations for whale evolution (Zabel & Gropengiesser, 2011).

To assess how accurately the text authors described their own text with the help of these items, we analyzed their texts for explanations and then evaluated their own choice of items. Each item categorized as 'contained in my text' was compared to the student's text through professional text analysis, to assess whether it really contained the respective explanation. The assessment was repeated with the items categorized as 'not contained in my text and potentially true' and 'not contained in my text and not true'. Based on the number of matching or non-matching categorizations in the whole sample group, we calculated the consensus rate for each student (Table 2), each item and each explanation pattern (Table 3).

3.3.2 Phase 3

By adding the individual test results of the nine students, we calculated (1) how often one particular item was grouped with other items overall, and (2) how correct these groupings were with respect to the explanation category. Through this procedure, we calculated the Quotient of Homogeneity (QH) for each item x (formula 1).

$$QH_{item\ x} = \frac{sum\ [items\ correctly\ grouped\ with\ item\ x]}{sum\ [all\ items\ grouped\ with\ item\ x]} \qquad (1)$$

We also calculated the QH for all of the explanation patterns with items y_1 to y_n using formula 2, where n is the total number of items in the explanation pattern. In our study, n = 3.

$$QH_{explanation\ pattern\ y} = \sum_{i=1}^{n} \frac{[items\ correctly\ grouped\ with\ item\ yi\ ]}{[all\ items\ grouped\ with\ item\ yi]} \qquad (2)$$

High QH values indicate that students perceive the respective item or pattern as being rather different from the other items and explanation patterns. Small QH values, in contrast, indicate that students could not clearly distinguish it from items of other explanation patterns (Table 4)(TABLES 2 AND 3 NOT MENTIONED YET).

4. Findings

4.1 Overall results

In phase 1, only six out of nine students produced texts with any explanations at all; the remaining three texts were categorized as 'mere descriptions of evolutionary change'. This proportion of descriptions instead of explanations has been found to be quite usual in pre-instructional texts, even when one of the students had already received instruction on the Theory of Evolution (Zabel & Gropengiesser, 2011). In phase 2, the nine tested students considered 4.6 of the 24 explanations to be 'contained in their text' (prominent explanation). The professional text analysis revealed that only a third of these assignments (1.6) was indeed correct, while the remaining two-thirds could not be confirmed by the expert (Figure 3), indicating a high number of false positive assignments. Interestingly, even two of the authors of mere descriptions believed to have explained whale evolution in their texts (Table 2). As to the 'potentially true' and 'not true' explanations, phase 2 of our diagnostic tool was quite fruitful (Table 2): on average, each student assigned 8.2 items as 'potentially true' and 11.2 as 'not true' (Figure 3, Table 2). All of these assignments proved to be 'accurate' in the sense that all of these explanations were indeed absent from the respective author's text (see section 4.3).

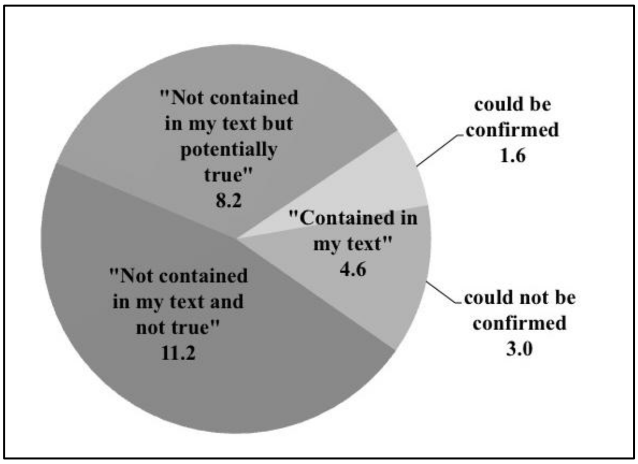

Figure 3. Mean values for assignment of the 24 pre-formulated items to the students' texts. In phase 2, the sample group (n = 9) was asked to assign all 24 items to one of the three categories 'contained in my text', 'not contained in my text but potentially true' or 'not contained in my text and not true'. The sections of the diagram indicate the average number of assignments per student in each of these categories. However, of the 4.6 items labeled as 'contained in my text', only one-third (1.6) proved to be correctly assigned, while the remaining 3.0 were 'false positive' assignments. This was revealed by a professional text analysis that compared text and items (see also Table 2).

Table 2. Assignment of items by each test person (TP). For the entire sample group (n = 9), the table indicates the explanation pattern(s) found in the student's text, and the student's own assignment of the 24 items. All columns based on expert analysis are shaded; for example, TP 1 considered a total of seven items to be contained in his text. Four of them could indeed be confirmed by the expert, resulting in a consensus rate (CR) of 57%. TP 3, TP 4, and TP 8 only provided descriptions of the evolutionary event in their text; nevertheless, TP 3 and TP 4 assigned explanatory items to it. The last column indicates which of the students had already received education in the theory of evolution.

TP	**Age**	**Explanation pattern in the text**	**'contained'**	**con-firmed**	**CR**	**'potentially true'**	**'not true'**	**Education in theory of evolution**
1	16	INT-I and SEL-T	7	4	57%	6	11	Yes
2	11	ENVI	6	2	33%	9	9	No
5	14	ENVI	3	2	67%	11	10	No
6	10	INT-I	2	0	0%	5	17	No
7	17	SEL-T and SEL-P	4	3	75%	4	16	Yes
9	16	INT-I	8	2	25%	7	9	Yes
3	13	no explanation	6	0	0%	9	9	No
4	15	no explanation	5	0	0%	11	8	No
8	17	no explanation	0	-	100 %	12	12	Yes
Mean value			4.6	1.6	40%	8.2	11.2	

4.2 Item homogeneity and discriminatory power

Phase 3. revealed how the students understood the meaning of our items, and whether the three items of one explanation pattern appeared to be sufficiently similar in their eyes. High QH values of an explanation pattern indicated that items of this pattern were mostly grouped with other items of the same pattern. In other words, QH is an indicator of item reliability and discriminatory power. As shown in Table 4, the QH values calculated for the different explanation patterns ranged from 0.26 (INT-I) to 0.62 (NEED). The table also indicates which other explanation patterns were frequently confounded with the pattern to be analyzed. For example, the pattern 'Usage of organs' (ORGA) was quite homogeneous (QH 0.61), but its items were nevertheless hard to discriminate from those of 'Intentional adaptation of individuals' (INT-I, item 3) and of 'Intentional adaptation over generations' (INT-G, item 2).

4.3 Item validity

Even if the three items of a pattern appeared to be quite similar from the students' perspective, this does not mean that the students understood the meaning of the items correctly (validity), as the consensus rates of the explanation patterns in Table 3 indicate. A closer look at the assignment data, using the results of phase 3, suggests that the sample group misinterpreted some of our pre-formulated items. For example, the explanation category NEED was not found in the texts of those who believed to have used it, although the three NEED items were perceived as being quite homogeneous (QH 0.62, Table 4). Another category with validity problems was ORGA: it also had homogenous items (0.61), but none of the four 'contained' assignments for ORGA items proved to be correct.

Table 3. Assignment of items by explanation pattern. For all eight explanation patterns, the table indicates how often the students assigned one of the three items to their text, either as being 'contained' in it, as 'potentially true', or as 'not true'. All items were assigned to one of these three options, so that the sum of all assignments in one line is always 27 (3 items x 9 students). The consensus rate (CR) expresses the correctness of the 'contained' assignment. For example, with respect to the INT-I explanation pattern, only 4 out of 6 assignments were correct.

Explanation	'Contained'	Con-firmed	CR	'Potentially true'	'Not true'
ENVI	13	4	30%	7	7
NEED	6	0	0%	12	9
INT-I	6	4	67%	9	12
INT-G	4	0	0%	10	13
ORGA	4	0	0%	14	9
BRED	0	-	-	2	25
SEL-T	5	4	80%	6	16
SEL-P	3	1	33%	14	10
Mean value	*5.1*	*1.9*	*30%*	*9.3*	*12.6*

Table 4. The quotient of homogeneity (QH) for the eight explanation patterns. High QH values indicate that students mostly grouped these items with items of the same pattern (reliability). Nevertheless, the students may have understood the meaning of the items incorrectly (validity), as the consensus rates of the explanation patterns in Table 3 indicate (n = 9).

Explanation	**QH**	**ENVI**			**NEED**			**INT-I**			**INT-G**			**ORGA**			**BRED**			**SEL-T**			**SEL-P**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
ENVI	0.46	**7**	**8**	**7**	4	1	2	1	3	-	6	3	2	-	1	-	1	1	-	-	1	-	-	-	-
NEED	0.62	3	-	4	**12**	**11**	**11**	1	1	-	-	2	5	1	1	-	-	-	1	-	-	-	1	1	-
INT-I	0.26	-	3	1	1	1	-	**6**	**4**	**4**	1	3	1	1	2	3	-	2	1	1	4	3	2	7	3
INT-G	0.27	5	3	3	1	4	2	1	3	1	**6**	**6**	**4**	2	3	2	4	2	3	4	-	1	-	-	-
ORGA	0.61	-	1	-	-	1	1	-	-	6	-	5	2	**13**	**10**	**13**	1	-	1	-	1	3	1	1	-
BRED	0.59	1	1	-	-	-	1	-	3	-	4	3	2	-	2	-	**12**	**12**	**12**	4	1	2	-	-	1
SEL-T	0.30	-	1	-	-	-	-	4	2	2	3	1	1	1	1	2	3	2	2	**7**	**5**	**6**	9	5	4
SEL-P	0.37	-	-	-	1	1	-	5	3	4	-	-	-	1	-	-	-	1	-	5	8	5	**5**	**6**	**9**

The two explanation patterns based on natural selection, SEL-T and SEL-P, showed the opposite problem. Students recognized the SEL-T pattern in their own texts quite accurately (CR = 80%, Table 3), but it was apparently difficult for them to distinguish it from the more sophisticated SEL-P pattern. In contrast to SEL-T, SEL-P includes the idea of true variation in a group instead of only one individual that differs from all others (Zabel & Gropengiesser, 2011). For the students, however, this difference was obviously not visible in our items, as the low QH values of both patterns indicate (Table 4).

In contrast to the students' positive assignments, which often proved to be false, the 'potentially true' and 'not true' assignments were correctly assigned by the entire sample group (CR = 100%). No explanation that had been characterized as 'potentially true' or 'not true' by a text author was actually found in his or her text (false negative). In contrast, two of the authors with merely descriptive texts categorized five (TP 4) or even six (TP 3) items as 'contained in my text' (false positive). Obviously, it was much easier for the students to recognize what they had *not* written in their text than to choose the items matching their own explanation.

4.4 Interviews

In the interviews, all students evaluated our diagnostic instrument as motivational and understandable. They mentioned that working with the pre-formulated explanations had opened their minds, and had made them start learning about evolution.

5. Discussion

Overall, our impression is that the diagnostic tool still has to be improved, but also shows some potential for the future of research and evolution teaching. Due to the small sample group in the usability test, the results are preliminary and can only reflect some tendencies.

5.1 Weaknesses of the method

The diagnostic instrument still bears some important weaknesses: the results indicate that there is a big gap between our open- and closed-format data on student conceptions. This may be partly due to the technical and language differences between the two sampling methods. In the science classroom, students often face problems in verbalizing their own thoughts adequately. The audio data from the students' voiced thoughts during phases 2 and 3 emphasize this, as some students said that particular items expressed exactly what they meant but had not been able to put into words in their text. On the other hand, the students misunderstood a considerable proportion of the items. Therefore, it could be advantageous to interview some students directly after phase 2. However, this gap between the open- and closed-format data also has a positive aspect: the interactive alignment of the method appears to qualify it not only for diagnostic purposes, but also for the process of teaching evolution. The combination of open and closed format potentially builds a bridge between the learners' own words and scientific language.

In addition, the partially low QH values in phase 3 show that some categories are not yet considered uniform. Therefore, it will be important to reformulate the items to enhance their homogeneity within the explanation patterns and to facilitate their discrimination from other patterns. For example, in the case of the two explanation patterns 'Evolution by variation of a type and natural selection' (SEL-T) and 'Evolution by full variation and natural selection' (SEL-P), it could be helpful to use visual accents, such as italics, bolding or underlining, to illustrate that only *one* animal or *all* animals are involved in the evolution process.

5.2 Strengths and potentials of the method

The relatively high number of potential explanations compared to the number of prominent explanations indicates the ability of this diagnostic method to depict the 'ecological diversity' of the student perspective (di Sessa, 2002). This option of our diagnostic tool is interesting in the context of a 'construction-in-interaction framework' (Boersma & Geraedts, 2012), suggesting that the process of conceptual change is more fluid and context-dependent than the classical model assumes. It is quite impressive how many different explanatory models the students in our sample group hold plausible, even if they did not think of these explanations themselves in the first phase. This result suggests that, at least in this small and very heterogeneous group, there is no static conceptual framework when it comes to explaining evolutionary phenomena, but rather a 'space of possibilities'. If this result persists in future studies, the consequences for teaching and learning evolution theory might be interesting. It could be a fruitful strategy to open up this 'space of possibilities' through discursive, interactive practices in the classroom, rather than to fight conceptual frameworks.

Our next step will be to modify the items and test them on a middle-size sample group, including only phases 1–3 to reduce the effort put into time-consuming interviews while simultaneously yielding a bigger database. Once the items and procedures are optimized, the diagnostic tool can be used on a large sample.

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6 TEACHERS AS DESIGNERS: PROMOTING TEACHERS' PROFESSIONAL GROWTH AS MENTORS OF OUTDOOR INQUIRY

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Abstract

Inquiry outdoors may promote affective and social outcomes, as well as a deeper understanding of biology and environmental science concepts. However, teachers face various challenges while implementing this approach. Mobile technologies may provide solutions to some challenges, but teachers need support to learn to integrate these technologies into their teaching. We developed a special professional development program that applies a "teachers-as-designers" (TaD) approach in which teachers are involved in the design of learning materials. We exposed 24 environmental science teachers to a technology-supported learning environment (LE) which integrates mobile applications to support outdoor inquiry, and involved the teachers in the design of a similar LE. This study explores how the TaD approach contributes to teachers' professional growth in the context of mentoring inquiry learning outdoors using mobile technology. Data sources included: observations, teachers' documented activity in the team-customized LEs, and nine interviews. Findings indicate that all teachers acquired new knowledge regarding the integration of technology into their teaching, and some showed professional growth as reflected in changes they made in their classroom practice. The potential of the TaD approach to promote teacher growth is discussed.

Keywords
Teachers-as-designers; outdoor-inquiry teaching; mobile learning; professional development; teacher professional growth

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Rationale

This study integrated outdoor learning and inquiry learning. Inquiry learning has been a prominent component in science teaching for decades (Crawford, 2014). Learning outdoors, particularly biology and environmental sciences, can help students deepen their conceptual understanding and develop positive attitudes toward science and related fields (Storksdieck, 2011; Lavie Alon & Tal, 2015). Integration of inquiry and outdoor learning has great potential to leverage deep learning. The teacher's role in guiding inquiry outdoors is crucial for student learning, but it is not a simple task. Challenges of teaching inquiry outdoors stem from the complexity of supporting both inquiry and teaching in an unfamiliar environment (Tal, 2001). The teachers are faced with cognitive, emotional and logistic difficulties. Thus, teachers, who often see outdoor teaching as a burden avoid it, and often hire external guidance (Tal, Bamberger, & Morag, 2005). This happens even though teachers have a better background to serve as mediators in outdoor learning because they are familiar with their students' strengths and difficulties, and have the pedagogical knowledge to guide them accordingly.

Further research is required to acquire the theoretical and empirical grounds for promoting teacher independence in guiding inquiry outdoors. In this study, we offer a unique approach to supporting teachers in the complex mission of guiding inquiry outdoors and developing their skills as facilitators of this process. We designed a teacher professional development (PD) program to promote teaching inquiry outdoors. The PD model applies a "teachers-as-designers" (TaD) approach, by which teachers are involved in the design and development of a learning environment (LE) for their students, including a website and mobile applications that support outdoor inquiry. The goal of this research is to explore the contribution of the TaD approach to teachers' professional growth in the context of mentoring inquiry outdoors using mobile technology.

2. Theoretical framework

This study is grounded in three bodies of knowledge: *inquiry learning* outdoors (to promote learning of biology and environmental sciences), *mobile learning* (as a means for supporting inquiry learning outdoors) and *TaD* (as an approach for implementing outdoor inquiry mobile learning).

2.1 Outdoor inquiry teaching

Inquiry can be conducted in class, in the lab or outdoors. In addition to cognitive outcomes (e.g., understanding concepts), learning outdoors can enrich the learning experience and promote affective (e.g., attitudes and interest) and social (e.g., student–student interactions) outcomes (Rickinson et al., 2004; Tal, 2001). Despite the potential of outdoor teaching to promote learning in biology and environmental sciences, simply going outdoors does not necessarily result in positive outcomes. The pedagogy involved in outdoor teaching is crucial for achieving the desired learning outcomes (Orion & Hofstein, 1994). This pedagogy should encourage students to investigate the unique environment (Orion & Hofstein, 1994), and one way of doing so is through inquiry. Other important aspects are preparation and follow-up activities as a way of properly implementing outdoor activity, thereby integrating it into the science curriculum (Orion, 1993).

In her study, Crawford (2000) followed a successful practice of inquiry and identified 10 roles of inquiry teaching, such as the ability to motivate students, diagnose their understanding, and direct and support their strategy development. These various roles make inquiry teaching a complex task. Indeed, research has shown that teachers lack the scientific and pedagogical knowledge to successfully implement inquiry teaching (DeBoer, 2004; Tal & Argaman, 2005).

When it comes to outdoor inquiry teaching, teachers feel that they do not have enough scientific and pedagogical knowledge, and report emotional and logistical difficulties (Storksdieck, 2011; Tal & Argaman, 2005). These challenges result in abandoning inquiry and adopting a more didactic approach to their outdoor teaching, or, on the contrary, letting students wander freely in the environment (Bamberger & Tal, 2007). To promote inquiry outdoors, teachers should be supported and guided to overcome these challenges. Technology, when designed and used properly, can assist.

2.2 Mobile learning

Technology has the potential to support inquiry by providing students with scaffolds (De Jong, 2006), such as tools for organizing collected data, just-in-time guidance, or tools that support interactions and collaborative learning (Kali & Linn, 2007). The development of mobile devices (e.g., smartphones and tablets) has enabled expanding the scaffolding of inquiry beyond the classroom walls, a process which is defined as "mobile learning". Mobile learning is learning "through conversations across multiple contexts amongst people and personal interactive technologies" (Sharples, Taylor, & Vavoula, 2007, p. 224), and is highly relevant in outdoor inquiry. For instance, in addition to supporting the aforedescribed process offered by technology for inquiry learning, mobile devices can reduce teachers' load when simultaneously mentoring several groups in the field. In addition, the outdoor inquiry process includes learning in different spaces—indoors and outdoors—and mobile devices can support the process by linking the different environments—class, outdoors, and home (Kali, Sagy, Kuflik, Mogilevsky, & Maayan-Fanar, 2015). However, to appropriately integrate new approaches like mobile learning into their teaching, teachers need to be acquainted with them, value them and learn how to apply them.

2.3 TaD

PD can provide an opportunity for teachers to experience new approaches, and new technologies to promote those approaches. A successful PD program should encourage teachers to learn collaboratively, while sharing and reflecting on classroom practice (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). To advance the implementation of new approaches, such as outdoor inquiry teaching, teachers should experience those approaches (Tal, 2001).

Integrating inquiry teaching, outdoor teaching and the use of technology requires teachers to combine three different kinds of knowledge: technological, pedagogical and content. Koehler and Mishra (2005) name this special combination of knowledge types TPACK (technological, pedagogical and content knowledge, Table 1), based on Shulman's theory of pedagogical content knowledge (PCK) (Shulman, 1986).

Similar to Shulman's notion regarding PCK, the integration of two or three types of knowledge is considered a unique type of knowledge required for thoughtful use of technology. For example, a teacher who is experienced in outdoor inquiry teaching (PK) and has a good background in ecology (CK), does not necessarily know how to achieve the learning goals of ecology through inquiry outdoors (PCK). Moreover, even if teachers can productively teach ecology through inquiry outdoors (PCK), and thoughtfully use mobile applications (TK), it cannot be assumed that they properly integrate these apps to promote outdoor ecological inquiry (TPACK). One way to assist teachers in developing their TPACK is by involving them in the design and development of learning materials that integrate technology, pedagogy and content. This approach is called TaD (Kali, McKenney, & Sagy, 2015). Studies of teacher learning through design have shown that this approach can advance teachers' professional growth through reflection and redesign of their class practice, and can promote the implementation of new learning materials (Koehler & Mishra, 2005; Voogt et al., 2011). Recognizing the individual nature of teachers' professional growth, Clarke and Hollingsworth (2002) suggested a model to follow and describe this process. The Interconnected Model of Professional Growth describes four domains in which changes can take place: one is *external*—external source of information and stimulus, and three are internal: (a) *personal domain*—knowledge, beliefs and attitudes, (b) *domain of practice*—professional experimentation, and (c) *domain of consequence*—salient outcomes following practices, as perceived by the teachers. "Teacher change" is defined as a change in one of the internal domains. A "change sequence" describes a process of one change leading to another through a mediating process of reflection or enactment. "Growth networks" are described in this model as sequences of long-lasting changes, which lead to professional growth. Using this framework, Voogt et al. (2011) showed how collaborative design in PD programs advances teachers' professional growth.

Table 1. Knowledge types included in the TPACK framework (based on Koehler & Mishra, 2005).

Type of knowledge		Explanation	Example
CK	Content knowledge	Knowledge of subject matter	Knowing the characteristics of a specific ecosystem
PK	Pedagogical knowledge	Knowledge of strategies, practices and assessments of learning, instruction goals and student difficulties	Knowing how to mentor inquiry processes
TK	Technological knowledge	Knowledge of modern technologies and how to use them	Knowing how to use Google apps
PCK	Pedagogical content knowledge	Knowing how to apply a specific pedagogy to a specific content	Knowing how to mentor groups as part of inquiry of a forest as an ecosystem
TCK	Technological content knowledge	Knowing how to apply technology in a specific content	Knowing how to use a specific simulation of the biomass pyramid
TPK	Technological pedagogical knowledge	Knowing how specific technology can support pedagogical goals	Knowing how to use collaborative documents to promote collaborative learning
TPACK	Technological, pedagogical and content knowledge	Knowing how to integrate a specific technology to support the pedagogy chosen for a specific content	Knowing how to use collaborative documents to support collaborative inquiry of the forest as an ecosystem

In the light of the advantages of PD and specifically the TaD approach, we designed a unique PD program to promote the integration of technology in outdoor inquiry teaching. In this study, we further examine how the TaD approach can support teachers' professional growth in the context of mentoring inquiry processes in the outdoors using mobile technology.

3. Research design

The research described here represents the first iteration of a design-based research (DBR). DBR enables researchers to examine theoretical questions in context and explore learning processes in real-world settings through formative assessment (Collins, Joseph, & Bielaczyc, 2004). DBR is characterized by design-enactment-evaluation iterations which lead to refined and improved design artifacts and to contribution to theory on teaching and learning (Juuti & Lavonen, 2012).

3.1 The design

The first iteration described here, took place in a PD comprising three face-to-face meetings and one virtual meeting. During these meetings teachers participated in three main activities organized in a learning environment (LE) especially designed for this purpose. Activities were designed according to principles considering: field trip integration (Orion & Hofstein, 1994; Orion, 1993), social infrastructure for technology integration (Bielaczyc, 2006) and design principles for scaffolding inquiry (Kali & Linn, 2007). The activities in the LE aimed to: a) expose the teachers to a technology-supported outdoor module to support inquiry in the outdoors, b) facilitate the collaborative design of a similar module of their own and c) experience mentoring using the module they designed (by peer instruction). The module included a website and mobile applications to support inquiry learning in the outdoors.

The PD LE comprised three parts in accordance to the three face-to-face meetings: 1) *teachers as learners,* 2) *teachers as designers* and 3) *teachers as mentors*. Each part included relevant instructions and collaborative documents. The first part, *teachers as learners*, was the outdoor module, including activities for an ecological inquiry in a botanical garden. In this part teachers experienced the inquiry process using the technology as students. It was divided into three sections, following Orion's model for field trip integration (Orion, 1993): pre-field trip preparation, field activities and wrap-up activities. This part also integrated two mobile applications to facilitate data collection in the field: Google forms for documenting the measurements and "Tumblr", a social network, for visual documentation. Both apps enabled sharing and collaboration. These apps were chosen following the results of a pilot study in which pre-service teachers reported on the usability of the applications for inquiry in the outdoors (Levy, Tal, & Kali, 2014). The second part, *Teachers as Designers,* included step-by-step instructions for the collaborative process of design and development of an outdoor module. The design process was focused on three aspects: *content*–choosing and developing the subject to be investigated by the students (e.g., water quality); *pedagogy*–defining teaching and learning goals and choosing adequate teaching and learning methods (e.g., how to promote student collaboration in the outdoors); and *technology*–choosing and developing appropriate technological tools which will serve the content and pedagogy best. Each team was also the owner of a copy of the original module. As a part of the design process, every team was required to edit their module and customize it for their developed inquiry activity. The third part of the LE included instructions for peer reviews following the peer instruction activity.

4. Research goal and questions

The goal of this research was to examine how the TaD approach contributes to teachers' professional growth with regard to mentoring inquiry processes outdoors using mobile technology. Three questions were formulated:

1. To what extent were teachers involved in the design and customization of their team's outdoor learning module?
2. What changes (e.g., in knowledge, beliefs and practices) did teachers report on, and what characterized their change processes?
3. How did the teachers differ with respect to their reported changes, and how can these differences be explained in light of their involvement in the design of their team's mini-website?

5. Data collection

Participants were 24 high-school teachers of environmental sciences enrolled in the PD program. They all had at least 9 years of teaching experience, including past experience in outdoor inquiry teaching. Data were collected through observations during the program, teachers' documented activity in the team websites, and post-program interviews with nine of the teachers. The interviews (about 45 minutes each) were conducted a few weeks after completion of the PD program and included questions to explore what the teachers had learned. The interviews were audiotaped and transcribed.

5.1 Data analysis

The observations during the PD program indicated teachers' engagement during the face-to-face activities. In addition, to evaluate the extent to which teachers were involved in adapting their module, the number of editing events, as documented in the "recent site activity" on Google sites, was counted for each participant.

The transcripts of the interviews were analyzed using the Interconnected Model of Professional Growth (Clarke & Hollingsworth, 2002). First, we used the model to classify utterances according to the different internal-change domains. Utterances related to the personal domain were categorized by types of knowledge included in TPACK (Koehler & Mishra, 2005), or attitudes and beliefs regarding integration of technology in teaching. Utterances that referred to changes in professional experimentation during the PD meetings and in school practice were classified as related to the domain of practice. Utterances that referred to the outcomes of enacting a new practice (during the PD meetings or in school) were classified as related to the domain of consequence. Second, we characterized change processes through the identification of "change sequences" (change processes modified by reflection or enactment). Finally, we looked for "growth networks" by identifying change sequences which continued after program completion.

6. Findings

6.1 Teacher involvement in the design

Observations showed that all teachers actively participated in the collaborative design during the PD program. However, documentation of the teachers' editing events in their websites showed that the extent of their involvement in the process of adapting their module varied.

The number of editing events ranged from 0 to 171 per teacher. The interviews enabled us to explore the meaning of such differences.

6.2 Teacher change

All interviewees reported changes in the personal domain (i.e., knowledge, beliefs and attitudes) and in the domain of practice (i.e., professional experimentation). Three of them also reported changes in the domain of consequence (salient outcomes following their practice). Table 2 summarizes the number of different utterances indicating changes in each of the domains.

Table 2. Analysis of the nine interviewees: number of editing events in the team websites and teachers' reported changes.

Pseudo-names	No. of editing events	Reported changes							
		Personal				Practice			Consequence
		Knowledge			Beliefs & attitudes	PD	Plans	School	
		TK	TPK	TPACK					
Sama	171	2	4	1	6	5	1	17	8
Adi	61	2	12	1	4	3	0	6	5
Nura	29	2	12	1	11	1	2	2	9
Avivit	40	2	8	1	1	2	2	1	0
Malka	21	2	6	1	5	4	2	1	0
Nihal	4	4	6	0	8	4	2	0	0
Alon	0	2	16	1	5	1	2	0	0
Madi	2	1	8	0	7	1	0	0	0
Michael	0	4	18	0	2	1	0	0	0

Changes in the personal domain were observed in knowledge, beliefs and attitudes. All nine teachers demonstrated new TPK by indicating the added value of the technological tools for teaching in general and for outdoor inquiry teaching in particular. For example, one of the teachers (Nura) reported on new TPK when she said:

> *As a teacher [I believe], they [collaborative documents] are very helpful. I can follow…and I can see who works, who doesn't, where they stand, where they are stuck...It contributes to strengthening teacher–student relations, because we are together all the time, not only during the 45 minutes of the lesson.*

They also felt that they had acquired skills for creating and editing Google forms which they practiced during the PD meetings, reflecting gained TK. For instance, Nura described her acquired skill for the technology's design, indicating her developed TK:

> *I was used to asking my kids to help me [with the technology] but now I do whatever I want. I do not turn to them anymore. I work for two hours and don't feel it, and I have outcomes.*

On the other hand, Alon, Madi and Michael did not feel that they had gained such technical skills regarding the editing of Google sites, explaining that this was either because they had not practiced enough during the PD program or because they had been absent from one of the PD meetings. These teachers also showed little (if any) involvement in adapting their module. In addition, six teachers demonstrated TPACK by their detailed description of activities they developed following the PD program. One teacher, for instance, described an activity she planned for her students that involved measuring "noise level" in groups, each group at a different spot in an industrial area, using their personal smartphones. Changes in beliefs and attitudes were reported in the form of statements on self-efficacy and self-confidence regarding the use of technology in practice (six teachers), and intentions to integrate the new technology into their teaching (nine teachers). Malka, for example, told us about her intentions to apply what she had learned in her classroom: *"I know that if I mentor outdoor inquiry projects next year, I will use it [Google forms]. I haven't created a Google form yet, but I intend to"*

Changes in the domain of practice were expressed in three aspects: (a) experimentations with design and development of learning materials during the PD program (all teachers); (b) detailed plans for activities that the teachers intended to implement in the future (six teachers); (c) descriptions of actual use of the technological tools during the PD program (as part of the peer instruction) or in schools—with students or colleagues (five teachers). For example, Adi recounted her experience when she applied the customized LE with her peers:

> *The third meeting was significant for me because first, I realized that the designed artifact is usable, and can be applied in the field. Second, I got feedback. I saw the features that needed improvement. The experimentation is important, to improve it [the design artifact].*

Changes in the domain of consequence were reflected in salient outcomes after using the technological tools they had edited to teach their students or colleagues (three teachers). These outcomes included: pedagogical aspects of the learning process (e.g., student collaboration), students' affective statements (e.g., enjoyment and enthusiasm), and insights regarding the quality of the designed activity (e.g. less successful components which need refinement). An example of the consequences on Sama's practice could be understood from the way she followed her students' learning processes using the collaborative documents:

> *The students know that I follow-up on their work [I know] what they do…I say to them: 'that's okay', 'not okay'…I know that they work together, and I see that all of the students work at the same time. That is something very nice.*

As already mentioned, change sequences reflect a teacher's development process, and growth networks (long-lasting change sequences) indicate professional growth. Analysis of the change sequences emerging from the interview data indicated three main processes: (a) reflective processes originating from participation in the PD program (the external domain), influencing the personal domain (32% of all sequences). These processes demonstrate knowledge, acquisition and changes in attitudes following the PD program; (b) reflective processes originating from professional experimentation (domain of practice), influencing the personal domain (24%). These processes demonstrate knowledge acquisition and changes in beliefs and attitudes following practice during the PD program and in class; (c) enactment processes originating from the personal domain affecting the domain of practice (20%), indicating application of the new knowledge in practice.

Professional growth networks were detected in six out of nine interviews. These teachers described how the PD program supported the expansion of their knowledge through practice and illustrated changes assimilated in their school practice—with students and/or colleagues.

To illustrate the analysis, we describe Sama's growth network (presented in Figure 1). Sama, with 15 years of experience in teaching environmental sciences, started the PD program with an open attitude toward technology, and high motivation to learn and implement the technology in her class. She indicated in her interview that she had been integrating technology in her teaching for some time. She used pictures, presentations, movies and simulations to illustrate the ideas she was teaching and to increase students' interest. Her students used Office programs for analysis, data-processing and presentation of data and results. She also used email to communicate with her students and to give feedback on their work. She emphasized that she had not used technology for promoting collaborations prior to the PD program. During the program, she led her team and was highly involved in the customization of the module, as observed during the meetings and in the editing events documented on the team website. Module customization included the addition of resources such as pictures and information, as well as instructions for inquiry activities (change in the domain of practice). Sama also reflected on the peer instruction, and could indicate problems with the designed activities (change in the domain of consequence) and realize which characteristics of the outdoor activity will not work when enacted with students (change in the personal domain). It also made her refine the activity according to her conclusions (change in the domain of practice). After the PD program ended, Sama continued to develop activities for her students (change in the domain of practice). She opened collaborative presentation files for six student groups. Each group was asked to investigate a different ecological system (using the internet as the information source) and collaboratively create a presentation to summarize their findings. Sama indicated that she followed her students' work in the presentation files, monitoring the learning processes, and observed their chat discussions, indicating their collaboration (change in the domain of consequence). She also reviewed their work, guided them and added her feedback (change in the domain of practice). The continuous design of new activities using the technology indicated Sama's professional growth.

6.3 Differences in teachers' professional growth

Examining the characteristics of the teachers' changes in light of their engagement in the design (Table 2) showed that teachers who demonstrated professional growth were highly involved in making adaptations and demonstrated a wider array of changes in the three dimensions. Teachers who showed scarce or limited involvement in making adaptations (e.g., Alon and Madi) demonstrated changes mainly in the personal domain and somewhat in the practical domain. The reported changes addressed experiences they had had during the PD meetings, but no changes addressed their teaching in school. Therefore, these teachers did not demonstrate professional growth.

7. Discussion

The teachers who enrolled in the PD program had previous experience in teaching outdoor inquiry projects. Nevertheless, they still had challenges to overcome in this context. We expected teachers to expand their knowledge and change their intentions regarding the use of technology in their practice as facilitators of inquiry learning. However, following the short intervention of the PD program, changes also occurred in the teachers' practice in class. These changes resulted in more student involvement and collaborative learning indoors as well as outdoors (as reported by the teachers).

As aforementioned, Clarke & Hollingsworth (2002) define teachers' professional growth as long-lasting change sequences. Our findings did show some growth networks, expressed in continuous integration of technology into the teachers’ school practice with students and with colleagues beyond the PD program. The TaD-based PD model contributed to the changes undergone by teachers and to their professional growth, as found in previous research (e.g.,Voogt et al., 2011). The teachers' involvement in the design contributed to the development of their TK and TPK. These teachers, some of whom started the PD program with low confidence in their technical abilities, felt capable of developing technology tools for their students. Considering the challenges of teaching inquiry outdoors (e.g., Tal & Argaman, 2005), the teachers learned how to utilize the technology, mobile technology in particular, to overcome some of these challenges. They recognized the added value of the technology in enhancing learning, and some of them described how they integrated the technology into their teaching. Not only did they learn how to integrate the tools into their teaching to support outdoor inquiry, but they also learned how to integrate them in other contexts to enhance collaborative learning. However, some of the teachers whose involvement in the design process was low did not apply the new knowledge developed during the PD program in their class practice. Thus, these professional changes were not classified as professional growth. They also mentioned in their interviews that they needed more opportunities to engage in the actual editing of Google apps. These notions and the prominence of the domain of practice in the change sequence analysis show that the teachers highly valued the contribution of professional experimentation to their change and growth. Therefore, we assume that the level of involvement in the module customization was crucial to teachers' PD and growth.

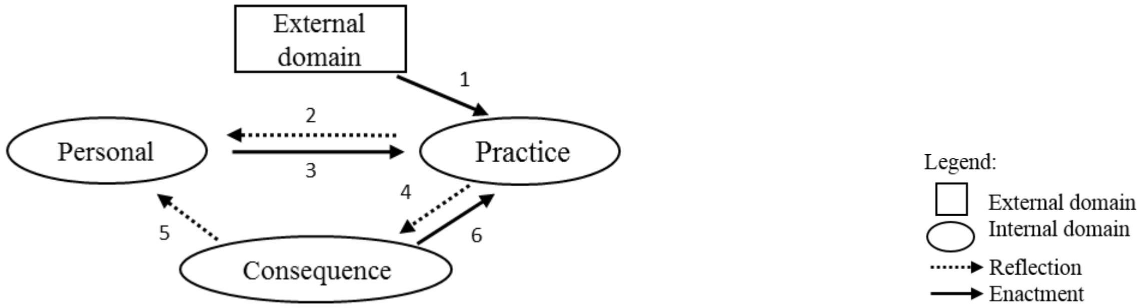

Figure 1. Sama's growth network, analyzed by the interconnected model (based on Clarke & Hollingsworth, 2002)

In conclusion, this study demonstrated how the TaD approach can help teachers overcome their concerns regarding the use of technology, and improve their practice as mentors of outdoor inquiry using mobile technology. Further research is required to explore the potential of the TaD approach to promote student learning, but the findings of the current research indicate that this direction holds great promise.

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7 ENHANCING THE AUTHENTICITY OF INHERITANCE IN BIOLOGY THROUGH SOCIO-SCIENTIFIC ISSUES AND VALUES IN BIOLOGY EDUCATION

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Abstract

With the aim of increasing authenticity and relevance in the genetics learning process in Biology education, we used a web-based module about simple inheritance, originally proposed by the University of California, Berkeley for American students and adapted by us for an Israeli context. We increased the module's relevance through an anchoring story of fundraising for cystic fibrosis (CF) patients, and also presented some moral socio-scientific dilemmas regarding the usage of money from fundraising in different aspects of life, such as: medicine, research, industry, etc. We also added two types of interactions with CF patients: a field trip to a CF hospital unit, and an online asynchronous interaction with a CF patient through an educational forum. We assumed that the use of socio-scientific issues in a scientific subject would expose students not only to the pure science along with its processes and rules, but also to human aspects and values that are relevant to the students' lives and can contribute to their value systems in a long-term process. The goal of the research was to explore the process of learning through the module and determine how the hospital visit and online interaction with a patient contribute to the students' interest and understanding of genetics.

Keywords

Authenticity; relevance; value system; web-based learning process; genetics

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

In this study, we adapted a web-based learning module on simple inheritance to the Israeli context with the aim of increasing its relevance and enhancing the meaningful learning of genetics by Israeli students. The work reported here takes advantage of a capability of the Web-Based Inquiry Science Environment (WISE), which allows the revision, adaptation and refinement of existing modules. When learning with WISE modules, students learn scientific content in relevant contexts, and develop a variety of thinking skills, such as asking questions, identifying and critiquing evidence, formulating arguments and hypotheses, and so forth. Interactive visualizations in WISE modules allow the students to explore complex phenomena and processes, and integrate knowledge from various resources (Linn, Lee, Tinker, Husic, & Chiu, 2006). In WISE, students can work individually, as well as in small groups. For teachers, WISE allows modifications, additions and on-going revisions to improve learning (Slotta & Linn, 2009).

The module begins and ends with a framework story of a boy who is sick with cystic fibrosis (CF). The students explore his family history to arrive at the conclusion that CF is an inherited trait. A new framework was developed for the module. It included value-related dilemmas in biology education, which refer to fundraising for CF patients. This context allowed for further investigation of other inherited traits and learning about genetic mechanisms. Our revised module, which was created in Hebrew, begins by introducing a newspaper ad, which reminds the public about a forthcoming CF donation day. In this ad (see Figure 1), a real girl, Shefa, tells the public about her daily routine: one hour of physiotherapy, three inhalation treatments, 50 pills, controlled physical activity, special high-calorie nutrition, and frequent hospitalizations. The ad culminates with the phrase "For you it is a donation, but for us it is like air for the next breath." We would like to note that in Israel, junior high school and high school students are requested to participate in door-to-door fundraising for certain approved non-profit organizations such as CF, diabetes and breast cancer organizations. In the revised module, after students are presented with the ad in the first activity, they are asked whether they would have volunteered to participate in such a CF fundraising program. To make an informed decision, students are invited to learn more about CF. Thus, right at the beginning of the module, the students, working in groups of three, were requested to make a decision. In various other tasks, students were required to make decisions and provide arguments for those socio-scientific decisions. The students are then referred to the Israeli non-profit CF organization where they can watch a short interview with two boys and get additional information about the disease and its treatment. At this point, the students begin learning about CF by suggesting questions for further learning, sharing their questions with their peers and choosing, together, the questions for their investigation. In this first activity we are already encouraging socio-scientific reasoning (Sadler, et al., 2007), and the students are required to make decisions based on both social and scientific perspectives.

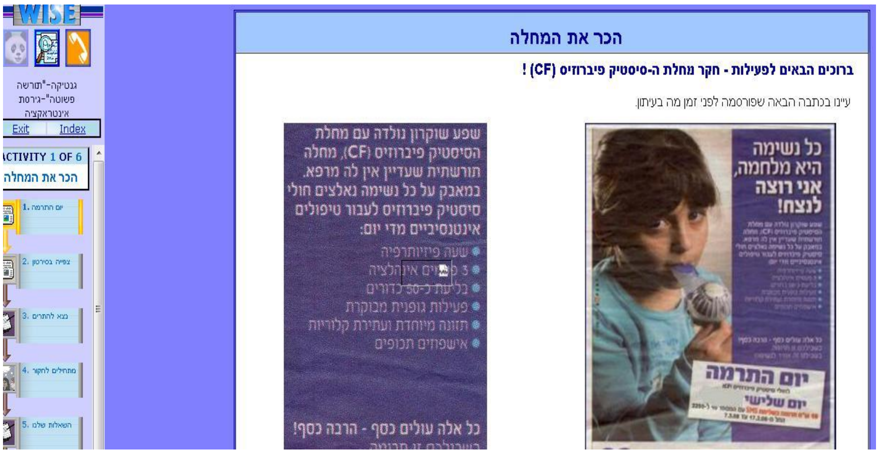

Figure 1. The opening page of the Hebrew CF module – fundraising.

Our project involved teaching genetics in an everyday context, while engaging students in dealing with dilemmas of patients, the patients' parents and the general public. At the end of the module activity, students were requested to make decisions about social actions such as fundraising, and whether or not it is right to try to prevent the birth of sick babies with genetic diseases, while interacting with real patients in person and online.

In addition to better contextualizing the module to the Israeli context, we added two components to the original module: a visit to a CF unit in a hospital and authentic communication through online interaction, which allowed students to talk with a CF patient. We were interested in patterns of learning with the adapted WISE module and more specifically, in the value of the two additions that aimed to improve the relevance of the module. Moreover, we believed that a "real-life" context could make a greater contribution not only to students' learning, but also to their value systems in a long-term run. According to the Israel Education Law, value education and knowledge conveyance are the two key components of students' education, and this study helps integrate value education into the process of conveying knowledge in Biology education.

2. Methodology

2.1. The participants

The participants were 10th graders from a school in Tel Aviv that serves a heterogeneous population of low to high socioeconomic status. Typically, simple inheritance is taught in Israel in the 9th grade, but in some schools it is taught in the 10th grade. In a pilot study, we developed the adapted module for which we changed the framework story of the module and the associated learning tasks. The adaptation was based on design guidelines for educational technologies found in the Design Principles Data Base (Kali, 2006; Kali & Linn, 2007).

2.2. The research questions

(a) What were the learning characteristics of the students who learned simple inheritance using the adapted Simple Inheritance module?

(b) How did the two enhancements—the hospital visit and the online interaction with a patient—contribute to (i) the students' interest in genetics, and (ii) their understanding of scientific ideas in genetics?

2.3. Data collection

Data collection included:

(a) a science-knowledge integration test, administered 1 week after students completed their learning with the module,

(b) a feedback questionnaire that included two parts: six Likert-type questions with four possible answers, and two open-ended reflection questions,

(c) the students' answers to the written tasks in the module,

(d) observation data collected throughout the enactments of the adapted Simple Inheritance module,

(e) evidence from students’ work in the module; for example, to assess student engagement, we used the question about their tendency to participate in fundraising for CF.

The knowledge-integration framework was used to develop a rubric with a 0–5 point scale to assess student responses (on the science-knowledge integration test), in order to identify the number of incorrect, partial, and complete connections that students make (Liu et al., 2008).

Differences between students’ outcomes in the two conditions (field trip and online interaction with a patient) were calculated using a T-test procedure. As we could not make a normal distribution assumption, we compared students’ attitudes toward learning with the field trip vs. the online interaction by employing the Mann-Whitney U test. To analyze the students’ responses to the open-ended questions in the module, we looked at students' claims and their justifications.

3. Outcomes: interest and engagement

According to our observations, there was extensive evidence for increased interest in genetics among the students. Evidence for students' deep engagement came from a task that was added to the original module in an attempt to increase relevance and encourage reasoning activities. In a short paragraph, we described a young couple who are expecting a baby. This couple found out that they both carry the gene for CF, which means that they have a 50% chance of having a sick child. The students were required to imagine that they are a genetic counselor and decide what to recommend to the parents.

After a short whole-class face-to-face discussion, students were required to write their recommendations. We observed the students' enthusiasm while thinking and debating about this task. The variety of student answers indicated that they understood the sensitivity involved. There were students who argued that the genetic counselor should only give the scientific and health information, with no recommendation regarding decisions. One group suggested that the counselor should help the couple better prepare themselves for the situation: *"They should learn about CF, in any case, so they won't be surprised and in order to face all the challenges."* Another group suggested examining the fetus: *"it's 50%, so there is a chance that the baby will be healthy, but if they know it's a sick baby, we would recommend an abortion."* A different group was convinced that the counselor should work with the couple on how to accept a sick child with love and provide the best possible treatment. It was hard to stop this discussion, which involved what the students had learned as well as their personal values.

One additional activity that aimed at increasing relevance was the fundraising activity, which served as an opening and summarizing assignment in the adapted module. In their responses to this task, the students expressed empathy, and referred to their responsibility as citizens. Here are some examples of students' responses to the task which inquired as to their attitude toward a fundraising activity:

> "*After we learned about CF, we realized that the public awareness is not sufficient, so we would like to participate and contribute to increasing awareness*."
>
> "*We will participate in the fundraising activity because it can help the patient. We will give them mental and financial support*."
>
> "*We will participate in fundraising, because it is important that people will contribute some of their time for others who need help and support*."
>
> In the post-task, the students were requested to recommend what to do with the money. In their answers, the students not only addressed scientific research and medical care, but also included better equipment and facilities for patients (Tal et al., 2011).
>
> "*We want to contribute money to an association that cares about CF patients and their parents; also, it is important to have an information center for parents who are going to have kids with the CF disease*."

Evidence from students' work in the module and the observation data indicated their deep engagement in inheritance issues as a result of enhancing relevance in teaching the Simple Inheritance module. Addressing the first research question, we can state that students had "hard-core" valuable characteristics with the intention of using scientific content to become valuable citizens.

To answer the second research question, we described and compared the contribution of the two enhancements (online interaction with a patient and the visit to the hospital) to students' interest and understanding of scientific ideas in genetics. The analysis of the open-ended responses to the question "In what way/s has the online interaction with the CF patient contributed to your learning of genetics in the Simple Inheritance module?" allowed highlighting the contribution of this addition to students’ learning. A few topics emerged in the students’ responses that reflect this contribution: the ability to ask questions, improved learning, learning new things, understanding the patients' challenges.

The responses to the same question that addressed the field trip provided stronger evidence for the field trip's support of meaningful learning and complementing this, relevance. While the students who were engaged in the online interaction addressed mainly effective contributions, the students who visited the hospital articulated the contribution more clearly. Moreover, they better connected the outside-of-school experience to learning with the module. An analysis of the contribution of the two additions to student learning, as reflected in the sophistication of their responses, is presented in Table 1.

Table 1. Analysis of student answers regarding the contribution of the online interaction and the field trip to the hospital

Answer orientation (positive vs. negative) and justification		Example	Frequency (%)	
			Online interaction [N=22]	Field-trip [N=28]
Negative	Not justified	N/A	4	
Negative	One justification	Talking with David did not help me understand genetics better, it only helped understanding his everyday functioning (online interaction) No, talking to David did not help me understand, while seeing his family tree helped better (online interaction)	19	**0**
Limited contribution	At least one justification	Not much, since David did not add anything new. He mainly talked about how the disease affects his life. What he did add was that he explained how a carrier or a sick person calculates the odds of a sick offspring, so David will not have kids with a carrier (online interaction) Not so much, because the visit took place after we completed most of the module, but it did help me connect what we already learned (field-trip)	14	**4**
Positive	Generic or one justification	Yes, David helped me understand the disease characteristics Yes, because learning in school with the teacher – the routine, is less effective than real interacting with patients (field-trip)	53	**69**
Positive	A claim and detailed justification	Talking with David in the forum helped because he explained about CF, and answered the question that interested me such as… (online interaction) Yes, the field-trip helped learning the subject. In the hospital, they showed a presentation that gives clear explanation of the disease. For example, we learned that in order to increase their life expectancy the patients need high calorie diet, they need to consume enzymes to catalyze the fat, practice out, do physiotherapy and inhalations… we were physically much close to the whole thing, and it made us want to learn more about the disease, its symptoms, cure and so forth (field-trip)	10	**27**

Table 1 indicates that the hospital visit was better perceived as a contribution to the students' learning than the online interaction.

4. Discussion

Our findings showed that the design of the adapted module, even without the additions, was successful in getting students interested in understanding the science behind the disease CF. The findings indicated that moral features in the project, such as involving students in making decisions about whether they would participate in a fundraising program, or what they would recommend to a family confronted with the possibility of having a baby afflicted with CF, were crucial to engaging students and promoting their interest in understanding genetics.

Relating science to personally relevant contexts is a well known instructional strategy for designing learning environments that can make science accessible (Linn, Davis, & Bell, 2004; Kali et al., 2008). Dewey (1963) stated that the role of the educator is to train the student in solving real problems which relate to real life. This approach supports education for values theory, which contributes to preparing pupils to cope mentally with value-related issues. This study, which involves value-related issues with biology education, contributes to both the students' understanding and their interest in scientific and moral issues of biology education.

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8 SCIENTIFIC REASONING AS AN ASPECT OF PRE-SERVICE BIOLOGY TEACHER EDUCATION: ASSESSING COMPETENCIES USING A PAPER–PENCIL TEST

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Abstract

This study aims to assess pre-service biology teachers' competencies in the field of scientific reasoning by using a paper–pencil test with 123 items for two scientific methods in the three disciplines of biology, chemistry, and physics. A sample of 2247 participants was asked cross-sectionally; this article focuses on a subsample of 626 pre-service biology teachers. Regarding the structure of the competencies, a unidimensional Rasch model provided the best fit to the data. This supports the assumption of scientific reasoning being a unidimensional construct that reflects the general epistemic structure behind the two methods *conducting scientific investigations* and *using scientific models*. Item difficulties and students' abilities revealed a good match. Multiple latent regression analyses showed positive effects of the variables *two natural sciences* and *study stage* on the latent ability, supporting hypotheses that predict greater abilities for students who study two instead of one science discipline, as well as students in more advanced stages of academic education. Based on the results, we discuss in what way several learning opportunities have a positive effect on the development of pre-service teachers' scientific reasoning competencies. Upcoming studies will investigate the students' competencies longitudinally, including possible interaction effects of the various group variables.

Keywords

Pre-service biology teacher education; scientific inquiry; scientific reasoning; scientific modeling; cross-sectional analysis

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

Biology education can only be successful if teachers' professional knowledge imparts, among other things, the central aspects of biological content knowledge (CK; cf. Hattie, 2009; Shulman, 1986). Only a few studies have focused on pre-service teachers' knowledge (e.g. Kunter, Baumert, Blum, Klusmann, Krauss, & Neubrand, 2013). That is why various researchers have highlighted the need for modeling and measuring these aspects for higher education (e.g. Riese & Reinhold, 2012). To address this challenge, the Ko-WADiS project focuses on aspects of scientific reasoning as a fundamental part of scientific literacy (American Association for the Advancement of Science, 1993; NGSS Lead States, 2013) and investigates competencies of pre-service science teachers and science students in biology, chemistry, and physics. As the educational system of most countries is influenced by national standards (cf. Germany: KMK, 2005; USA: NGSS Lead States, 2013), one of the aims of science teacher education is to implement these standards (cf. Bybee, 2014; KMK, 2013). Teachers are required to acquire knowledge in the field of scientific inquiry in order to teach, analyze, and support their students successfully. They therefore need to develop a conceptual understanding of scientific methods (Schwartz, Lederman, & Crawford, 2004).

This paper is about the Ko-WADiS project. The long-term goal of this international collaborative project is to evaluate the development of pre-service science teachers' competencies in the field of scientific reasoning, in order to provide empirically sound suggestions for the implementation of scientific reasoning into curricula of pre-service science teacher education (cf. Lederman & Lederman, 2014); in so doing, one may promote an adequate understanding about science in higher education. We collected data during the academic education phase of pre-service biology, chemistry, and physics teachers, as well as from science students, to assess the structure and development of their competencies. This article focuses on cross-sectional analyses of pre-service biology teachers' competencies. Competencies are hereby limited to cognitive domain-specific skills, which are described as dispositions needed to solve certain problems or exercises (Klieme, Hartig, & Rauch, 2008).

2. Theoretical background

2.1 Pre-service biology teacher education

Academic biology teacher education in Germany includes several academic lectures as well as practical classes. The latter are held for all biology students, including pre-service biology teachers. In addition, pre-service teachers receive seminars on pedagogical content knowledge (PCK) as well as on pedagogical knowledge (PK; Shulman, 1986). Since scientific inquiry, as an aspect of scientific literacy (Bybee, 2002; NGSS Lead Stats, 2013), is explicitly and implicitly taught in a variety of academic courses, pre-service biology teachers' competencies should be investigated in detail.

Pre-service science teachers need a comprehensive academic education to develop competencies in the field of scientific inquiry, because they are asked to implement experiments, observations, and models in their science classes (cf. Capps & Crawford, 2013) - not only as aspects of theoretical knowledge ('learning science'), or of characteristics of scientific inquiry ('learning about science'), but also of an expertise in scientific inquiry such as problem-solving ('doing science'; cf. Hodson, 2014).

In Germany, each pre-service teacher has to combine two subjects during their academic education. Various combinations of STEM subjects, social science subjects, and linguistic science subjects are possible. For the science subjects, three study stages can be defined, which have specific characteristics (Table 1). The steps between the different study stages are indicated by an increasing number of firmer comprehensions; for example, the module “Introduction to biology education” is presented during the 3rd and 4th terms, consisting of two consecutive courses (study stage II). It combines various aspects of learning (about) science and further, inspires students to reflect on scientific methods in the context of education, which might be a way to foster students to develop their competencies (cf. Hodson, 2014). During the 7th and 8th terms (graduate pre-service teacher education; study stage III), a more meta-reflecting perspective about different scientific methods and their use in class can be stated.

Table 1. Outline of pre-service biology teachers' study program in Germany without aspects of PK (cf. e.g. Das Präsidium der Freien Universität Berlin, 2007, 2012; Der Präsident der Humboldt-Universität zu Berlin, 2007a, 2007b).

Degree program	**Study stage**	**Main contents of courses: Pre-service biology teachers**	**Courses in biology**	
			as natural science	**and its educational aspects**
Bachelor	**I**	… are taught general scientific concepts	basic	/
	II	… begin to reflect more explicitly on inquiry aspects	advanced	basic and advanced
Master	**III**	… intensify their understanding of an interaction between explicit and implicit aspects of scientific reasoning	in depth	in depth

2.2 Scientific reasoning competencies

Study stage

Regarding the hypothetico-deductive approach (Godfrey-Smith, 2003; Popper, 2003), the characteristic scientific methods are modeling, experimenting, observing, comparing, and arranging (Crawford & Cullin, 2005; Gott & Duggan, 1998, Klahr, 2000; Zimmermann, 2007). The competencies that are needed to understand the processes through which scientific knowledge is acquired are comparable for the three scientific disciplines of biology, chemistry, and physics and can be described as *scientific reasoning competencies* (Giere,

Bickle, & Mauldin, 2006; Klahr, 2000), an intersection of *scientific thinking* (Kuhn, Amsel, & O'Loughlin, 1988), and *scientific inquiry* competencies (Liu, 2010; Mayer, 2007).
Which variables should be focused on while planning scientific investigations? What is the purpose of a scientific model? These example questions, referring to the methods *observing, experimenting*, and *modeling*, are fundamental parts of science education. Observing is defined as a theory-driven investigation to collect data by applying criteria and explore correlative relations (Duggan, Johnson, & Gott, 1996; Wellnitz & Mayer, 2013), whereas experimenting explores causal conclusions by manipulating variables systematically (Gott & Duggan, 1998; Wellnitz & Mayer, 2013). Both methods can be subsumed under the dimension *conducting scientific investigations* (Klahr, 2000). Modeling describes the process of *using scientific models* to demonstrate or explain scientific ideas and in particular to generate and test hypotheses, as well as to decide whether a model in reference to the data has to be changed (Oh & Oh, 2011; Passmore, Gouvea, & Giere, 2014). According to Mayer's (2007) definition of scientific inquiry as a domain-specific problem-solving process, and additional to aspects of scientific modeling (Upmeier zu Belzen & Krüger, 2010), we identified two classes of scientific methods that are underpinned by seven specific skills of scientific reasoning (Table 2). Each of these skills refers to one step of a general scientific inquiry process at the intersection of the three scientific disciplines. Having an elaborated view of scientific reasoning means to have a cognitive disposition that enables pre-service biology teachers to apply each of these seven steps to real-life scientific problems or exercises. Aspects concerning scientific methods, therefore, have to be implemented in the curricula of higher education.

Table 2. Scientific reasoning competencies concerning the methods "conducting scientific investigations" and "using scientific models" (cf. Mayer, 2007; Upmeier zu Belzen & Krüger, 2010).

Competence	**Scientific reasoning**	
(Sub-)Competencies	Conducting scientific investigations	Using scientific models
Skills	Formulating questions Generating hypotheses Planning investigations Analyzing data and drawing conclusions	Judging the purpose of models Testing models Changing models

2.3 Previous research

Recent approaches of modeling pre-service science teachers' competencies have focused on domain-specific (e.g. Riese & Reinhold, 2012) and domain-combining aspects (e.g. Borowski, Neuhaus, Tepner, Wirth, Fischer, Leutner, Sandmann, & Sumfleth, 2010). Empirical studies have revealed higher performance of students who have had multiple learning opportunities (e.g. Riese & Reinhold, 2012). Thus, in addition to doing science, an explicit meta-reflection about science could be promising for teaching scientific inquiry aspects during academic lectures, as well as during practical classes in higher education (Duschl & Grandy, 2013; Hodson, 2014; Kunz, 2012; Lawson, Clark, Cramer-Meldrum, Falconer, Sequist, & Kwon, 2000). Across the scientific disciplines of biology, chemistry, and physics, scientific reasoning competencies are generalizable (Godfrey-Smith, 2003). Whereas the inquiry methods *conducting scientific investigations* and *using scientific models* have already been investigated with regard to domain-combining for school education (e. g. Nowak, Nehring, Tiemann, & Upmeier zu Belzen, 2013), higher education studies have been neglected. Moreover, the extent to which a connection of competencies within the same field reveals an interaction across similar scientific problems—and can therefore be considered a unidimensional aspect of scientific inquiry—has been discussed (Mayer, 2007). Researchers found evidence of students having a less advanced understanding of models and modeling related to biology than of those related to chemistry or physics (Krell, Reinisch, & Krüger, 2015), which could indicate the relevance of studying more than one STEM subject. In this context, it can be stated that the academic self-concept is a useful predictor of academic achievement: it seems that combining subject-specific education is preferable to integrated approaches (cf. Jansen, Schroeders, & Lüdtke, 2014).

3. Research questions

To investigate scientific reasoning as an aspect of pre-service biology teacher education, we examined two questions:

(a) Which psychometric structure can be found for pre-service biology teachers' scientific reasoning competencies? (i) Referring to our theoretical framework, a unidimensional structure of scientific reasoning is hypothesized (Godfrey-Smith, 2003; Popper, 2003). (ii) An alternative hypothesis emphasizes the differences between the two scientific methods *conducting scientific investigations* (Klahr, 2000) and *using scientific models* (Upmeier zu Belzen & Krüger, 2010), therefore we predict a two-dimensional model.

(b) In what way do the scientific reasoning competencies differ between various groups of pre-service biology teachers? Two hypotheses were generated, which both assume differences in scientific reasoning competencies as a result of multiple scientific learning opportunities—not only quantitatively (more lessons to take), but also qualitatively (advanced and in-depth courses; cf. Riese & Reinhold, 2012). (i) Pre-service biology teachers with a second science subject (chemistry or physics) outperform pre-service biology teachers with a second non-science subject due to the opportunity to learn (about) science in multiple ways during academic education and in more domain-combining perspectives on sciences (cf. Table 1). Following up on previous research concerning the deeper understanding of models and modeling related to chemical or physical aspects and to the academic self-concept, a subject-specific education combining two sciences could result in better test performance of pre-service biology teachers (cf. Jansen et al., 2014; Krell et. al., 2015). (ii) We also predict differences in the performance of pre-service biology teachers in various study stages of academic education: students in higher stages (i.e. advanced academic courses) outperform students in early stages, reflecting their multitude of possibilities to learn (about) science.

4. Research design and method

The goal of the Ko-WADiS project is to investigate the development of scientific reasoning competencies of pre-service science teachers during their academic education at different universities in Germany (Freie Universität Berlin, Humboldt University of Berlin, University of Duisburg–Essen, and University of Cologne). Furthermore, biology, chemistry and physics students, as well as pre-service science teachers in Austria (University of Vienna, University of Salzburg and University of Innsbruck) were tested as control groups. To model competence development, students had to take the test at least four times: in the first and fourth term of the undergraduate phase and in the first and fourth term of the (post)graduate phase. The standard period for undergraduate studies to a Bachelor's degree is six terms. Graduate studies last four terms, leading to a Master's degree. This article focuses on cross-sectional analyses using responses of German pre-service biology teachers.

4.1 Test construction

A paper–pencil test with multiple-choice items was used to assess students' competencies. Such tests provide high efficiency, reliability, and objectivity at relatively low cost (Stecher & Klein, 1997). During the process of item construction, the importance of appropriate and valid construct representation was addressed by including three standardized constructions steps (Mathesius, Upmeier zu Belzen, & Krüger, 2014). First, a guideline for theory-based and systematic item development was used to construct open-ended test items, each of which addressed one of the seven specific skills of scientific reasoning. Second, we collected the responses to these open-ended tasks of 259 pre-service science teachers and science students and used them to generate multiple-choice answer options. Capturing students' common ideas and conceptions of scientific reasoning to generate multiple-choice options can enhance distractor attractiveness and comprehensibility, thus improving the validity of the interpretation of the test scores as measures of students' competencies (Sadler, 1998). Students' answers used as multiple-choice attractors represent scientifically adequate ideas, whereas the distractors represent non-adequate alternative conceptions. All items consist of a text body presenting necessary information, including pictures, graphs, or tables, and have a standardized item instruction and four answer options (see Figure 1). The whole construction process was supervised by experts, to keep the attractor and three distractors similar in complexity, scientific vocabulary, and length (cf. Burton, Sudweeks, Merrill, & Wood, 1991). Third, all 166 multiple-choice items (58 items dealt with biological problems) were tested in a pilot study (N = 834 academic students). Analyzing item difficulty, discrimination parameters, and item characteristic curves, as well as evaluating the criterion-related validity of the assessment (e.g. Hartmann, Upmeier zu Belzen, Krüger, & Pant, 2015), 123 items (42 items dealing with biological problems) were selected for the final test.

The phantom of Heilbronn
In the period from 2007 to 2009, the media covered a number of murder cases. At all murder scenes, DNA evidence was found and analyzed by the police. From the findings it was concluded that one person was responsible for the murders. Further investigations led to the result that the person is an employee of a cotton swab company. Apparently, the employee had contaminated the cotton swabs, which were used for the preservation of evidence, with her DNA during packaging.

Which measures should have been taken into account during the investigation to avoid such confusion? Tick a box.

☐ During the investigation, the cotton swabs should have been touched only with gloves.
☐ Unused cotton swabs should have been tested as well.
☐ The cotton swabs should have been packaged in a protective atmosphere before using.
☐ The manufacturer should have been designated the cotton swabs as "not sterile".

Figure 1. Item example for the scientific method *conducting scientific investigations* and the skill *planning investigations*, with 1 attractor (= B) and 3 distractors (translated from German by the authors).

4.2 Measurement instrument

The measurement instrument contained 123 multiple-choice items which were assigned to 20 different test booklets with 41 item blocks using an unbalanced incomplete matrix design (Gonzalez & Rutkowski, 2010). Each booklet included six blocks with 18 items in total. Each block contained three items that combined the same method (*conducting scientific investigations* or *using scientific models*) with the same content area (biology, chemistry, or physics). In addition, the test included questions about demographic data such as studied subjects, number of semesters, university, age, and sex.

4.3 Survey and sample

Students were given enough time to process all items. Completing a test booklet took about 35 minutes. In the cross-sectional study, a total of 2247 participants were tested during winter term 2013/14 and summer term 2014. In this article, we present analyses of a sub-sample of 626 pre-service biology teachers from three universities in Germany (67% female; Freie Universität Berlin, Humboldt University of Berlin, University of Duisburg–Essen; distributed over the different groups; Table 3). On average, students were 23.96 years old (SD = 4.58). All participants answered at least 50% of the items contained in their booklets.

Table 3. Sample of 626 pre-service biology teachers, divided by *study stage* (I–III) and *studied subjects;* students in *study stage II* had finished at least one academic course in biology and its educational aspects.

Studying Biology and a second…	*Study stage I*	*Study stage II*	*Study stage III*	Total
… science subject	64	40	21	125
… non-science subject	264	165	72	501
Total	328	205	93	626

4.4 Psychometrics analyses

ACER ConQuest 3.0 (Adams, Wu, & Wilson, 2012) was used for data analysis. To analyze the fit of the presumed theoretical structure to the empirical data, different uni- and multidimensional models of Item-Response Theory (IRT) wereapplied. To estimate the pre-service biology teachers' abilities, plausible values (Wu, 2005) were drawn. Multiple latent regressions were used to investigate group differences for the variables *study stage* and *number of science subjects*.

5. Findings

5.1 Structure of competencies

The range of achievement estimates was well covered by the item difficulties (Figure 2). Item infit (weighted mean square; *wMNSQ*) was satisfying for all items ($0.93 \leq wMNSQ \leq 1.04$).. Uni- and multidimensional IRT models were used to test the empirical structure of scientific reasoning competencies. Unidimensional modeling reflects a competence structure in which scientific reasoning competencies are generalizable across different methods and disciplines. The two-dimensional models refer to hypothesized differences between the methods *conducting scientific investigations* and *using scientific models*. In addition to the uni- and two-dimensional models, we specified a seven-dimensional solution in which all skills were modeled as dimensions. With the seven-dimensional models, the calculations did not reach the convergence criteria, even if these criteria were reduced, indicating that the data do not fit a seven-dimensional structure. One- and two-parametric models were specified. The one-parametric (1PL) model assumes equivalent discrimination parameters for all items, whereas the 2PL model allows estimating item-specific discrimination parameters.

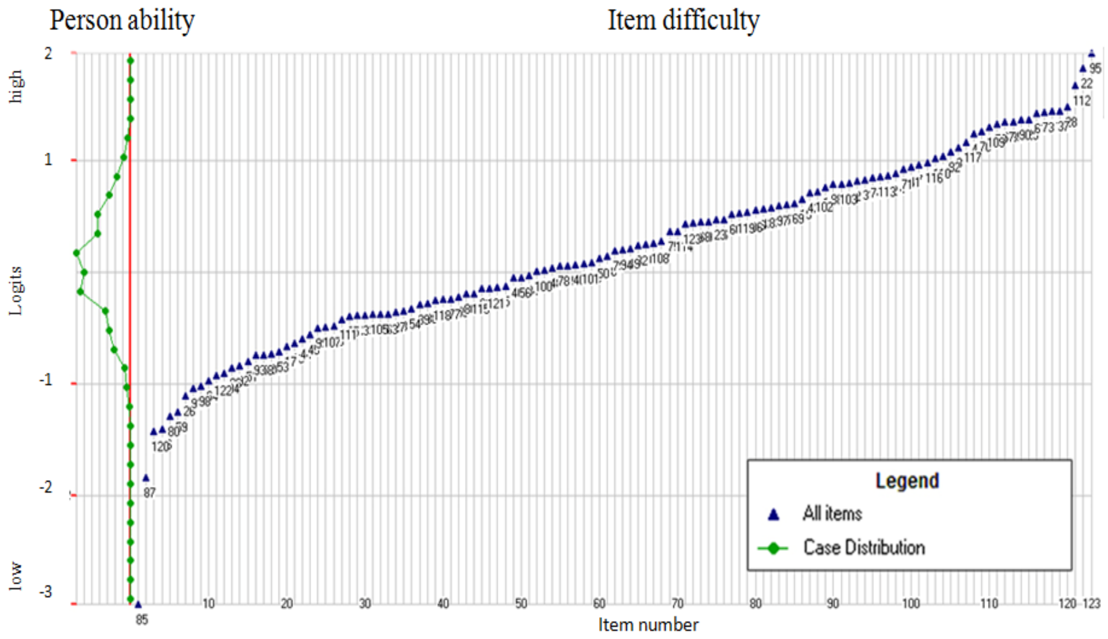

Figure 2*. Wright Map for the unidimensional model, showing the distribution of achievement estimates* (person *abilities; left) and item difficulty (right) of 123 items for the scientific reasoning test.*

According to fit indices (Bayesian Information Criterion, BIC; Akaike Information Criterion, AIC; and Consistent Akaike Information Criterion, CAIC; see Table 4), a unidimensional 1PL model showed the best fit to the data. In the two-dimensional models, high latent correlations between the two scientific inquiry methods were found (0.793 for the 1PL model and 0.919 for the 2PL model). In terms of reliability, the 2PL model is preferred, as it provides the most reliable estimates of person achievement. As 2PL-based achievement estimates also “produce a somewhat more sensitive measure of a latent trait” (Stewart, 2012, p. 20), they will be used for the statistical analyses described in this paper.

Table 4. Analysis of model-data fit and reliability of the EAP/PV achievement estimates. Unidimensional = scientific reasoning as one dimension, two-dimensional = scientific methods *conducting scientific investigations* and *using scientific models* as two dimensions. 1PL = one-parametric model, 2PL = two-parametric model.

Model	**df**	**Deviance**	**BIC**	**AIC**	**CAIC**	**EAP/PV reliability**
Unidimensional 1PL	124	14,516.15	15,320.85	14,764.00	15,444.85	0.441
Unidimensional 2PL	247	14,336.44	15,939.21	14,830.00	16,186.21	0.597
Two-dimensional 1PL	126	14,516.44	15,333.83	14,768.00	15,459.83	0.406/0.406
Two-dimensional 2PL	372	14,336.82	16,750.55	15,080.00	17,122.55	0.581/0.577

5.2 Group differences

The first hypothesis predicts that pre-service biology teachers who also study chemistry or physics (*two natural sciences* = 1) will outperform pre-service biology teachers without a second science subject (*two natural sciences* = 0). The second hypothesis predicts that students in more advanced stages of academic education will outperform students in early stages. *Study stage* was recoded into the dichotomous variables *study stage II* (1 = yes) and *study stage III* (1 = yes), each in comparison to stage I as the reference group. To test these hypotheses, multiple latent regression analysis was applied. Latent regression allows estimating group differences directly in the IRT model (Adams, Wilson, & Wu, 1997).
In comparison to the IRT model without regressors, the EAP (Expected A-Posteriori) / PV (Plausible values) reliability improved to 0.664. Results of the multiple regression analysis are shown in Table 5.

Table 5. Latent regression of *two scientific subjects* and *study stages II* and *III* on the achievement scale (predictor variables, unstandardized regression coefficients, and standard errors).

Predictor variable	*B*	*SE(B)*
Two natural sciences (1 = yes)	0.774^{***}	0.100
Study stage II (1 = yes)	0.499^{***}	0.089
Study stage III (1 = yes)	1.279^{***}	0.118

$^{***}p < 0.001$

The results support the first hypothesis, with a significant effect of the predictor *two scientific subjects* on the latent ability estimate. The second hypothesis is supported by significant effects of *study stages II* and *III* on ability. A summary of the abilities broken down by groups is shown in Figure 3

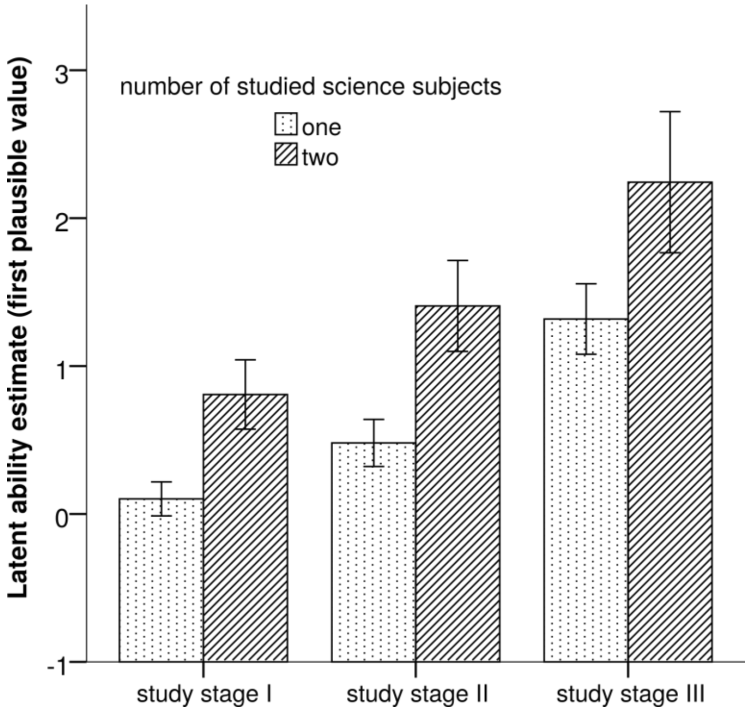

Figure 3. Latent ability estimate (first plausible value), broken down by *number of natural sciences* and *study stage*. Error bars indicate ± 2 SE.

6. Discussion

The distribution of item difficulties fit the distribution of the pre-service biology teachers' abilities appropriately, indicating that the test was neither too simple nor too challenging for the sub-group of pre-service biology teachers. Weighted MNSQ values were acceptable (Bond & Fox, 2007). The EAP/PV reliability of the test was 0.664. This is satisfactory for our heterogeneous construct and comparable to other standardized tests for scientific inquiry competencies (Terzer, 2013: 0.45; Wellnitz, 2012: 0.59), although it is lower than for most psychological tests (cf. Adams, 2005). In fact, the issue is decisive: it can estimate population parameters as in this study or an individual student's abilities (Adams, 2005).

The analyses on the empirical structure with unidimensional models (1PL, 2PL) for scientific reasoning and two-dimensional models (1PL, 2PL) for the inquiry methods *conducting scientific investigations* and *using scientific models* revealed best fit for the unidimensional 1PL model. Regarding the first research question, the theoretical structure of one dimension of scientific reasoning can be found in the empirical data. A high correlation between scientific methods indicates that scientific reasoning competencies in the area of *conducting scientific investigations* and *using scientific modeling* are highly associated, supporting the assumption of a unidimensional competence structure. This finding is in accordance with the concept of a hypothetico-deductive approach which is generalizable across different empirical scientific methods (Godfrey-Smith, 2003) and across similar problems or exercises (Mayer, 2007). Nevertheless, the items may be related to a more common factor of cognitive ability which may contribute to the unidimensional structure found in the results. To control for such

confounding effects, future measures with the Ko-WADiS test will be complemented by tests for general cognitive ability and general problem-solving competencies. Analyses for a three-dimensional structure for the subjects biology, chemistry, and physics show equal results, as well as the best fit for a unidimensional model ($N = 3010$ academic students of all three disciplines; see Hartmann, Mathesius, Stiller, Straube, Upmeier zu Belzen, & Krüger, 2015). This is not consistent with other domain-combining studies (e. g. Nowak et al., 2013), whereby the participants in these samples were pupils and not pre-service teachers. One could argue that scientific reasoning competencies are a multidimensional set of skills during school education, but develop to a unidimensional skill when trained extensively. Moreover, common elements in our study were the standardized construction guide, the standardized item instruction and the studied subjects of the pre-service science teachers.
Results of the latent regression analysis investigating various groups of pre-service biology teachers show positive regression coefficients for the variables *two natural sciences* and *higher study stage*. With regard to the second research question, both regression coefficients support our hypotheses and are consistent with previous studies. As shown by other authors, multiple scientific learning opportunities seem to contribute to increasing scientific inquiry competencies (Kunz, 2012; Lawson et. al, 2000). Learning opportunities of pre-service teachers who study two natural sciences result in a quantitatively higher number of lessons to learn (about) science, but in addition, could result in a qualitative effect for learning and doing science because of more perspectives on science (cf. Hodson, 2014). However, not only the length (total hours per term) and extent of learning opportunities concerning scientific inquiry in academic lectures and practical classes determine the development of competencies, but also CK (Riese & Reinhold, 2012). Pre-service biology teachers at higher study stages reveal a greater performance on the test, which could indicate the development of competencies.

In the next stage of the project, the measurement instrument will be used to assess pre-service biology teachers' competencies longitudinally from the beginning until the end of academic education. Data will be analyzed by using different uni- and multidimensional IRT models in order to investigate the development of the achievement estimates over four observation points. Interaction effects between the variables will be investigated to reveal a more detailed view of scientific reasoning as an aspect of higher education and the possibility of development.

7. Conclusion and prospects

Scientific reasoning competencies can be seen as a unidimensional construct. Our cross-sectional analyses of pre-service biology teachers' competencies showed differences between various groups, with positive effects for students studying two science subjects and for those at higher study stages. In the next stage of our project, further steps will be taken to test the validity of the interpretations of the test scores as measures of scientific reasoning competencies. Besides content-related validity aspects, which were already considered during the construction process (Mathesius et al., 2014), students will be asked to explain their cognitive thinking processes by means of the “thinking aloud” method (Ericson & Simon, 1980). For comparison, another questionnaire about professional knowledge of pre-service science students will be applied, which focuses broadly on pre-service biology teachers' CK, PCK, and PK (Großschedl, Harms, Glowinski, & Waldmann, 2014). Assessing the academic self-concept of pre-service science teachers could also provide comprehensive insight into different performances of the various groups of pre-service biology teachers (cf. Jansen et al., 2014). To assess validity, evidence of relations to other constructs and variables – a measurement instrument for general cognitive ability (Liepmann, Beauducel, Brocke, & Nettelnstroth, 2012) – was also used in a subsample; evaluation will follow in due course. Aside from this, the acquisition of learning opportunities delivers information on the development of pre-service biology teachers' competencies (Duschl & Grandy, 2013): how and when are the seven steps connected during a general scientific inquiry process – i.e., academic lectures or practical training (cf. Hodson, 2014)? In particular, focus will be on courses during the indicated study steps, and the extent to which explicit approaches might help acquire competencies effectively must be proven (Duschl & Grandy, 2013). Although we found initial evidence indicating a performance increase during academic education, there is still room for further gains. In particular, the longitudinal study will provide hints regarding evaluation and improvement of pre-service science teacher education.

Acknowledgments
Project Ko-WADiS was founded by the Federal Ministry of Education and Research (BMBF) as part of the initiative KoKoHs “Modeling and Measuring Competencies in Higher Education”.

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9 CAN HIGHER-EDUCATION INSTITUTIONS CONTRIBUTE TO STUDENTS' DEVELOPMENT OF SUSTAINABILITY LITERACY? THE CASE OF AN ISRAELI UNIVERSITY

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Abstract

Higher education (HE) plays an important role in promoting a sustainable future, since HE students are tomorrow's citizens, professionals, and decision-makers. A major challenge in HE is designing educational activities that promote the development of sustainability literate graduates. To promote this goal, multiple learning outcomes should be enhanced, and sustainability ideas should be integrated into all programs. The aim of this study is to explore the ways different learning experiences promote sustainability literacy of HE students. The research was performed in a leading science and engineering university in Israel. Data were collected through an online questionnaire and semi-open interviews. The main findings were: (a) a positive moderate and significant correlation between the number of courses students enrolled in that deal with environmental issues, and the perception of the contribution of the learning period ($r = 0.5$ $p < 0.001$); (b) about half of the students reported a change in their sustainability literacy, but only 10% explicitly described university learning as the main reason for this change; (c) learning experiences that were recalled as most significant were varied, including formal, informal and campus learning.

Keywords

Education for sustainability; higher education; sustainability literacy; curriculum; informal education

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction

Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED, 1987). Higher education (HE) plays an important role in promoting a sustainable future, since HE students are tomorrow's citizens, professionals, and decision-makers (Cortese, 2003; Orr, 1995; Rowe, 2002). The pressures of climate chaos, injustice and limited resources have resulted in the acknowledgement of a need for graduates to have appropriate skills, knowledge and empowerment to respond to and mitigate the coming crises, and build a renewed sustainable future (Hegarty et al., 2011). Assuming that sustainability is relevant to all students, it is essential to integrate it into all academic disciplines (Clugson & Calder, 2000; Hopkinson et al., 2008).

There are many potential ways to integrate sustainability into the curriculum across the university. Courses dealing with sustainability can be interdisciplinary or field-specific, mandatory or elective, and can be a single course or part of a cluster (Rowe, 2002). However, integrating sustainability across university curricula requires thoughtful attention to pedagogical and organizational issues, and poses many challenges. This study aims to shed light on how students view the ways in which sustainability can be integrated across the curriculum, and on pinpointing the experiences of sustainability learning that are perceived as most significant by the students.

2. Theoretical framework

2.1 Sustainability literacy

Learning outcomes in the field of sustainability in HE are often defined as encompassing multiple aspects of human learning. They include both cognitive and affective development, and a list of skills that ought to be taught to students. Attitudes, motivation, and professional and civic skills are all seen as central outcomes of education for sustainability, along with knowledge acquisition and cognitive development (Mintz & Tal, 2014; Svanström, et al., 2008). A concept that incorporates various types of learning outcomes in the field is *sustainability literacy*. Sustainability literacy requires the integration of skills, attitudes, dispositions and values that are necessary for the promotion of a sustainable world. A sustainability literate individual is empowered to critique his or her society, be aware of unsustainable trajectories, and get involved in the rewriting of self and society along more sustainable lines (Stibbe & Luna, 2012). In the UK, for example, the government has identified sustainability literacy as a "core competency" for professional graduates; this emphasis on competency was proposed to be significant, since it suggests the insufficiency of learning solely about what sustainability is; sustainability literacy should also address students' attitudes and dispositions to develop their strategies for reasoned decision-making (Winter & Cotton, 2012).

Designing educational activities that promote the development of sustainability literate graduates is a major challenge in HE (Hopkinson et al., 2008). Sections 2.2 to 2.4 address this challenge from three perspectives: integrating sustainability concepts across the curriculum, pedagogical considerations, and extracurricular learning.

2.2 Integration of sustainability across the curriculum

Since sustainability is relevant to all students, it is essential to incorporate it into all academic disciplines (Clugston & Calder, 2000). However, integration of sustainability across the curriculum faces multiple pedagogical and organizational challenges. International conventions have indicated the importance of teaching about sustainability for *all* college students (UNESCO, 2012), and many university leaders worldwide have committed to international agreements and declarations for the integration of sustainability, such as the Tailloires Declaration (ULSF, n.d.).Yet, most students graduate with insufficient knowledge and skills in sustainability (e.g. Azapagic et al., 2005; Yavetz et al. 2009). There seems to be a gap between the rhetoric of policy documents and the reality of education for sustainability in the classroom; most action taken by universities so far has been through the management and impacts of its operations and campuses, rather than through pedagogical or curricular reform (Christie et al. 2013; Wals & Blewitt, 2010).

Introducing sustainability into the curriculum is challenging: sustainability is an interdisciplinary field with scientific, environmental and social aspects. In addition, ethical and philosophical commitments are inherent principles of sustainability (Hegarty et al., 2011). Education for sustainability requires a continuous cultural production process, and the training of professionals who are committed to the ongoing search for the best possible relationships between society and the natural environment, and who take into account the values related to sustainability, such as equity and respect for biological and cultural diversity (Aznar Minguet et al., 2011). All of these elements make the integration of sustainability across the curriculum a demanding task, and indeed, many barriers have been found to its implementation, including instructors' insufficient content knowledge and pedagogical knowledge, perceived irrelevance to the core disciplines, and fear of indoctrination (Christie et al., 2013; Hopkinson, et al., 2000).

On the other hand, because of its interdisciplinary nature, there are many ways sustainability can be integrated across the curriculum. Courses dealing with sustainability can be interdisciplinary or field-specific, mandatory or elective, and can be a single course or part of a cluster of courses (Rowe, 2002). Sometimes sustainability is integrated in various courses without explicitly using the term itself (Hopkinson, et al., 2000). Therefore, it seems that one of the challenges in studying sustainability in HE is to trace the ways in which it is or can be integrated into various courses, and to study how these efforts are perceived by the students.

2.3 Pedagogical considerations

To promote the multiple facets of sustainability literacy (cognitive, affective and skills), students must be provided with various learning experiences that involve cognitive, affective and practical engagement (Sipos et al. 2008). Active and collaborative learning are highly recommended in teaching sustainability because of their potential contribution to the development of both cognitive and affective learning outcomes (Domask, 2007). Some of the pedagogical recommendations are: discussions of ideas, thoughts and ethics as a way of promoting autonomous thinking (Wals & Corcoran, 2006), field trips to industries, natural environments, communities and social institutions (Ben-Zvi-Assaraf & Ayal, 2010), and collaborative learning that enables the educational process to shift away from the goal of knowledge transfer toward personal transformation (Moore, 2005). Therefore, the challenge for HE in the field of sustainability lies not only in integrating sustainability concepts into the curriculum of all disciplines, but also in promoting the use of transformative pedagogies (Wals & Corcoran, 2006).

2.4 Extracurricular learning

Extracurricular learning refers to any learning activity that takes place on campus but is not part of formal courses in the various programs. It is usually informal and voluntary. Two concepts that are often used with respect to extracurricular learning in HE are *informal learning* and *campus learning*. Informal learning refers to a range of activities on campus that are not part of formal courses, such as volunteering, internships and various on-campus events. Informal learning activities and informal learning environments have been acknowledged as important in the fields of environmental and sustainability education. Informal learning can provide many opportunities for direct engagement in the natural and social environment, experiential learning, and active and participative learning. It offers activities that are important to environmental and sustainability education and that yield various learning outcomes, cognitive as well as affective (e.g.: Morag & Tal, 2012; Palmer, 1998). These advantages of informal learning are relevant to HE as well. Informal learning activities that relate to sustainability in HE can provide students with opportunities to learn about sustainability, and equip them with the skills and attitudes required to promote a sustainable future.

Campus learning refers to the ways in which building design and management operations, such as recycling bins and electricity management, are reflected in students' learning (Hopkinson et al., 2008; Orr, 1992, p. 105). It is argued that management operations not only impact daily behaviors, but also communicate institutional values and attitudes (Hopkinson et al., 2008). Since there are many barriers and limitations to integrating sustainability into the formal curriculum, extracurricular learning of sustainability can be an important way of integrating sustainability into the learning experience in HE (Winter & Cotton, 2012).

2.5 Student development in HE

One of the questions to be asked while studying the integration of sustainability in HE and its effect on students is whether it is realistic to expect that young adults will show changes in their cognitive skills, attitudes and behaviors while in college, whether cognitive and moral development continue to grow at this stage of life, and whether HE institutions can make a change in students' attitudes.

A whole body of research in the field of psychological and social development in HE provides a clear answer to this question: yes, both cognitive and moral development continue in adult life. Research on HE students has shown that learning experiences in HE have the potential to contribute to cognitive and moral development, and to changes in attitudes and values (King & Kitchener, 1994; Pascarella & Terenzini, 2005). Therefore, it is realistic to expect that, as in other fields of personal growth, sustainability literacy can be developed during the college years. Thus, incorporating sustainability in the HE curriculum and extracurricular activities has the potential to develop students' sustainability literacy. The main question of this study is, therefore, how can this be done?

3. Previous research on teaching sustainability across the curriculum

Many studies in the last decade have described the teaching of sustainability in a specific HE course (e.g. Ben Zvi Assaraf & Ayal, 2010; Tal, 2005). These case studies note teaching methods and pedagogies appropriate for Education for Sustainability, but the degree to which these pedagogies are achievable across disciplines has not yet been documented (Christie et al., 2013). Several large-scale studies have been conducted to study students' knowledge and attitudes in the field of environment and sustainability (e.g. Azapagic, Perdan, & Shallcross, 2005; Yavetz, Goldman, & Pe'er, 2009); however, these studies focused on student outcomes rather than on the practices and experiences that yielded them.

Very few studies have investigated the field of extracurricular learning about sustainability in HE (e.g. Lipscombe, 2008; Winter & Cotton, 2012). Winter and Cotton (2012) found that various decisions of university authorities on practices such as recycling and electricity usage can impact students' conceptions of sustainability. Yet, there has been little research on extracurricular learning in HE, and more research is needed to understand the contribution of extracurricular learning about sustainability in HE.

4. Research objective and questions

The present study aims to add to what is known about incorporating sustainability in various learning activities across the university (formal, informal, and campus learning), to understand what pedagogies are being used, and to determine which learning experiences are perceived as most meaningful in promoting sustainability literacy.
The research questions were:

1. How do students perceive the contribution of their study period to their sustainability literacy?
2. Does student perception of their sustainability literacy correlate with their enrollment in "environmental" courses?
3. What learning experiences are viewed by the students as significant in promoting the development of sustainability literacy?

5. Method

5.1 Settings

As already noted, sustainability can be integrated into the curriculum implicitly without even using the term 'sustainability'. It can also be integrated in various other ways: as a course, a module in a course, or even a single lesson or home assignment. Because of the agreement about the importance of meaningful sustainability learning, research on integration of sustainability across the curriculum should take place not only in the context of explicit sustainability learning but also in various institutions and disciplines that are not explicitly introducing sustainability learning. This research was conducted in a leading science and engineering university in Israel. The university has a green campus certification, given by the Israeli Ministry of Environmental Protection to institutions that meet several criteria in terms of management and curriculum; nevertheless, sustainability has not been defined as a goal in teaching or research in the university's strategic plan. However, many courses offered in a variety of programs deal with the environment, and therefore can be relevant for investigating whether and how teaching environmental topics enhances sustainability literacy.

5.2 Research tools and participants

Following the premise that sustainability can be integrated into HE activities in various ways, we collected data from students in several different programs who took part in various learning activities. We were interested in investigating formal, informal, and campus learning. In the formal learning aspect, we were interested in any course that addresses environmental and sustainability issues. Data were gathered by an online questionnaire and interviews. The rationale behind integrating information from these two sources was (a) our interest in collecting data from a large number of students who were enrolled in many courses, and (b) having the opportunity to conduct in-depth analysis.

5.2.1 The online questionnaire

The online questionnaire that consisted of open-ended and closed items was administered anonymously to approximately 2000 seniors from all departments of the university through the institutional listserve. Responding was voluntary. We received responses from 386 seniors from all 17 departments, giving a response rate of 19.3%.

The three open-ended questions focused on learning experiences recalled as significant in promoting sustainability literacy, and descriptions of perceived changes in knowledge, attitudes and behavior related to sustainability. Closed items were composed of a five-point Likert scale, which focused on the contribution of the entire period to the development of six aspects of sustainability literacy: knowledge, concern about the environment, professional skills and motivation to enhance sustainability in professional activities, awareness of the links between civic engagement and sustainability, and behavioral intentions. Factor analysis of the six items revealed that they are all related to only one factor, and Cronbach's alpha of all six was 0.92, indicating that they represent one contrast, which we termed "perceived contribution of college education to sustainability literacy". We constructed a measurement to present this contrast based on the average score of the six items. In addition, we collected background information on students' age, gender, department, and courses in which they were enrolled (see Appendix).

5.2.2 Interviews

Semi-structured interviews were performed with 16 seniors who had enrolled in at least one learning activity (formal or informal) focusing on the environment. The interviews were guided by the questionnaire items; they were audio-recorded and transcribed verbatim. The interview data were content analyzed. Quantitative analysis was conducted with the SPSS 21 package.

5.3 Rationale for using self-reports on learning contributions

The overall epistemological view of the research was to listen to the students' voice as an important source of information on the issue in focus.

The open-ended questions focused on students' perceptions of significant learning experiences. The study of significant learning and life experiences is a line of research strand in environmental education and education for sustainability. In such studies, participants are asked to recall experiences related to a specific learning program or to a life experience perceived as significant. Students can be asked about both the ways the program affected them and the program attributes that contributed to transformational experiences (Liddicoat & Krasny, 2012). The rationale behind these studies is that if educators understand the type of experiences that motivate responsible environmental behavior, they will be able to foster the development of an informed and active citizenry (Chawla, 1999; Hsu, 2009).

The closed items of the questionnaire required ranking the contribution of college years to the development of various aspects of sustainability literacy. Assessment based on self-reports is common in the field of HE (Astin, 2012, p. 123). The advantage of such studies is that they enable collecting data on various undergraduate experiences in a short time. Self-reported retrospectives are sometimes assumed to suffer from an upward bias; however, they allow accurately capturing how different student populations characterize their own learning gains (Douglass et al., 2012), thus suiting the objectives of the present study.

6. Findings

Of the 386 participants, 51% had enrolled in at least one course that focused on the environment. Figure 1 presents the number of such courses that the respondents had enrolled in.

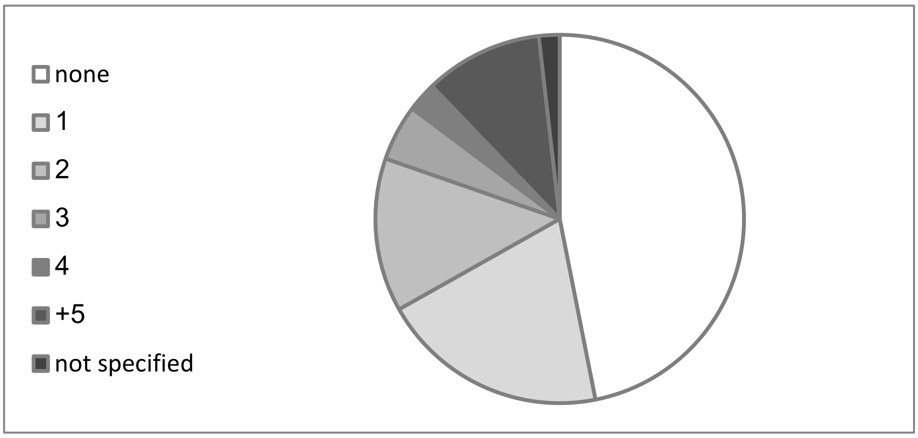

Figure 1. Student enrollment in courses focusing on the environment.

Only 9% (34) had enrolled in one of three informal activities on campus that deal with sustainability: the environmental branch of the student union, the local Engineering Without Borders (EWB), and "The Green Trend"—an Israeli environmental organization of student activists.

6.1 Students' views of the contribution of college to their sustainability literacy

In addressing the open-ended question about the contribution of college to the development of their sustainability literacy, almost half of the students (47%) indicated that they were more environmentally oriented than at the onset of their studies. However, only 10% explicitly viewed the university and their formal learning as the cause for this change. Others stated that sources of influence were friends, personal growth and the media. The open-ended responses to this question provided rich information about the students' perceptions of the ways in which their studies dealt with sustainability. Many claimed that the main focus of their program was on gaining technical and scientific knowledge, and even provided cynical responses about being asked about sustainability in college, claiming that none of their courses addressed this issue. It seems that for most students, sustainability was not seen as something they ever learned about in their program.

Findings from the closed items were in line with the open-ended ones: the average ranking of the measurement of perceived contribution of formal and informal studies to sustainability was low (mean 2.62, SD 1.17 on a five-point scale).

6.2 The perceived contribution of enrollment in courses that focus on the environment to sustainability literacy

A relatively good correlation was found between the number of environmental courses a student had enrolled in and the perceived contribution of studies ($r = 0.5$ $p < 0.001$). Yet, even students who had enrolled in five courses associated an average contribution of 3.8 to the courses and other activities.

To better understand the relationship between courses dealing with environmental topics and their perceived contribution to sustainability literacy, we looked at the contribution to sustainability literacy by department. Departments that the students indicated as contributing more to sustainability literacy were Biotechnology and Food Engineering (3.55) and Biomedical Engineering (3.66). Biotechnology and Food Engineering students' responses to the open-ended questions gave some explanation for this finding. The respondents offered some examples of how sustainability was integrated into professional courses in a single lecture, or as student-centered activities without being the main topic or a specific course. The interviews provided some more explanations for why participating in courses that deal with environmental contents did not always promote sustainability literacy: the interviewees clarified the difference between courses that deal with environmental contents and others that deal with sustainability issues. It turned out that, often, teaching about environmental topics focuses on specific scientific and technological aspects rather than on the "big" picture, or the relationship between environmental and social processes and ethical aspects. The following quotes from the interviews give some examples of student statements:

> *"It is a matter of focus. Some courses that deal with environmental contents focus on very specific scientific aspects, and don't give the whole picture. Others give a much more open view, and link the specific contents to other environmental economic and social issues."*
>
> *"I have participated in several courses that deal with environmental topics, but they always focused on scientific and engineering aspects. No one talked about environmental ethics, values, or things like that."*
>
> *"During my studies, the focus was always on the economic aspects rather than on environmental aspects."*
>
> *"The courses focused on understanding environmental phenomena but not in the way humans affect the environment, and mutual relationships between environmental, social and economic aspects. The concept 'sustainability' was not mentioned in any of the courses."*

6.3 Learning experiences viewed as significant in promoting the development of sustainability literacy

The data for the third research question were obtained from the open-ended questions in the questionnaire and from the interviews. Table 1 presents the distribution of experiences that were recalled as significant by the questionnaire respondents. Only 23% of the survey respondents recalled a learning experience that was significant to the development of their sustainability literacy. Various other experiences were recalled as significant.

Table 1. Significant experiences in promoting sustainability literacy (n = 386).

Sphere of learning	Significant experiences	n	Total (%)
Formal	Courses focusing on environmental topics	46	71 (18%)
	Courses not focusing on environmental topics	19	
	Graduate project	1	
	Field trips	5	
Informal	Student organization	7	14 (3%)
	The Green Trend	2	
	Engineers Without Borders	4	
	Community gardening	1	
Campus learning	Recycling activity	3	4 (1%)
	Information boards on environmental issues	1	
Total		89	89 (23%)

A similar pattern was found in the interviews: although many of the interviewees had enrolled in more than three courses that focused on environmental topics, they recalled only a few courses that promoted sustainability literacy. Table 2 presents some examples of meaningful experiences.

As can be seen in Tables 1 and 2, many of the learning experiences in the formal sphere that were recalled as significant were from courses in which the environment or sustainability were not the main topic. Rather, there were specific assignments or lectures in which sustainability issues were highlighted. In addition, it is important to note that many of the experiences that were recalled as significant, in both the formal and informal sphere, were of active and participative learning.

Table 2. Examples of experiences that were recalled as significant.

Formal	*Learning assignments of redesigning a neighborhood in my hometown, while taking into consideration environmental aspects.*
	A field trip in which we saw how sustainability is being promoted in real life. This was an extremely important learning activity.
Informal	*Volunteering in Engineering Without Borders (EWB) was a very meaningful period for me. I realized that you can help people while using your professional knowledge.*
	In EWB, I dealt with real-world problems and searched for solutions, a practice that was missing from my formal studies.
Campus learning	*I was in charge of handling the compost bins in the student dorms. I searched for the best ways to make compost and promoted composting habits among students.*
	The recycling bins, and the signs that remind us to print on both sides, were extremely effective.

7. Conclusions and discussion

This study of the integration of sustainability in activities across one Israeli university focused on the students' perception of the contribution of their learning to the development of sustainability literacy. We found that most of the participants were reluctant to acknowledge the contribution of their college period to the development of sustainability literacy, although 51% had enrolled in at least one course on environment. An reason for this reluctance was found in the participants' explanations of the difference between teaching about the environment and teaching about sustainability. It seems that quite often, courses focus mainly on specific scientific aspects or on technological solutions. By neglecting other important aspects, these courses do not promote sustainability literacy. The distinction between teaching about the environment and teaching sustainability is in line with theoretical perspectives on education for sustainability in HE that stress the importance of holistic and systematic views of environmental and social issues. It is also congruent with calls to integrate discussions on ethics and values, even while teaching scientific content (Sipos et al., 2008; Wals & Corcoran, 2006).

We also found that significant experiences for sustainability literacy were often a single lecture or assignment within a course, rather than a whole course dedicated to the environment or to sustainability. Thus, it seems that integrating sustainability as a part of a course could be a good way to introduce the idea to students. Three advantages of integrating sustainability within existing disciplinary courses are: (a) it does not put extra pressure on the already overloaded curriculum, as would adding a new course that focuses on sustainability; (b) it conveys a message that sustainability considerations are an essential part of being a good professional, rather than being just another issue that is unrelated to professional decisions; (c) since sustainability literacy requires knowledge of many issues and development of various competencies, dealing with sustainability in many topics and in different opportunities enables students to develop a deeper understanding of this complex interdisciplinary field, as well as the required skills and attitudes for promoting a sustainable future.

We also found that active and meaningful learning activities are key factors in promoting the development of knowledge, skills, and motivation for sustainability, in both formal and informal activities.

Finally, we suggest that a major way to integrate sustainability across the curriculum is by providing professors and instructors with the knowledge and skills to integrate sustainability contents and pedagogies into their courses. To do this, the university authorities should further enhance their encouragement and motivation.

8. Research limitation and suggestions for further research

This research provides insight into how HE can contribute to the development of sustainability literacy. Its major limitation is the focus on one science and engineering-oriented university. Since this university does not actively promote the integration of sustainability across the curriculum, it is important to collect further data from other universities that provide more opportunities for learning about sustainability, and to investigate their influence on their students' sustainability literacy development.

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Appendix

Dear Student

This questionnaire is for our research on education for sustainable development (ESD) in higher-education institutions. Responding will take approximately 15 minutes. All of the required information is anonymously given, and only for the purpose of this study. We appreciate your collaboration.

1. General Information

   Age: __ Gender: f / m Department ______________

2. Have you participated in any extracurricular activity that deals with sustainability/social activity/environmental organization? Yes/No

   If the answer is yes, please indicate the name of the activity.

3. How many courses dealing with sustainable development or environment did you enroll in during your studies?

   Please indicate the names of the courses.

4. On the next form, please indicate the extent to which your knowledge and attitudes have changed since you started your university studies.

	5 = very big change				**1 = very small change**
Knowledge of human effects on the environment					
Concern regarding environmental issues					
Prioritizing sustainability considerations in professional decisions					
Professional knowledge in sustainability solutions					
Considering civic activity to deal with environmental issues					
Awareness of the ways in which my daily decisions affect the environment					

5. In comparison to the beginning of your studies, how would you define your "environmentalism" today?

1 – Today I am more of an environmentalist than at the onset of my studies
2 – There is no change
3 – Today I am less of an environmentalist than at the onset of my studies
Please explain your answer.

6. Was there any particular learning experience during your studies that you recall as being significant to your personal/professional development concerning human–environment relations, and/or sustainable development?

(this could be, for example, a course, a single lecture, or extracurricular activity)

Please describe that experience and how it contributed to your development.

7. Comments:

Thanks for responding,
The research team

10 FACTORS INFLUENCING CONCEPTUAL CHANGE WHEN SOUTH AFRICAN LEARNERS ENCOUNTER EVOLUTION

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Abstract

Evolution was initially met with much debate, concern and conflict when it was included in the South African school curriculum in 2006. The aim of this investigation was to determine what conceptual change occurs when learners are taught evolution and what factors influence this change, looking in particular at learners' conceptual ecologies and the role of religious beliefs. Conceptual change involves the change of learners' existing understanding to adopt new concepts. Learners were given a pre- and post-instruction survey and concept-mapping task, and a sample of learners were interviewed post-instruction. Results showed that learners made significant conceptual changes and that religious beliefs were the main contributing factor to learners' conceptual ecologies and the conceptual changes that occurred. This study highlights the notion that conceptual change theory is not sufficient to explain how all learners learn evolution. Learners who experience cultural conflict follow various other learning paths explained by collateral learning. Collateral learning emphasises the importance of learner cultures in learning and highlights the importance of teaching for cultural border crossing.

Keywords

Evolution; conceptual change; collateral learning; cultural border crossing

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

1. Introduction and background

Prior to 1994, evolution was excluded from the South African school curriculum because it conflicted with the government's religious beliefs (Dempster and Hugo, 2006). Since 1994, the curriculum has undergone a series of reforms and evolution was explicitly introduced in 2006. It is thus a relatively new topic in South African schools. Many teachers find themselves expected to teach evolution without having had it in their own schooling, and without having taught the topic previously. Many Life Sciences teachers have a negative view of evolution (Holtman, 2012). Holtman (2012) also observed a gap between scientists and the general public in the understanding and acceptance of evolution, and teachers follow public trends. Knowledge concerning evolution is primitive, and teachers buy into and support misconceptions (Anderson, 2007; Holtman, 2012). Most South Africans identify themselves as Christians and the general perception is that evolution is anti-religious. There is still conflict between evolution and religion. A number of research papers have focused on the problems and concerns arising in South Africa with the inclusion of evolution (Abrie, 2010; Dempster and Hugo, 2006; Holtman, 2012; Sanders and Ngoxla, 2009; Stears, 2011; Tucker, 2012).

The focus of this study was the conceptual change of learners' ideas when taught evolution, and the influences that affect this conceptual change. The conceptual change model developed by Hewson (1981) and Posner et al. (1982), and later expanded on and further developed by Hewson and Hewson (1992), Demastes et al. (1995, 1996), Tyson et al. (1997) and Sinatra et al. (2008), can be used to describe and follow the conceptual change process. Conceptual change refers to a constructivist way of learning. In its simplest form, conceptual change involves the change in learners' existing understanding to adopt new concepts. Conceptual change theory is widely used to explain and understand the learning process in science.

Conceptual change theory provides a framework for this study, as it addresses certain challenges faced with biological evolution rooted in learners' prior conceptions and conceptual ecologies. Evolution is a controversial and counter-intuitive topic in schools and because of this complex, controversial intersection, evolution is an excellent content area in which to study the influence of learners' conceptual ecologies (Demastes *et al.*, 1995). However, due to the controversial nature of the topic, conceptual change cannot be considered in isolation in this study. Cognitive conflicts arise from cultural and religious differences between the learner's lifeworld and what they are taught at school, and another framework needs to be considered to understand how learners deal with such conflict. This study presents evidence that conceptual change theory does not adequately explain learning for every child, and introduces collateral learning theory as an alternative, particularly in topics where learners experience conceptual conflict.

Collateral learning was first proposed by Jegede in 1995 and is defined as an accommodative mechanism for the conceptual resolution of potentially conflicting tenets within a person's cognitive structure. Collateral learning helps explain how learners learn when cognitive conflicts arise from cultural and religious differences between the learners' lifeworld and what they are taught at school. Collateral learning generally involves two or more conflicting schemata held simultaneously in long-term memory (Jegede and Aikenhead, 1999; Aikenhead and Jegede, 1999). Collateral learning acknowledges learners' prior knowledge and at the same time, allows them to access science concepts (Herbert, 2008). Jegede (1995) and Aikenhead and Jegede (1999) describe different types of collateral learning according to the degree to which conflicting ideas interact with each other and the degree to which conflicts are resolved: parallel, simultaneous, dependent and secured collateral learning.

All learners come to class with some ideas or preconceptions about the origin of life. Preconceptions are influenced by parents' opinions, religious leaders, media, culture and indigenous knowledge (Cavallo and McCall, 2008; Demastes *et al.,* 1995). These preconceptions, coupled with a learner's religious orientation, form a learner's conceptual ecology, which teachers need to consider when designing instruction (Cavallo and McCall, 2008; Mathews, 2001; Sinatra *et al.*, 2008; Smith, 1994). Work done by Cavallo and McCall (2008) and Lawson and Warsnop (1992) showed that the attitudes of learners and teachers will affect the type and quality of learning and teaching that occurs in the classroom. Helping learners understand evolution is not simply a matter of adding to their existing knowledge, but rather helping them see the world in different ways (Sinatra *et al.*, 2008). The present study attempts to follow the path of conceptual change adopted by two groups of South African learners as they encounter evolution. Collateral learning theory is included because it has been found to be valuable in explaining patterns of learning science in societies with strong religious and/or traditional belief systems (Aikenhead and Jegede, 1999), as is the case in South Africa.

The main research questions that guided this investigation were: 1) What are some of the contributing factors to South African learners' conceptual ecologies and preconceptions towards evolution? 2) What conceptual changes occur when learners are taught evolution? 3) What factors influence this conceptual change? The answers to these three questions formed a foundation of data that could then be built upon to determine its use and meaning for everyday teaching and learning, i.e., how do learners learn evolution? Including both conceptual change and collateral learning theories provides the means to address this practical question. Thus, the ultimate goal and outcome of this research is to answer the critical question: How can conceptual change and collateral learning theories be used to explain how all learners can learn evolution effectively?

2. Research design and method

A well-resourced, multicultural, co-educational secondary school in the KwaZulu-Natal midlands area was the site for this investigation. The medium of instruction was English, although this is not the home language of many of the learners. This school's Grade 12 Life Sciences classes were the focus of the investigation. There were two classes of learners (n = 45) aged 17 or 18 years. Learners came from diverse socio-economic backgrounds. Each class had its own teacher. Both teachers had similar qualifications and held leadership positions within the school. The design of the investigation was based on methods used by

Rutledge and Mitchell (2002) and Mathews (2001) and comprises four parts: a concept-mapping task, survey, extra questions and interviews. The teacher effect was determined to be non-significant ($p > 0.05$, two tailed t-test) at the beginning of the statistical analysis of the results, so the two classes were combined into one for further analyses.

2.1 Part 1: concept mapping

A concept-mapping task based on that of Rutledge and Mitchell (2002) was used because it provides an open-ended method for learners to communicate their conceptions and knowledge structures about evolution. Learners were asked to draw a concept map plotting everything they knew about the topic of evolution, making links between ideas, including religious ideas and points of view. Learners were also asked to identify which of the concepts and ideas they believed to be true or plausible. This was done by circling, marking or highlighting the relevant concepts and ideas on the concept maps. The maps were analysed for trends and used to gain an overall impression of the conceptual framework concerning evolution. To further identify patterns and valuable data, an organising system of data reduction was used (McMillan and Schumacher, 1993).

2.2 Part 2: survey

A 15-item survey concerning specific beliefs and ideas about evolution and whether learner knowledge is based on scientific or non-scientific notions, adapted from Mathews (2001), was implemented. The survey was scored using a 5-point Likert-type scale. Results indicated whether learners' ideas are scientific or based on non-scientific notions. The survey included questions assessing scientific knowledge (questions 1–4, 6 and 10), religious beliefs (questions 5, 7–9, 12 and 15), supernatural beliefs (questions 11 and 13), and opinions (question 14). Data analysis was conducted according to these question groups.

Concept mapping and the survey were carried out pre- and post-instruction. The results from the pre- and post-surveys were plotted on various bar graphs to identify changes made by learners, in particular whether they moved towards a more scientific understanding. A paired sample t-test was used to determine the significance of differences between the mean pre- and post-survey scores, whilst one-way analysis of variance (ANOVA) was used to test for a difference between the mean scores of the groups of questions. A multiple comparison, least-square difference assessed exactly where the change was that emerged in the ANOVA. Pearson correlation was performed to identify potential relationships between the questions in the pre- and post-instruction survey. The data derived from the statistical tests were then examined to identify possible shifts in learners' beliefs, attitudes and scientific understanding of evolution. Concept maps provide further evidence and detail concerning such changes.

The survey questions were:

1. Landforms like the *Drakensberg Mountains* were created by God and have not changed since
2. Certain types of living things, such as dinosaurs that once lived on Earth, no longer exist.

3. Fossils were intentionally put on Earth to confuse humans
4. All humans originate from Africa from where they populated the rest of the world
5. The creation story is the best account of how the Earth was created and populated with life
6. Humans and apes are as closely related as humans are to dogs
7. Living organisms are different from non-living things because they possess some kind of special force.
8. Human beings are different from other living organisms because they possess a soul
9. All events in nature occur as a predetermined plan.
10. You have the same genes as bacteria for essential life processes
11. Living organisms on Earth may have come from an alien life form
12. It seems reasonable that the universe was created by God.
13. Aliens sometimes land on Earth

2.3 Part 3: extra questions questionnaire

This questionnaire was used to probe learners' acceptance of evolution, specifically with regards to macro- and microevolution and natural selection. The extra questions questionnaire also provided learners with the opportunity to express their opinions and concerns about evolution; this entailed learners listing and explaining concepts that they found easy to understand or difficult to deal with. Questions also asked learners to explain if they felt evolution was compatible or incompatible with their religious beliefs and whether or not they thought evolution should be included in the school curriculum. The extra questions were analysed for general trends that emerged for individual learners as well as groups of learners. A simple data reduction technique was applied to the questionnaire and the results were tabulated.

2.4 Part 4: interviews

The purpose of the interviews was to collect detailed qualitative data directly from learners. Data generated by the interviews were analysed for general trends as well as identification of data that could support or explain trends noticed in parts 1–3 of the study. The questionnaire and interviews were carried out post-instruction only.

Once the data analysis was complete, learners were classified according to their cultural backgrounds, scientific knowledge structure and religious stands according to the categorisation scheme of Costa (1995), later revised by Jegede and Aikenhead (1999) and Aikenhead (2001). Learners are categorised according to the ease with which they succeed in school science; which in turn is related to how their world views align with school science

(Aikenhead, 2001). Jegede and Aikenhead (1999) and Aikenhead (2001) closely linked this categorisation scheme to understanding the process of collateral learning and cultural border crossing, making this an appropriate scheme to apply to this investigation. Criteria used to group learners were designed to fit this investigation specifically using results of learner survey scores, concept maps and extra questions. Before the analysis of the results, further criteria were established and narrowed to suit this study, based on the design of the tasks given to the learners (grouping criteria is based on predicting learner response on tasks and surveys). Table 1 summarises the group descriptions of Jegede and Aikenhead (1999) and gives examples of further criteria used to group learners. For the sake of consistency, group names have been kept the same as those initially described by Costa (1995) and Jegede and Aikenhead (1999); they do not indicate level of intelligence but instead, how learners see the world.

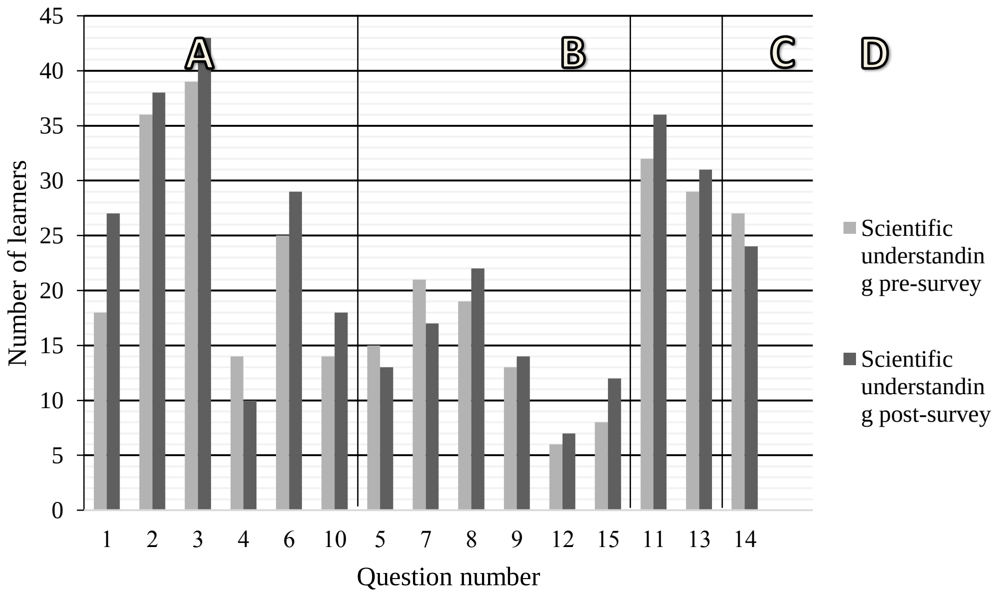
Table 1. Summary of learner group descriptions

Group	Group description	Example of grouping criteria
Group 1 *(Potential scientists)*	Accept evolution in its entirety No cultural clash with science concepts Show deep understanding of concepts	Obtains positive score change from pre- to post-survey Accepts macroevolution on the extra questions questionnaire
Group 2 *(Other smart kids)*	Accept evolution Have difficulty with some aspects only Transition to school science is manageable	Obtains a score change of 0 or positive from pre- to post-survey Includes 3 or more scientific concepts on post concept map
Group 3 *(I don't know)*	Uninterested and lack enthusiasm Superficial understanding of science concepts	Answers inconsistently across the various tasks Shows a poor understanding of natural selection
Group 4 *(Outsiders)*	Strongly religious learners Learners reject evolution completely Impossible border crossing because cultures clash severely	Obtains a negative or positive score change not greater than 2 from pre- to post-survey States personal beliefs on concept maps and questionnaire
Group 5 *(I want to know)*	Accept parts of evolution only Science and religious views overlap Effective understanding of science concepts	Few scientific concepts included in concept maps Maintains religious beliefs throughout tasks

Most learners were classified into groups 2, 3 and 4 (28.9, 20.0 and 22.2% respectively). Group 5 included 15.6% of the learners, and group 1 was smallest with 13% of the learners (n = 45).

3. General trends and findings

The general trends and findings from learner interviews and written answers can be summarised briefly as follows: (a) religious learners, mainly from group 4, showed greatest conflict when learning evolution, and were least likely to change their ideas; (b) some learners, mainly from groups 5 and 2, found overlap between religious/cultural views and the theory of evolution; (c) many learners found evolution boring (there were learners from all groups who indicated this); (d) teachers emphasized that evolution is “just a theory”, adding to learners' negative attitudes. These important trends, amongst others, started emerging in the survey results. Graph 1 shows the number of learners that held a scientific understanding of the subject addressed by each question in pre- and post-surveys. Questions are grouped based on the content being questioned: scientific knowledge (A), religious/cultural (B), supernatural (C) and opinions (D).

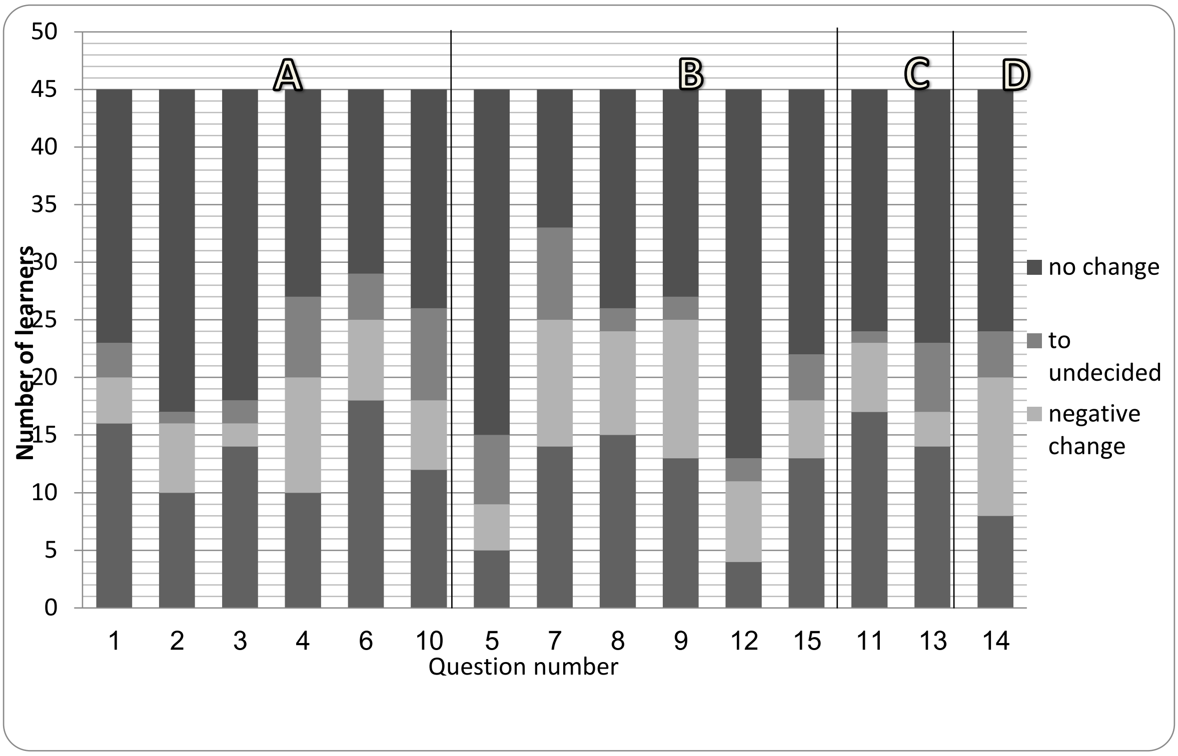


Graph 1.. Bar graph showing the number of learners with a scientific understanding pre and post surevy.

In Group A, five of the six questions showed that more learners had a scientific understanding post-instruction than in the pre-survey. These questions address knowledge issues such as fossils, genetics and landforms. Question 4 differs from the other questions in that fewer learners had a scientific understanding post-instruction than pre-instruction. The question refers to the out of Africa theory as an explanation for human origin, which can be closely linked to the religious ideas of Adam and Eve and cultural heritage and lineage of learners. Thus, the pattern of answering resembles that of religious-based (group B) questions, rather than scientific-based questions, and in this case fewer learners had a scientific understanding post-instruction.

The supernatural-type questions showed a more scientific understanding post-instruction, while a drop occurred in the opinion question: Should evolution be taught in school? A large proportion of learners showed no change between pre- and post-survey scores. They retained their view, be it scientific or non-scientific.

Graph 2 accounts for all four types of score changes, those that moved towards a scientific understanding and those that moved away from it, those that became undecided and the large proportion that remained unchanged. Every question has at least one learner in each of the four categories. A large portion of the learners showed no change for each question, questions 5 and 12 showing the greatest with 30 and 32 learners not changing their ideas from the pre- to post-survey, i.e., maintaining their unscientific, or in this case due to the content of the question, religious views. Questions 5 and 12 also showed the largest resistance to change.



Graph 2. Bar graph showing the type of score change made by learners for each survey question.

Table 2 shows the results of key questions from the questionnaire. Distinct patterns of answering emerge, which coincide with the outlines and criteria used to group learners. For example: all learners in group 1 accept macroevolution, believe natural selection to be true and find most of evolution to be incompatible with religious beliefs.

Table 2. Table showing how learners answered in the extra questions questionnaire. Comp., compatible; Incom., incompatible.

Question	Group 1		Group 2		Group 3		Group 4		Group 5	
1	Accept	Reject	Accept	Reject	Accept	Reject	Accept	Reject	Accept	Reject
	3		11		2	2		6		5
2	Believe	Don't	Believe	Don't	Believe	Don't	Believe	Don't	Believe	Don't
	3		11		3	2	1	5	6	
5	Comp.	Incom.	Comp.	Incom.	Comp.	Incom.	Comp.	Incom.	Comp.	Incom.
		3	4	7	1	4		6	1	5
6	Should	Not	Should	Not	Should	Not	Should	Not	Should	Not
	3		11		2	3	2	4	4	1

Questions included in the extra questions questionnaire:

Circle the underlined word in each question below that best completes the sentence and then give an explanation as to why you said so.

1) I reject / accept the theory of macroevolution because...
2) I believe / don't believe natural selection to be true because...
3) During the section on evolution I found the following concept difficult to deal with because....(state the concept and then explain why)
4) During the section on evolution I found the following concepts interesting and easy to understand because...(state the concept(s) and explain why)
5) I find evolution compatible / incompatible with religious beliefs because...
6) Evolution should / shouldn't be included in the Life Science curriculum because...

Table 3. Table of main concepts identified from pre- and post-instruction concept maps.

	Pre-concept map[a]		Post-concept map[a]	
	Total	*%*	*Total*	*%*
Big Bang Theory	10	22.2	2	4.4
Humans evolved from apes/primates	32	71.1	16	35.6
Believes Christian religious view	18	40	8	17.8
Does not believe evolution to be true	12	26.7	7	15.6
I don't know much	13	28.9	0	0
Emotive language against evolution / Emotional	9	20	1	2.2
Lamarck's Theory	0	0	28	62.2
Lamarck's Theory explained	0	0	14	31.1
Darwin's Theory	2	4.4	30	66.7
Fossils	0	0	15	33.3
Mass extinctions	0	0	12	26.7
Natural selection	1	2.2	25	55.6
Natural selection explained	2	4.4	17	37.8
Definition of evolution given	5	11.1	13	28.9
Survival of the fittest	1	2.2	14	31.1

[a]Shaded figures indicate a major change.

Table 3 shows that in the pre-instruction concept map, 71.1% of learners associated the idea of humans evolving from apes with evolution. In contrast, only one learner still included emotive/emotional language against evolution in the post-instruction concept map. The pre-concept maps revealed that 28.9% of learners admitted that they did not know much about the topic. This figure declined to 0% in the post-concept maps, i.e., no learner felt they did not know anything about the topic. This is a vast improvement from pre-concept map numbers where 0% knew about Lamarck and only two learners mentioned Darwin. Also, the importance that learners placed on the idea that humans evolved from apes/primates decreased in the post-concept maps. There is a clear shift in concepts included in the pre- and post-concept maps of learners from all groups, i.e., there is a shift away from purely religious views and human evolution, to a balance of scientific concepts.

4. Discussion

For conceptual change to occur, learners need to find the new concept intelligible, plausible and fruitful, and there must be a level of dissatisfaction with existing conceptions (Posner *et al.,* 1982). This form of conceptual change is called accommodation and is an appropriate framework to consider when investigating how learners learn the 'basics' of evolution (i.e., the fundamental concepts such as Darwin's theory of natural selection), because it takes learners' current concepts into consideration (Posner *et al.*, 1982).

The boundaries of the conceptual change model lie in Posner et al.'s (1982) and Hewson's (1981) initial explanation of how conceptual change occurs. Learning is considered a logical and rational activity and conceptions undergo a holistic change (Demastes *et al.,* 1996). Hewson (1981) explains that a new concept can either be rejected (an explanation from strongly religious learners in group 4), or incorporated in three possible ways: memorizing by rote (i.e. Fatima's rules and group 3 learners), assimilation, or accommodation (a possible explanation for group 1 and 2 learners). The limitation of this school of thought, however, is that it can explain the learning that occurs superficially, i.e., learning the "basics", but it does not take into account learners' social backgrounds (religious beliefs and cultures), goals, emotions and motivations, which play a significant role in conceptual change (Demastes *et al.,* 1995). Conceptual change theory focuses on what learning is and not what it depends on (Posner *et al.,* 1982). The present study shows that learning heavily depends on learners' backgrounds, especially religious learners.

Demastes et al. (1996) recognised conceptual change theory as useful because it takes learners' prior knowledge into consideration, but that it is not sufficient to explain how all learning takes place because not all conceptual change fits neatly into the conceptual change model. Instead Demastes et al. (1996) suggested that learning a concept can take a variety of pathways. Learning often does not take a logical holistic approach as suggested by conceptual change theory, and this needs to be considered when investigating how learners learn evolution, because religious learners' views and beliefs play an important role in the process of conceptual change.

Collateral learning can be used instead to explain this phenomenon. Collateral learning explains the pathway of learning that religious learners follow because, as this study shows, religious learners do not abandon or replace their religious beliefs with evolutionary biology concepts. Instead, these learners can construct two meanings (one religious and one scientific) of a concept simultaneously. Collateral learning pays particular attention to cultural conflicts between learners' lifeworld and what is taught at school (Aikenhead and Jegede, 1999). Unlike conceptual change, collateral learning emphasizes the role that learners' cultural backgrounds have in learning and the capacity of the learners themselves to think differently. Aikenhead and Jegede (1999) recognised the conflict between Christian faith and science and identified collateral learning as a tool to understand how such learners learn.

Collateral learning has been closely linked to the idea of cultural border crossing (Aikenhead, 2001; Aikenhead and Jegede, 1999). The learner groups established in this study take the notion of border crossing into account. The groups categorise the degree of ease with which learners apparently cross cultural borders and negotiate transitions into school science. Table 4 summarises the categories as described by Costa (1995) and Aikenhead (2001).

Table 4. The type of border crossing experienced by each group.

Group	Type of border crossing
1 Potential scientists	Smooth
2 Other smart kids	Manageable
3 I don't know	Hazardous
4 Outsiders	Impossible
5 I want to know	Adventurous

Border crossing depends on how different learners see their beliefs in relation to what they are being taught in class, as well as the assistance learners receive (how teachers teach) to make such transitions easier. Forcing a scientific view on learners produces enculturation and learners playing by Fatima's rules (Cobern and Aikenhead, 1998; Aikenhead 2000). Achieving successful enculturation is a challenge in the classroom and needs to be a focal point or "goal" for teachers to teach evolution successfully. Enculturation can, however, only succeed when learners' life culture harmonises with what is being taught, i.e., learners in groups 1 and 2 and possibly 5; learners in group 3 and 4 will react by playing by Fatima's rules or rejecting evolution completely. Thus teachers should not teach to enculture all learners. The ideal would be to approach the teaching of evolution with the goal of ensuring that all learners fall into groups 1, 2 and 5 so that enculturation can occur and learners' culture overlaps with scientific culture.

Learners in group 4 are most likely to follow the pattern of parallel collateral learning (which is similar to dual construction), if they do not reject the theory of evolution completely (as some learners did). This way of learning does not require learners to accept concepts linked to evolution, they merely need to memorise, and to some degree, understand what they are taught in class. This type of learning (also followed by group 3 learners) is referred to as shallow learning by Aikenhead (2000). Learners that follow a "shallow learning" route do not see the need to develop a deeper understanding of what they are taught. This explains how religious learners "scored" well in the concept maps. They accessed one schema (scientific knowledge) in the context of the concept-mapping task, eliminating conflict with religious beliefs and thus eliminating the emotive language used in the post-concept maps.

Dependent and secured collateral learning explains how religious learners in groups 5 and 2 learn. These learners find a cultural overlap between scientific concepts and religious beliefs. Group 1 and 2 learners followed what is expected from the conceptual change model. Aikenhead (2000) describes these learners as making an in-depth level of meaning for school science and rejecting Fatima's rules. This is only a small proportion of learners in this study. Figure 1 shows the unique interaction between conceptual change and collateral learning models and learner groups. The Figure attempts to illustrate the possible learning paths that each particular group of learners is most likely to follow. Conceptual change explains how learners learn the "basics" of evolutionary theory (i.e., material that is not necessarily controversial in nature, such as natural selection and comparing Darwin and Lamarck), and it is followed by learners in all groups. Collateral learning theory then "takes over" where conceptual change theory fails to appropriately explain the learning process. Collateral learning explains how religious learners learn evolution by addressing how these learners approach and deal with the deeper issues of the theory of evolution that clash with their beliefs and lifeworld.

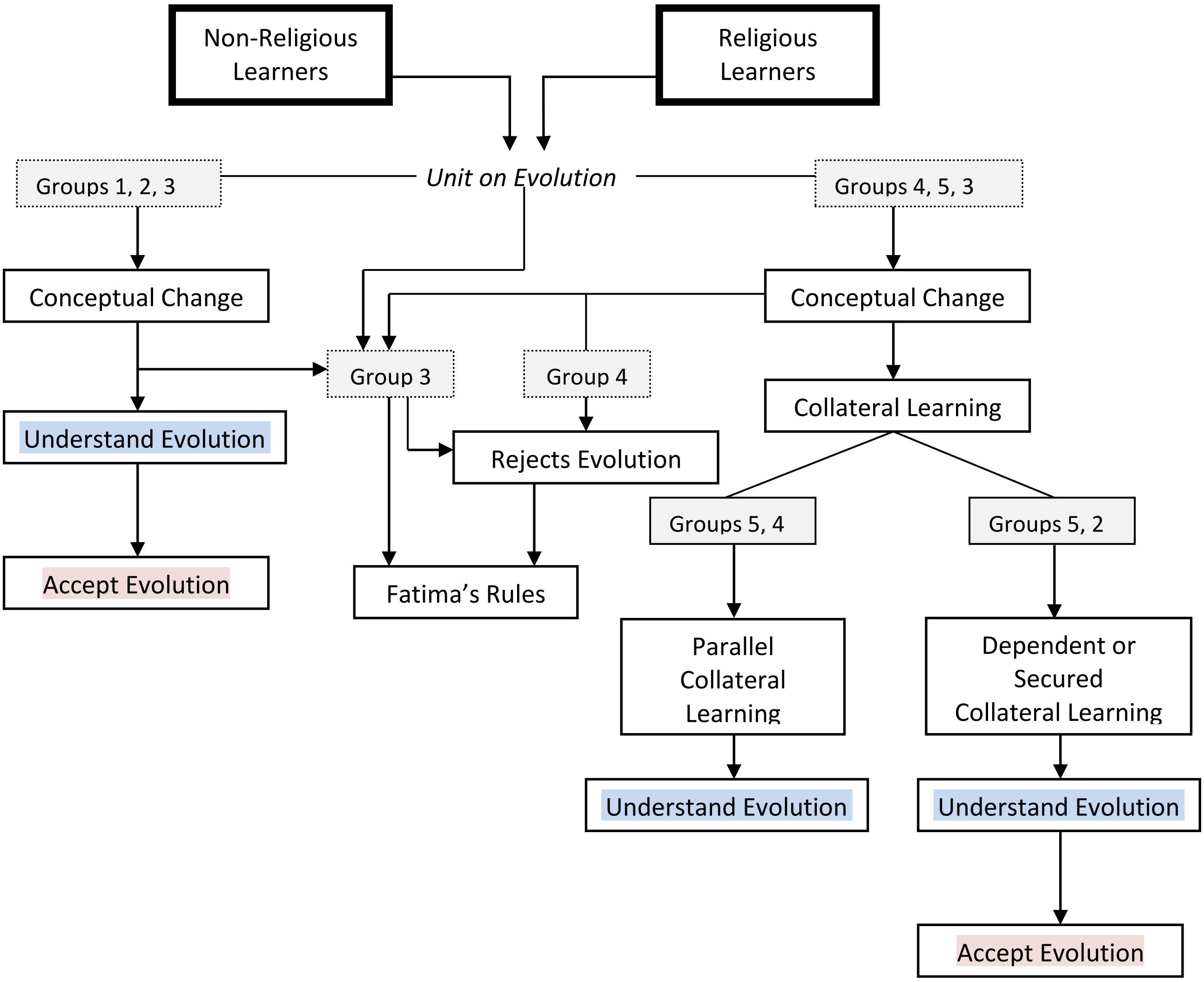


Figure 1. Possible learning paths followed by different groups of learners.

Figure 2, on the other hand, illustrates how learners can move between groups. Learning is a dynamic process, and learners' beliefs, views and knowledge structures are continuously being challenged in class. It is thus possible for learners, depending on what is being taught and how it is being taught, to move between groups. Figure 2 illustrates the possible movements that learners can make from the different group settings.

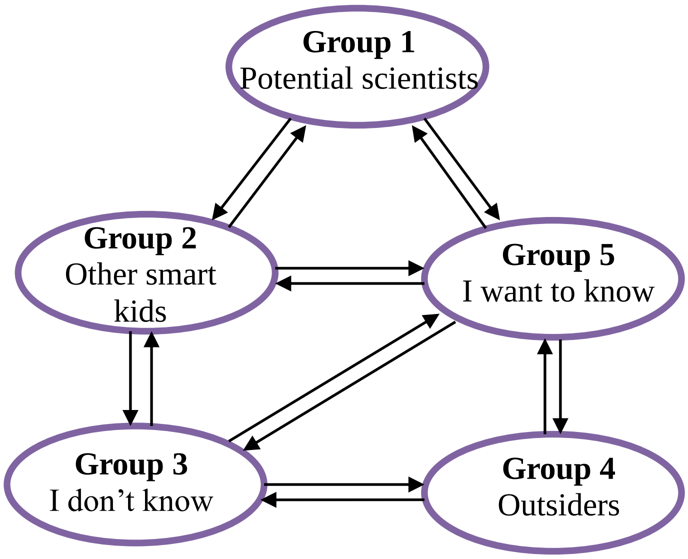


Figure 2. Flow chart illustrating possible movement between learner groups.

5. Conclusion

Results indicate that learners made significant conceptual changes and on the whole, demonstrated a better understanding of evolution post-instruction. Learners' initial understanding of evolution was of a human evolution aspect only, where apes evolve into humans. This understanding of evolution shifted to Darwin's theory of natural selection post-instruction. Learning evolution can be considered a much more complex process than learning other, less controversial, concepts in biology. Learners' conceptual ecologies play a far greater role in learning than expected and must be considered when teaching this unit of work. The potential cognitive conflict created by teaching evolution can be dealt with by schools in the manner in which they teach evolution. Significant conceptual change and increased understanding reduced the controversy. This study also highlights the notion that conceptual change theory is not sufficient to explain how all learners learn evolution. Instead, collateral learning needs to be considered because it more accurately explains how religious learners learn evolution. Collateral learning emphasises the importance of learners' cultures in learning. Ultimately, conceptual change explains how some learners learn evolution, and collateral learning helps explain others; and it is how these two theories work together that explains how all learners can learn evolution effectively.

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Symposium on Current Issues in Biology Education Research

SYMPOSIUM ON CURRENT ISSUES IN BIOLOGY EDUCATION RESEARCH

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Introduction

In 2014, we celebrated 20 years of ERIDOB. The ERIDOB Academic Committee therefore dedicated a special symposium at the 2014 conference in Haifa to exploring what exactly is meant by 'Research in Didactics of Biology', and what questions are, or should be, addressed in this research area.

Experienced researchers in Didactics of Biology from different countries were asked to write a short piece on their thoughts about these questions. The symposium consisted of a structured discussion with all participants. For this discussion, four main themes, listed below, were defined, based on the articles.

This section of the proceedings presents the papers written by researchers from 10 countries, and the summary of the group discussions held at the ERIDOB conference in Haifa. This summary is arranged to follow the above-mentioned questions. We hope this provides a useful basis for further deliberation.

A. What defines the scope of ERIDOB research?

ERIDOB differs from other science education research groups, such as ESERA, in being relatively small and therefore relatively efficient; the participants are more closely associated in terms of training, background and interests. The conference should consider having 'keywords' instead of strands and having topics to preface the strands; moreover, the format should be opened up beyond empirical studies to include methodological and theoretical strands. We should consider including: 'adult education', 'research methods', 'interdisciplinary education', 'special needs', 'nature of science', and 'early age education'.

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

Government and politics influence biology and therefore biology education, and we therefore need to constantly update the scope and the methods that need validating-even though those methods are difficult to categorize due to the transdisciplinary nature of biology. Similarly, there is a need to continually update and agree on the language and terminology used, and to contextualize biology education by looking at it from different perspectives, such as through the lenses of conceptual change, biology in a social context, systems thinking, the nature of science, argumentation, cognitive psychology, and design-based research. We should consider how we learn, cognitively and affectively, and design projects with this aim in mind. In addition, there is a distinct lack of research impacting teaching.

B. What is ERIDOB's focus?

Should our focus be aligned with the big biological themes or with big themes within science education? We should start from general contemporary biology themes as these are most relevant. These would include, for instance, the nature of science, argumentation, risk assessment, metacognition, moral reasoning, etc. The ERIDOB conference would be enhanced if more papers were presented that have theoretical outcomes contributing to theory formation in relation to these main themes of science education, so that scholars from other fields could also benefit from our research. This would also enhance ERIDOB's profile and status.

The 'how' and 'why' questions are equally important and there should be more theoretical and philosophical papers providing an in-depth exploration of biology education; this could provide guidance and inspiration for curriculum designers and policy-makers.

ERIDOB conferences should endeavour to provide more time and space for discussions and interactions among researchers (e.g., round tables or symposia such as this one).

C. What research methods should ERIDOB be promoting?

There has been a recent shift in emphasis on the types of science education research being undertaken. For example, simple research on misconceptions is no longer sufficient; there is now more of a need to understand the importance of mechanisms to explain findings. This requires more qualitative, narrative-based research, including case studies. Design-based research is growing in importance in science education, but less so in biology education research. The latter needs to take into account developments in neuroscience and the use of new technologies by young learners. These are likely to become increasingly important areas for research and will inform the methods that we use.

Biology education research could stand to better draw on well-established social science research methods. For example, we could learn from psychologists (who tend to be strong on design and the validation of instruments), from historians (who are strong on documentary analysis), and from sociologists (e.g., their use of critical discourse analysis). In some European countries, our Ph.D. students are trained in the full range of social science research methods, but we do not see much evidence of these in biology education research. Regardless of our choice of methods, we need to ensure that the tools that we use are properly validated.

There are strong national differences between the methods that are used and changes in journal policy (formal and informal). The emergence of new journals (e.g., *Cultural Studies of Science Education)* can shape what gets published in terms of research methods and theoretical frameworks used.

D. How can ERIDOB become more influential and effective?

There remains a gap between what is published in the biology (and science) education research field and what happens in the school classroom, i.e., there is a difference between research-based knowledge and classroom-based knowledge. Bridging this gap should involve better communication with policy-makers, and we need to be more aware of how policy-makers receive their information and make decisions about curriculum.

ERIDOB could have an important role in investigating and bridging this gap. It could provide more time for symposia and round tables, among others, to discuss the big picture and make international connections leading to collaborations. Perhaps opportunities to read papers in advance of the discussions should be afforded. We could consider setting up small special interest groups in, for example, classroom practice, policy-making and internationalization.

The Committee might also initiate talks with a wider community, such as ESERA and NARST, to see what synergies might develop. This could be developed into workshops on publications and we should consider the publication of special issues from ERIDOB that would be aimed at teachers.

11 OUR DOUBLE HELIX: ERIDOB IN THE FACE OF THE TWO STRANDS OF BIOLOGY "DIDAKTIK"

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In this paper, I will look back at the shift toward the empirical in the Didaktik of biology in the 1990s and in this connection, to the start of ERIDOB. Two decades later, it seems to me that it is time to deal with the strengths and weaknesses of empirical research in Didaktik of biology. Furthermore, I question whether placing the focus on empirical research might end in neglecting certain crucial scientific tasks in the area of development. In this context, I discuss the requirement and conditions of literacy-based scientific modeling projects.

1. The shift toward empirical research and the formation of ERIDOB

From the 1960s, the main focus of the work in didaktik of biology being carried out at universities was to develop and test novel approaches and new materials for teaching biology in schools. This move to find a new way of teaching biology (as well as chemistry and physics) stemmed from what we came to call the Sputnik Shock of 1957. Governments hoped that a modernized approach to the sciences in schools would be instrumental in keeping their country strong in the face of international competition—competition that they had begun to fear following the success of the Soviet Union in the space race. Against this background, institutes were set up to address the new demands on science education, such as the BSCS in Colorado Springs and the IPN at the University of Kiel.

The development and trialing of approaches and materials for use in schools was not, however, regarded as true *research* by the researchers in the sciences and other reference disciplines at the universities. By the 1990s, there was a real danger of the Didaktik of biology being banished from our universities, along with the didactics of all of the other subject matters. If academics in these fields were to face up to this challenge, they would now be required to engage in internationally recognized research. In the mid-1990s in Germany, this did indeed open a new, empirical chapter in didaktik of biology and the other natural sciences, as well as mathematics. Recognition and opportunity came in the form of funding from DFG, the German Research Foundation, which provided the first grants for empirical research in science education, most notably in Didaktik of biology.

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An early initiative to support empirical research at the European level came from the group representing itself as "European Researchers in Didaktik[2] of Biology" (ERIDOB). ERIDOB was founded with the aim of promoting empirical research in the Didaktik of biology in Europe—and in the process supporting the didaktik of biology at universities across the continent. Accordingly, from the beginning, ERIDOB conferences had a clear empirical focus. There were also affairs with relatively small numbers of participants, which had the characteristics and feel of a workshop. All of the projects were to be discussed by all of the participants. Younger colleagues, for whom empirical research was new, were to find support from more experienced researchers.

When we look back at the motivation for this shift toward the empirical in didaktik of biology, we can see that the part played by educational policy, as well as the politics of academic disciplines, cannot be ignored.

2. Strengths and weaknesses of empirical research in Didaktik of biology

Empirical research in Didaktik of Biology focuses on basic research on teaching and learning biology, as well as on subject-related design-based research. Empirical research in Didaktik of biology can in general be said to have considerable strengths, but also some weaknesses.

- The unassailable advantage of basic research on teaching and learning biology in our field is bought at a price. Empirical projects are bound to pursue a closely defined line of questioning about the teaching and learning of a necessarily restricted aspect of biology. This restriction is, above all, a matter of practicality; only relatively small projects can be successfully implemented within a manageable time frame. In university working groups of a typical size, broad-based research programs are doomed to failure. The requirement that a line of questioning be sharply focused on is therefore, on the one hand, a great benefit with respect to the progression of knowledge and the development of theory. But this same feature is also a drawback: it becomes all too easy to lose sight of the diversity and complexity of teaching (objectives, contents, methods, media, interests, previous experience, etc.), as well as the diversity and complexity of biosystems and biosciences in general.
- Some empirical studies in Didaktik of biology operate within the framework of a politically mandated concept of literacy and typically address scientific literacy. One example here would be the analyses carried out in connection with PISA. The advantage of this arrangement is that the empirical research it spawns will have strong links to practice and a relevance to educational policy. In the context of international comparative studies, it

[2] In the naming of the new group, we deliberately use "Didaktik" for this term as it comprises explicitly both a functional and a personal dimension of literacy (see below). We purposely spelled it twice with k to distinguish it from didactics, spelled twice with c. In this way, we avoid the connotation of methods, which used to be connected with "didactics", at least formerly.

will be easier for the work to feed into that of the wider international research community. A disadvantage of this proximity to educational policy, however, is that the research will be required to take on board any concurrently prevailing general goals of education. And there is a danger that this can happen without adequate reflection. In all events, there is the danger that (supposedly) objective research findings will be obscured by normative influences and beset by the vagaries of educational policy.

- Empirical findings in Didaktik of Biology draw on theories from the psychology of teaching and learning. This is a great advantage in that findings relating to the learning of a subject can be interpreted within the frameworks of these theories. But there is a danger that the analyses which then emerge under the banner of Didaktik of biology, rather than serving to develop a theory of learning or teaching for biology, actually serve to develop a theory of learning in general, which sits more within the remit of psychology. This is always the case when a project could just as well have been conducted by psychologists.
- The strength of design-based research lies in its describing and explaining subject-related teaching and learning processes and developing subject-specific teaching and learning theories—a unique characteristic of this kind of research (see for example “Jojo(yo-yo?) learning” in genetics). In contrast, a sole analysis of the overall learning effect of a new teaching model does certainly allow us to evaluate how effective it will be in practice, but it cannot enlighten us as to whether a different approach might have led to better results. So in that sense, we cannot describe it as progress in terms of knowledge. One development project rarely builds on another and for that reason, the wheel is likely to be reinvented on a fairly regular basis.

So my first point is that when we engage in subject-referenced empirical research, the advantages of knowledge enhancement and theory development are coupled with the drawbacks of normative constraints, a restriction in the scope of the scientific approach, a possible loss of reference to our subject itself and, in the case of the analysis of overall learning effects, a loss of progress of knowledge. However, the indication of these problems should on no account be seen as a questioning of the great importance of subject-related empirical research for ERIDOB.

3. Criteria for scientific modeling

Another question we should consider is whether a focus on empirical research leads us to neglect the pursuit of genuinely *scientific* tasks in the area of development. One of our paramount tasks in this area is the modeling of subject teaching, taking into account the needs of the target group and the wider concept of what in German we call Bildung.[3] Scientific

[3] In English, this term means subject knowledge-based literacy. But one needs to consider that two dimensions characterize it, a functional one and a personal one. For example, *Scientific literacy* is the functional form of literacy developed by dealing with natural sciences. In short, it is determined by certain competencies of deliberate action in the world based on subject knowledge. *Personal literacy* is characterized by a subject knowledge-based world- and self-reference, which contributes to the personal development, self-conception and self-reflection of an individual. Personal literacy provides the individual with a normative orientation to

modeling involves choosing scientific contents and competencies, reducing their complexity, and transforming them into subjects of learning-in fact referring to dimensions of literacy. It would, I suggest, be an appropriate task for ERIDOB to systematically develop a catalogue of relevant criteria for scientific modeling. The following four criteria may serve as examples.

3.1 Critical reflection on the educational goals of school curricula

In many countries at present, biology teaching is no longer defined by its input but rather by its outcomes, a development which has been decisively influenced by international comparative studies (such as TIMSS and PISA). This means that certain competencies are to be nurtured and teaching content has to be conceived, presented and understood in relation to certain basic concepts. At stipulated points in a student's progression through the system, it will be ascertained whether these goals have been achieved. Teaching will, on the whole, tend to be focused on this assessment and is underpinned by a *functional* concept of literacy. In the sciences, as I mentioned earlier, this is usually termed "Scientific Literacy".

Teachers cannot help but model their subject teaching on this concept, whereas a *scientific* approach would first of all engage in critical reflection of the overarching objective, for example in view of its consequences (in this case, teaching to the test) or its ideological base (e.g., the maintenance of economic competitiveness or the utility principle). In addition, a scientific approach will confront the functional concept of education with a non-functional one, for example, with the concept of non-utilitarian and self-determined personal development tempered by responsibility for the good of the wider community and with respect for individual human dignity. In this context, scientific Didaktik of biology concerns itself with *alternative* anthropological conceptions and views of the world and aligns these with biological themes. It makes it clear that there will always be an ideological background influencing modeling and thus the structure of teaching topics such as ecology, genetics and evolution. *Scientific* modeling will show how pedagogical norms, anthropologies and views of the world-all of which teaching topics are assigned to—fit into a more general framework. At the same time, it shows alternatives. It ensures that the goals, which young people are subject to in the educational process, are transparent.

3.2 Reflection on the educational goals of academic disciplines

Specific educational objectives are constituents of all scientific disciplines, regardless of whether they are reference disciplines for school curricula. Academic disciplines such as the biosciences are shaped, among other things, by communication and learning processes. Journal articles and lectures are vehicles to disseminate research goals, methods and results; reviews present and interpret the state of the art of knowledge in a particular area; university textbooks endow their subject with a particular structure. In each case, "learning objects" are modeled for the scientific community, each appropriate to its own group of addressees.

action. The common relation to action characterizes functional and personal literacy as two dimensions of one subject knowledge-based literacy.

Depending on the general objective, university textbooks may include contents and methods of other disciplines characterized by different ways of thinking, for example theory of science or ethics. They can include political concepts as well, such as sustainable development. The contents and methods can also be selected with the graduates' future employers in mind. As a look at a range of textbooks on the same topic will show, didactical modeling never leads to one single result, because the structure of a subject as represented by a university textbook is governed by educational objectives; in other words, it is determined by norms. *Scientific* subject matter didactics therefore has to indicate the normative dimension of the publications through which a subject is communicated, in particular of those texts which are used to model the subject for the teaching of a particular target group. At the same time, it needs to be explicit about the criteria of its own models.

3.3 Incorporation of general theories of teaching and learning and of general subject matter Didaktik

When teachers are modeling new teaching units, their own memories of previously successful or less successful teaching will have a decisive influence on their decision-making. Academics of subject matter Didaktik will also consider general and subject-specific teaching and learning theories and findings of empirical studies obtained in the framework of such theories (cf. students' preconceptions).

It would also be helpful—though this is thinking for the future—for them to be able to incorporate a general theory of subject matter Didaktik. This is a field that is very much under development at present (for example within the German Association for Fachdidaktik[4]). It describes and substantiates the common and differentiating features of school subjects and shows how these each contribute to the students' functional and personal literacy.

3.4 Incorporation of subject-specific teaching and learning theories

Such theories are results of subject-related design-based research and a unique characteristic of subject matter Didaktik as described above.

These four criteria form the basis of *scientific* modeling of a given subject. The list, of course, warrants expanding.

4. Consequences for ERIDOB

By now it should be clear that Didaktik of biology, like all subject matter didactics, has two constitutive strands (our "double helix"). One is scientific modeling for teaching purposes of the fundamentals of the reference subject itself—a theoretical, literacy-oriented approach. The other is research into subject teaching and learning—an empirical process-oriented approach. Design-based research could include both strands.

[4] Fachdidaktik means Subject Matter Didaktik.

The presentation and discussion of empirical research projects will continue to be *the* hallmark of ERIDOB. But I invite us to consider whether ERIDOB could now also regard the discussion of theoretical projects, addressing *scientific* modeling, as another part of its raison d'être in its own right. This would also be advantageous for our empirical research: the critical attitude of colleagues engaged in modeling science toward norms set by others could be helpful to Didaktik of biology at the planning stage of empirical projects. It could guard against non-reflected acceptance of extrinsic norms and thus guard against our discipline inadvertently serving as the non-critical handmaiden of (fickle) educational policy.

12 ON THE ISSUE OF 'RESEARCH IN THE DIDACTICS OF BIOLOGY': DEFINITIONS AND DEMARCATIONS

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In this paper, we discuss the definitions and demarcations of *Research in the Didactics of Biology*, and address the questions of what can and should be included in this field of research. Didactics of Biology is not a commonly used term in the English-speaking world, and can in fact be misinterpreted since the English meaning of the word didactics is related to instruction and lecturing, according to the Oxford English Dictionary (Didactics n.d.), especially intending to teach moral content. However, in the European tradition, the term, derived from the Greek *didaktikos*, to teach, has the meaning of "the art or science of teaching" or "the theory and practice of teaching and learning" as described in the Swedish National Encyclopedia (Didaktik n.d.), and the term in most European languages has this meaning, i.e., *didaktik* (Ger., Swe.), *didactiek* (Ned.), *didactique* (Fr.), *didáctica* (Sp.). Based on this tradition, the term didactics was used to denote the organization *European Researchers in Didactics of Biology* (ERIDOB), although the term used internationally would be *Biology Education Researchers.* Therefore, we see the two concepts—*Research in the Didactics of Biology* and *Biology Education Research*—as synonyms, and will use them as such in this paper. Since the first ERIDOB conference in Kiel, Germany in 1996, 10 conferences have been organized biannually. However, due to the rapid changes and growth in this field of research in the last decade, its boundaries have been discussed. What is the scope of this field of research and consequently, what should be the focus of the ERIDOB conference? These are the questions addressed in this paper.

2. The science of biology

The boundaries of research in the didactics of biology are perhaps not as well defined as one might think at quick glance. The first issue that needs to be addressed is what constitutes the science of biology. This question can intuitively be answered as knowledge of the living organisms on earth and how they interact (Mayr 1997). This definition is often perceived as clearly demarcating the field, although the boundaries of the science of biology can be quite

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

blurry at its intersection with chemistry, engineering, informatics, psychology and social sciences. Since the 1950s, the close intersection between biology and chemistry regarding molecular sciences and biochemistry has been a question of debate in the aftermath of the molecular revolution in genetics. More recently, biology has merged with engineering and informatics in the area of biotechnology, which has led to the artificial engineering of genes and organisms. To achieve technological and scientific advances, the ability to interpret and store large amounts of biological data has become a necessity (Zwart 2008). The intersection has been clearest in the realm of molecular sciences, but many of the mentioned areas are cross-disciplinary and could not be accomplished by biologists alone.

Another debated area of the science of biology is in what way humans should be included in the biological sciences. Anatomy and physiology are mostly included, but usually in relation to the medical sciences or life sciences. Yet another division is between "green" and "white" biology, the former relating to organisms and ecosystems on a macro scale, the latter to the molecular sciences. Sometimes "biology" is defined as "green" and "life sciences" as "white", so where does that leave the field of biology education research? We can also use the issue of the human being's position within the science of biology as a point of reference in terms of questions related to behavior. When studying animal behavior, we refer to ethology, which is clearly positioned within biology. However, individual human behavior is related to psychiatry (medicine) and psychology (social science), which is not part of biology, although there is the sociobiology movement (Wilson 2000), which aims at crossing this border, and more closely relating human behavior to that of other species. We can extrapolate the issue about the position of humans within biology when we talk about how humans interact in groups, creating social groups and cultures. Then we definitely transcend into the realm of social sciences, although the border is pushed back and forth depending on new findings in, for example, epigenetics.

To complicate the issue further, human activity (in the realm of social science) impacts other living organisms through air pollution, mass extinction, global warming, changes in ecosystems and so on (in the realm of biology), with the result that these issues are addressed at an academic level in both biology (i.e. conservation biology) and social sciences. In addition, new academic disciplines have been established to meet the cross-disciplinary problems caused by humans, for example, the environmental sciences that draw on biology, earth sciences, chemistry, and social sciences such as economics and politics (O'Riordan 1999). Hence the science of biology is not static, and biology education and biology education research have to constantly revise what to include in the subject of biology when constructing curricula or performing research.

3. Didactics of biology as a field of research

As shown in this brief review, the disciplinary boundaries of biology, in academia and society, have changed over time toward increased specialization, on the one hand, and more inter- and multidisciplinary work, on the other. However, the science of biology is not the same as the science of teaching biology or biology education, even though the same multidisciplinary tendency can be noted. Biology didactics is about teaching and learning (the science of) biology from preschool to tertiary education. Here, there is an important disparity since the boundaries of biological science are determined by the scholars performing the science, but the subject of biology in education is at all levels (except tertiary education) decided by political decisions, most often manifested in steering documents, such as curricula and syllabi. Moreover, these steering documents define biology in many different ways, depending on the various educational aims.

The overall aim of biology and science education focuses on either scientific literacy or more conventional knowledge of science. This is a topic that many scholars have discussed from a broader science education perspective over the last decades, and its development over time has been toward a greater focus on the literacy perspective (Sjøberg 2009). This field has also been described as including non-scientific content: "In general, scientific literacy was at least partially associated with an individual's ability to make informed decisions about scientifically based personal and societal issues" (Lederman & Lederman 2011, p. 127). Roberts (2007) talks about *Vision I* as the processes and products of science, and *Vision II*, pertaining to citizenship knowledge, as situated knowledge that includes both scientific and other societal knowledge. If the emphasis is on scientific literacy, then the school subject of biology tends to be defined in a broader sense, including aspects of the social sciences that are not included in the academic science of biology, such as: health issues, nutritious food, drugs, sex education, environmental issues and sustainability issues. If the aim of *research in biology-specific teaching and learning* is to include <u>all</u> research related to the *school subject* of biology, a broader and more inclusive definition of biology education is required. The concerned research community has to decide whether a wider definition that includes all biology education is desirable or if it needs to be limited in some way, and if so, how? One way to do this is to base this discussion on the two Visions proposed by Roberts. Should our research include only Vision I or both Vision I and II?

As discussed above, the current reforms in science education emphasize the aim of teaching science for all, with the ultimate goal of developing scientific literacy (OECD 2007) as in the Vision II perspective. In this view, science instruction must go beyond teaching "a body of knowledge." There are three domains that are critical in developing scientific literacy, according to McComas and Olson (1998): a body of knowledge, a set of methods/processes, and a way of knowing. The first domain, the body of knowledge, is perhaps the most easily defined component since it relates directly to the science of biology, as discussed in the first part of this paper, albeit with some pitfalls, as pointed out. However, the two other domains that we could refer to as the *nature of science* (NOS), and *scientific inquiry* and *laboratory work*, could be more troublesome, since we often view those fields of research as autonomous and independent of the scientific disciplines (biology, chemistry and physics) to which they are related. However, we believe that it is important to study these areas within each science discipline separately as well (e.g., Olander 2013). Moreover, in many countries, there have been great changes in the curriculum concerning the NOS, scientific inquiry and laboratory work. The new curricula place more emphasis on procedural knowledge, the NOS, and promoting scientific literacy (e.g. Osborne & Dillon 2008). Should these fields then be viewed as part of science education or biology education? We would argue that they can be both!

The NOS is generally inherent to many critical issues in science education, such as: boundaries between science and non-science, issues of the tentativeness of science, the use of observation and inference in science, etc. (Lederman 2007), but there are also subject-specific issues in biology education with no counterpart in the other natural sciences. These include, for example, the evolution/creationism debate, the relationship between science and religion, and as Lundström and Jakobsson (2009) studied, the area of science and pseudoscience. Moreover, research has also shown that different aspects of the NOS can be experienced differently by students and teachers in the different disciplines. For example, biology and physics students understand models and their relationship to reality differently (Gericke, Hagberg & Jorde 2013), and the same goes for biology and physics teachers (van Driel & Verloop 1999). There is reason to assume that the same result could be anticipated for the domain of scientific inquiry. In physics, a more reductionist approach prevails compared to the more holistic system approaches used in biology, and these approaches are probably reflected in the respective subject-specific teaching and learning practice.

There are many research studies and reviews scrutinizing the uniqueness of school laboratory work (e.g. Lunetta, Hofstein & Clough 2007) and the striking similarities in how and why lab sessions are conducted in school science. But there are significantly fewer comparative studies about differences in the goals and practices of lab work between the various school science subjects. In biology, the main goal is often to help students identify objects and phenomena (Ottander & Grelsson 2006), and in physics, the focus is on determining relationships between physics quantities and processing data (Tiberghien, Veillard, Le Maréchal, Buty & Millar 2001). A comparative approach highlighting the differences involved in the issues of the NOS, scientific inquiry and lab work in biology education in comparison with other sciences would be an important area for research in biology education, while more general issues of the NOS and inquiry are more appropriately communicated in the wider science education community.

Another important research field that is found outside school is the informal learning of biology, for example, investigations concerning what and how people learn when they visit museums or science centers, participate in community-organized activities such as outdoor learning at field centers, and from media (Rennie 2014). In addition, investigations of the learning that takes place via everyday conversations on topics of diet and workout or in blogosphere discussions on inheritance and diseases have been shown to be useful (e.g., Rocksen 2012). We would also regard these types of investigations as being within the boundaries of "research in the didactics of biology" although they are not necessarily part of school biology. Hence, there is no need to restrict biology education research too narrowly.

A consequence of the earlier suggestion that biology education is the result of political decisions, as well as pragmatically evolved teaching traditions, is that the definition of the school subject of biology varies over time, between countries and districts, school levels and even teachers that implement the curricula differently. For example, in several countries, biology does not exist as a school subject in its own right in preschool or primary school, where it is included in the general topic of science. If biology topics are taught thematically intertwined with other sciences, should this be included in the field of biology education research? We argue that it should, for example, as socioscientific issues or sustainability issues, but it is important that the emphasis be on the biology component. Moreover, biology education also takes place outside school in many forms of informal learning outside the boundaries of school biology. Therefore, school biology alone cannot be used as a demarcation line for research in the didactics of biology. Practical ways of dealing with these boundary issues in formal arenas such as the ERIDOB conferences are addressed in the next section.

4. Implications for ERIDOB

In the last section, we argued that biology education is a political construct and when defining biology education research, we have to relate to that fact. However, as a research community, we do not have to follow the selection made by politicians and school administrators, but can define our own field. Nevertheless, we should not forget that our research is closely related to practice, since we study the phenomena of teaching and learning biology. If we depart too much from school biology, our relevance to society at large might be questioned. In this case, we fear that the research community would face big problems.

We cannot find specific or detailed criteria for defining what constitutes research in the science of biology-specific teaching and learning as outlined in the previous discussion, because the definition of biology as a school subject varies with time, country and school level, and because the learning of biology also takes place outside school. Therefore, it would be hard to reach an agreement on such shared specific criteria for the ERIDOB conference. However, we recognize that *if* there is a view among participants that the relevance of biology education to ERIDOB is too low, the conference has a problem since the argument for establishing the conference was the need of a forum for biology didactic research. If the contributions are not about biology education, why is there a need for this conference?

One way to deal with this issue is to demand that each proposal include a description specifying the *implications for biology education*, to define the ways in which the contribution adds to our knowledge about biology education, and as a consequence each author needs to define their own subject of biology and relate their work to it. For example, in line with the discussion in the previous section about NOS and scientific inquiry, we do not think that all research on general issues using biology as a context is relevant to the ERIDOB community, i.e., research in which the context can be replaced with chemistry or physics without any problem. We argue that the biology connection must be exemplified through biology teaching or through comparisons between the subjects of biology, chemistry and physics to qualify as contributions to the ERIDOB community. Similarly, teaching and learning at a general level are not relevant to the community either since they have to have an implication for biology education.

One way to make "biology" visible in a proposal or paper is to use overall theoretical frameworks that integrate the subject or content of the subject into the analysis. Several frameworks describe the process of transformation of the academic discipline into a school subject (which has been discussed previously in this paper). One framework is proposed by Chevallard (1989), who coined *didactique transposition* in France, another by Ongstad (2006), who described the concept of *omstilling* in Norway. These and other theories are useful tools to clarify the difference between the academic science of biology and the school subject of biology. Thus, it is, for example, possible to clarify what is biology in biology education and what relates to other domains, i.e. what questions relate to biological knowledge and which to values and political issues, etc. Other frameworks that could be used to address subject content from a classroom perspective are pedagogical content knowledge (PCK) introduced by Shulman (1986) and curriculum theories, for example, using the multidimensional framework developed by Porter (2006) to study in a way that the *content* can be analyzed as enacted, intended, assessed and learned curricula. These are, of course, only suggestions and by no means required to make the "biology relevance visible"; as already stated, we believe that the most important thing for the author is to make the link or implication to biology teaching and/or learning explicit in each and every proposal.

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13 FRAMING BIOLOGY EDUCATION RESEARCH IN SCIENCE EDUCATION RESEARCH

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1. Introduction: the place of biology education

What is the purpose of biology education research (BER)? Which research objectives are currently relevant? Which methods are appropriate to study them? What are the criteria for producing high-quality research on biology education? What insights have been gained from BER in the last decades? How does BER relate to the wider fields of science education and educational research? What challenges face biology education researchers? In particular: what challenges face researchers in the ERIDOB community?

My argument in this paper is that to enhance its quality and visibility, BER should be firmly framed within science education research. This claim is supported in a discussion of some of the questions raised above, in particular in the view, grounded on epistemology, that considers science education and biology education as a part of educational and social sciences, and not natural sciences.

First a reflection on ERIDOB's name. When we first met in Kiel in 1996, the name "Didaktiks", soon changed to "Didactics", emphasized the European context, the name of our field (*Didáctica*, *Didactique*, *Didaktiks*) in most Indo-European languages, except English. We are aware of its association with lecturing and rote-memory learning. The price paid for this is, for instance, that a web search for "biology education research" yields, in the first 6 pages, or 60 results, only one related to ERIDOB, the index of the Braga meeting with "Biology Education" in its title. Researchers searching the web will find instead many results about SABER, Society for the Advancement of Biology Education Research (http://saber-biologyeducationresearch.wikispaces.com). SABER, which means "knowing" in Spanish, was founded only 4 years ago by US scholars. I am not suggesting changing the name of ERIDOB, but perhaps adding Biology Education to it (for instance ERIDOB/BE), and certainly to the title of the conferences, which are now international.

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

A greater challenge than visibility on the web is our impact on the biology education community. Sadly, the research published in the ERIDOB proceedings seems almost invisible. I cannot remember seeing it cited in refereed journals, except for my own and some other ERIDOB members' papers. Aside from increasing our impact by improving research and publishing in journals indexed in the Journal Citation Report (JCR) of the Social Science Citation Index (SSCI), I suggest, first, that ERIDOB needs a permanent webpage, where proceedings may be downloaded, and second, the need for interaction with other biology education communities such as SABER or BER.

2. The goals and objectives of biology education research: looking at epistemology

I began with the last question but, turning to the first, I think that there is consensus about our goal: to increase knowledge about learning and teaching biology, in other words about students' and teachers' cognition and performance; for instance, to design and test teaching strategies promoting students' engagement in scientific practices, such as argumentation or modeling (NGSS, 2013), or to generate and refine evidence-based learning progressions. This is connected to insights gained from research, such as the need to use students' ideas as departing point of instruction, or the adoption of student-centered approaches, such as inquiry-based and problem-based learning (Osborne & Dillon, 2008). These are instances first, of cutting-edge research objectives, and second, of educational implications, shared by the larger science education community.

I argue that the research objectives pursued by BER should be substantially the same as those sought by science education research. This claim is based on a conceptualization of biology education and science education as fields belonging to the educational sciences, in other words to *social sciences,* although with interactions with science studies (history, philosophy, epistemology or sociology of science, here of biology), and with the disciplinary fields of science, here biology. Drawing on epistemology, the knowledge that biology education seeks to construct, its *aim*, using Chinn et al.'s (2011) terms for the components of epistemic cognition, is knowledge about how people learn biology (a social object), rather than knowledge related to organisms or biological systems (natural objects).

A criterion for high-quality research is the coherence between goals and methods. The methods—understood as underlying theoretical approaches to studying something—and particularly the methodologies that are coherent with our goals, related to people cognition and performance, are drawn from the social sciences. They may be qualitative or quantitative, and use approaches from sociology, ethnography or psychology, tools and schemes from philosophy or linguistics, content or discourse analysis or a range of others, all belonging to the social sciences (Erickson, 1982).

This does contradict the existence of biology education as a field exploring specific issues and themes. For instance, many educational issues are content-dependent; genetics or ecology have particular learning problems. On the other hand, teachers' pedagogical content knowledge (PCK) has unique features in each discipline, so we need to study PCK in biology. In a recent paper (Jiménez-Aleixandre, 2014), I examined determinism and underdetermination in genetics, a question with deep implications for socio-scientific issues such as racism, although there are certainly also methodological differences among genetics, entomology, ecology and cell biology.

Conceptualizing biology education as part of social sciences, even when explicitly accepted by all or almost all of our community, may challenge the implicit professional identity of some researchers who like to think of themselves as biologists studying education rather than as educators with a background in biology. Elsewhere, I discussed this paradox for Spanish science teachers and educators, identifying their profession (in IDs) as chemists, biologists or physicists, rather than as teachers. The perceived higher status of natural sciences versus social sciences may be a reason for this.

3. Concluding remarks: the need for a stronger alignment with science education

If we, biology education researchers, belong to the social sciences, to education, I suggest three implications for ERIDOB researchers: (a) a need to *align our research* (objectives, methods) with current research in science education, which is crucial for increasing publication in JCR journals; (b) including among our goals *the ambition to have an impact on the larger science education* community; (c) a need for *interdisciplinary cooperation with other social scientists*, such as psychologists or linguists.

About the *alignment*, there is room for improvement in ERIDOB: for instance, a search of the selection of 2012 papers in the Journal of Biological Education (JBE) and on the website yielded no results about “practices” (although argumentation and modeling were represented), “learning progressions” or “metacognition”, three cutting-edge research lines (there are others). This is quite different from the topics of papers in high-profile science education conferences from the same year (and even previous years), such as ESERA or NARST. It is even different from research papers from European science educators with a background in physics (e.g., a learning progression paper in the Journal of Research in Science Teaching by Neumann et al. in 2013). A concern of the ERIDOB community is the relatively low publication of its research in major journals indexed in the SSCI JCR, although publication in JBE is an improvement. I think that increasing this requires a stronger alignment with current concerns of science education research.

About the goal to *impact science education*, or even education, this is related to the first suggestion. To achieve it, we need to at least: (a) address issues that are relevant to the larger research community; (b) do so with methods that are considered rigorous and of quality by that community, and (c) publish our research in venues, journals and books read by science education researchers, aside from journals focusing on biology education. Some instances are the journals Science Education, Journal of Research in Science Teaching, both within the 10 first positions in JCR 2012; International Journal of Science Education, Research in Science

Education (first quartile, Q1) or Science & Education (Q2). Evidence of impact are some highly cited papers from our community (e.g., Duncan, Rogat & Yarden, 2009; Jiménez-Aleixandre et al., 2000; Zohar & Nemet, 2002). Although the content in all cases is genetics, they are cited by science educators from outside biology education, because the addressed issues transcend their disciplinary context. This parallels the beginnings of BER in the 1980s, when we read and quoted physics education papers about conceptual change, because of the scarcity of papers on conceptual change in biology, a situation that we would like to see reversed or at least balanced.

About *interdisciplinary cooperation*, an outstanding example is the French science education research community (Erduran & Jiménez-Aleixandre, 2012). In other countries this may be less simple as science educators are based in disciplinary institutes.

In summary, this is an exciting time for education and science education and we, the biology education researchers, need to fully participate in it.

Acknowledgements: Work supported by the Spanish Ministry of Economia y Competitividad, code EDU2012-38022-C02-01. Thanks to Anat Zohar for helpful suggestions about the first draft, and to María José Gil Quílez for presenting it.

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14 CURRENT ISSUES IN BIOLOGICAL EDUCATION RESEARCH: THE CASE OF HEALTH EDUCATION

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Health education promotes a feeling of responsibility for one's own and others' health, enabling each individual to critically perceive each actual situation and adopt the most appropriate and efficient behaviour. In this view, health education is education for the lives of individuals and communities, contributing to the learning of how to improve not only one's own physical health but also interpersonal relationships, leading to a general improvement of collective well-being (Larue *et al.*, 2000). Health education addresses the person as a whole, mobilises knowledge, beliefs, social representations, behaviours, and interactions with the physical and social environment. It is not meant to say what one must do; rather, it is meant to inform and create conditions that will allow a person to acquire the competence to make (as much as possible) free choices for what he/she estimates is healthier for him or herself, as well as for the others.

The nature of knowledge in health education is rather unique for several reasons. First, health issues are usually acquired by traditional means, mainly following family practices and empirical knowledge, with little scientific basis. Often, this traditional knowledge is an epistemological obstacle (Bachelard, 1938; Astolfi *et al.,* 1997) to the acquisition of new scientific knowledge.

Second, the source of the scientific knowledge to be transmitted in the field of health education is biomedical knowledge which, traditionally, is not devoted to the education perspective. Moreover, biomedical advice is usually formulated by reference to current health problems, which often emerge as controversial with time (Sandrin-Berthon, 1997; Ewles & Simnett, 1999).

Third, scientific knowledge concerning health issues is often manipulated by commercial lobbies, mainly from the agriculture, food and pharmacological sectors, addressing health misinformation in product advertising and propaganda (Souccar & Robard, 2004).

Finally, health scientific knowledge is usually statistically validated at the population level—Epidemiology, Public Health—identifying determining factors (age, sex, lifestyle, environment) for each disease, and aimed at establishing a causal link between these factors and disease growth (Vetter & Matthews, 1999; Helman, 2000). What is true in terms of the probability of disease growth in a population cannot be applied to the individual.

Health education tends to be based on a topical approach, which means working separately on issues such as eating, safety, sexuality and relationships, substance use (smoking, tobacco, other drugs), bullying, etc. This topical approach has been criticised for several reasons: it can be *"problematic or ineffective as such approaches are sometimes based on assumptions relating to human behaviour, which are difficult to justify and not supported by evidence"* (IUHPE, 2008: 4); adding up the teaching sequences of such a diversity of topics presents a huge amount of time, which imposes limits on the teachers' actions, who tend to transmit information only (Pizon, 2008). Therefore, instead of an exhaustive topic-by-topic approach, a more effective one would be to develop children and young people's life skills and competencies, enabling them to consider the different health topics in the reality of the social and environmental contexts of their lives (IUHPE, 2008). Furthermore, uniting themes, such as "learning how to take care of oneself and of others" and "preventing health risk behaviours", could cut across topics at a theoretical and pedagogical level.

For the prevention of risk behaviours, educators must bear in mind all of the above factors when implementing pedagogic activities on the prevention of risk behaviours in the classroom, which are associated with knowledge, attitudes and awareness. These three approaches are shown in Figure 1 and can be described as follows:

i) Scientific knowledge – To approach the problems caused by substance misuse: implement pedagogical approaches to the physical, psychological and social dimensions of the risk behaviours' effects, based in scientific knowledge. Attention must be paid to ethical issues concerning potential effects of the approach regarding stigmatisation of the smoker, drinker or drug-abuser.

ii) Attitudes – To develop personal and social competencies: develop self-esteem, stress management, risk management, conflict management. These competencies empower children and young people to make informed decisions, to make choices, to take action and to develop positive attitudes toward health risks.

iii)*Awareness – To approach the environmental context:* make children and young people aware of their specific familiar and close social environment to identify critical situations facilitating the risky behaviour. This implies developing critical thinking.

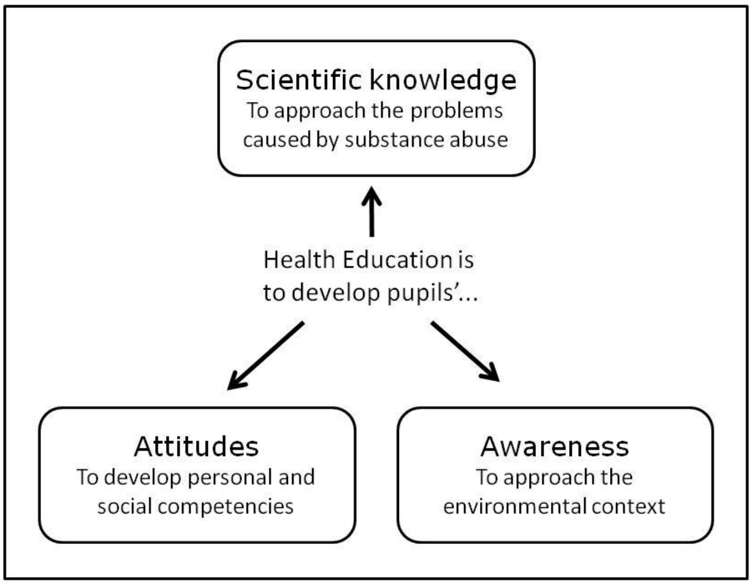

Figure 1. Dimensions to take into account during school activities for the prevention of health-risk behaviours.

Defining the teacher's role in health education is rather delicate for several reasons. First, health and health education lie at the intersection between the private (pupil's family) and public (public health policies) domains related to behavioural issues which are determined culturally and as the most intimate of personal decisions. Furthermore, in health domains, recommendations change with time given the extraordinary progress in knowledge and the construction of new scientific models as well as fashions governing what is considered moral and what is considered immoral. In addition, in the contemporary world, where the importance of appearance is emphasized and where many consider a perfect body and perfect health to be the ultimate aim, can it be hoped that schools will contribute to the promotion of a single healthy mode of living or a body cult?

In the field, it is not easy to identify the school's mission regarding the balance between formal curriculum and the power of models transmitted by the media. Biology teachers, having specific training in biology and biology education, are expected to implement health education in schools. In general, they have good competencies in teaching biology and health (*scientific knowledge*) but have little or no training in working with students' *attitudes* and *awareness* (Figure 1) of health issues. Therefore, the aim of teacher training in health education is to help teachers get a clear view of their responsibility in health education and its ethical limits. Before giving them methodological tools, teacher training aims at helping them build their professional identity (Jourdan et al., 2008).

The way in which health promotion is organised and implemented in each country differs depending on the history, objectives and structures of that country's school system (Pommier & Jourdan, 2007). Developing research, and affirming and reinforcing the work done in teachers' training in health education are major issues to promote teachers' competencies for providing opportunities to children and young people to be more empowered about health and health risks as they grow up.

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15 RESEARCH IN DIDACTICS OF BIOLOGY: CURRENT PROBLEMS AND FUTURE PESPECTIVES

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In this paper, I address my view on Research in Didactics of Biology (RiDoB). This is my personal view and it cannot be generalized as THE German perspective. My note will focus on three assumptions concerning the quality of RiDoB under the recognition of two questions: what is missing in RiDoB, and what is there to do next?

1. General note: three interactions that direct research in didactics of biology (RiDoB)

The choice of research questions raised for RiDoB depends on which corner of the triangle we start from (Figure 1). We try to describe phenomena of the world, we categorise and quantify, we develop theories to explain or predict these phenomena. Based on our results, we make suggestions to optimise teaching and learning of biology by influencing political decisions. In this triangle, a theory systematically links inductively or deductively won realizations of a knowledge range with one another. A theory allows to describe, explain or predict individual phenomena. Empirical research designates investigations that are based on methodologically controlled observations in the broadest sense—such as tests, interviews, questionnaires, experiments—and not on speculation. Theory and results of empirical research are used for optimisation of behaviour. This hopefully results in suggestions for future political decisions.

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

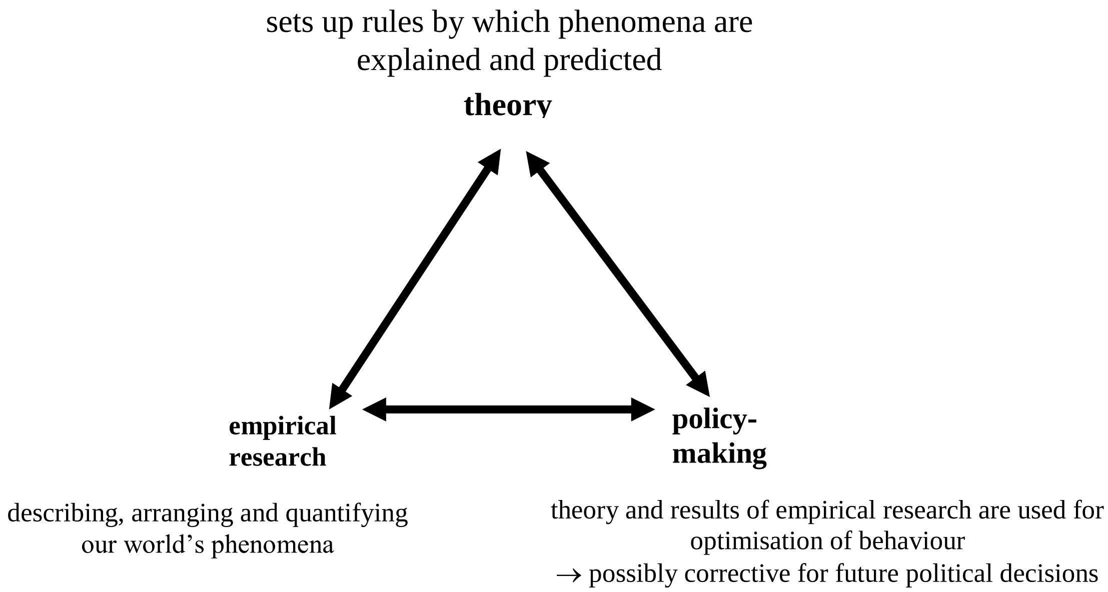

Figure 1. Interactions between theory, empirical research and policy-making (cf. Rost 2013).

I highlight some important research questions for the field of biology education. According to Rost (2013), educational questions fall into one of seven groups:

1.	1.	Existence	Is there such a skill?
2.	2.	Description	What is it like?
3.	3.	Covariation	Does it correlate with … ?
4.	4.	Structure	What is its internal structure?
5.	5.	Prediction	Can it be forecasted?
6.	6.	Cause and explanation	How does it work? What causes it?
7.	7.	Training and optimisation	How can it be made more efficient

2. First assumption: RiDoB has to be based on theory!

We need a discussion about the meaning and use of theory. I like to highlight the relevance of theories in RiDoB as follows: a theory is a general principle that is set up in order to clarify a group of relations between events. A theory consists of statements about causes and effects of circumstances; it is intersubjectively verifiable, reproducible, trustworthy due to results that have been confirmed repeatedly and from various directions, and, in principle, falsifiable. Only research which is based on theory creates the opportunity to enhance knowledge in didactics of biology.

Research lacking a theoretical underpinning runs the risk of generalising results by chance (type I error). How should an audience member decide whether the presented results are relevant? We need criteria from the theory to determine the validity of every comparative or even superlative adjective in a presentation.

To use a theory, one must take four functions into consideration (Figure 2). The green letters indicate the aim or observation, whereas the red letters symbolize what we would like to know. A theory is the instrument that will help find information about this relationship and develop one's research. RiDoB should connect the hypotheses and discussion to the theory in one of these senses. Finally, to avoid misunderstandings, the relation between theory and empirical research in biology education is not strictly deterministic (if A then always B), but rather probabilistic (if A then very likely B).

	if …		then …
TECHNOLOGY	A	→	B
timeline	-------|--------------------		
What has to be done to reach B?			
PROGNOSIS	A	→	B
timeline	-------|--------------------		
Which consequences stem from A?			
EXPLANATION	A	→	B
timeline	-----------------------|---		
How could B happen?			
DESCRIPTION	A	→	B
timeline	-------|--------------------		
What should be taken into consideration?			

Figure 2. Four functions of a theory.

German educational research was strengthened by the publication of *"Theory Book"* (Krüger & Vogt, 2007), in which 21 German researchers in didactics of biology described the theories they used in their research. I do not know whether this book was helpful in a direct way, via the description or explanation of theories, but in an informal sense, this book represented a starting point, giving young researchers in our profession an idea of what is essential and fundamental for RiDoB.

3. Second assumption: RiDoB needs standards for methodological approaches that are commonly known

It is obvious that we need different methods to answers our research questions. To help researchers handle the variety of approaches, we published *"Method Book"* (Krüger, Parchmann, Schecker, 2014). In this book, 48 colleagues and researchers in didactics of biology, chemistry and physics described different approaches with respect to research design (e.g. action research, comparative studies, laboratory studies), qualitative data analysis (e.g. guided interviews, qualitative content analysis, group discussion, Delphi studies, narrative data, thinking aloud method), the evaluation of quantitative data (classical test theory: e.g. performance test, questionnaire, multilevel analysis; probabilistic test theory: e.g. Rasch analysis, influence of task characteristics on task difficulty).

Without saying that there is a quantitative–qualitative split in RiDoB, we do have research groups working either predominantly qualitatively or quantitatively. Between these groups there is acceptance, but in some cases, no real understanding of the different methodological approaches. This problem has intensified with the application of probabilistic test theory. Perhaps ERIDOB could declare a minimal standard of methodological knowledge of research strategies. This may help develop an appropriate scientific exchange. As in biology, our research areas and methods are becoming more complex and not everybody can learn all approaches while doing a doctorate. Nevertheless, those who understand different approaches have the benefit of choice.

Finally, one concern in many quantitative presentations is: to judge the relative impact, significance is not the right information. One has to take the effect size into consideration.

4. Third assumption: ERIDOB needs to declare standards and topics of RiDoB!

Finally, I try to open the discussion with some stimuli concerning the future development of ERIDOB to overcome some problems. I believe that a standard paper (additional to the policy paper) is a good approach. Here I mention some topics that should be included in such a paper.

4.1. Theory-based empirical research

We should realise the value and use of theories. Furthermore, predominantly in quantitative research, we need the formulation of hypotheses. We must think about replication studies with samples in our countries to foster representativeness. We have to start meta-analyses and have to recognise the value of effect size.

4.2. Consequences of professionalization

With the emerging demands for empirical standards (classical and probabilistic test theory), we need the cooperation of the psychological staff. ERIDOB should probably offer methods workshops and invite researchers from other disciplines, such as psychology.

4.3. Academic vacancies-improvement of the ERIDOB information system

Research groups are mostly lacking postgraduate students. Instead, the staff usually includes a teacher with a high number of teaching hours, who is often a brilliant teacher in seminars but is almost no help in filing an application for a third-party fund. We *"lose"* many PhD students after finishing their thesis to schools. ERIDOB should develop a European communication forum to reveal where staff is needed. Most German, Dutch and Scandinavian researchers are well versed in the English language.

4.4. Questions to be answered in future

Some questions of self-determination and self-discovery for ERIDOB: What is the singularity and identity of RiDoB? What are biology educational research areas that are respected by ERIDOB? What are the examination objects that define RiDoB?

We have to define which topics are of interest for RiDoB! Are areas such as philosophy of science or nature of science aspects of RiDoB or only of research in science education? Is research on interests, motivation or self-determination in biology classes RiDoB or research in psychology? Is the development of a test instrument RiDoB?

I suppose that the topic of an accepted presentation at ERIDOB is relevant for RiDoB. Reviewers of a submission for the proceedings regarding the same topic should be informed that a rejection cannot follow the argument: the topic is not relevant for RiDoB.

To find relevant topics, I recommend taking national and international curricula (e.g. Australia: ACARA, 2012; Germany: KMK, 2005; UK: QCA, 2007; USA: NGSS Lead States, 2013) into consideration. I suggest three main topics concerning a standard paper for RiDoB: learning and teaching biology, learning and teaching about biology, and learning and teaching the practice of biology (cf. Hodson 1992).

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16 THE FUTURE OF BIOLOGY EDUCATION RESEARCH

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Biology education is a relatively young discipline and the field is so ripe for exploration that a researcher may feel like the boy in the parable who put his hand into a pitcher of figs and hazelnuts and grasped so many in his eagerness that he was unable to withdraw his hand and burst into tears.

However, there are other dangers in addition to biting off more than one can chew. One can flit from attractive topic to attractive topic (cf. the confusion effect in animal behaviour), failing to produce a solid and coherent body of work. Or one can be in awe of other research traditions, pushing one's own biology education research into a Procrustean bed.

1. Where to start?

In determining a programme for biology education research, there are three main starting points: biology, education and research.

If one starts with biology, one starts, in an approach that derives from Hirst's (1965) 'forms of knowledge', with the distinctiveness of biology. For a start, biology sits within the natural sciences, which have a methodology that traditionally emphasises knowledge as objective, universal and amenable to rational inquiry (but see Feyerabend, 1993, who is suspicious of the claim that science is as objective as is commonly supposed). Within the natural sciences, biology, of course, is the study of life. In a sense we are spoilt for choice—there are some 10 million extant species and each of these, even on its own, can be researched in a myriad of ways. The most important biology research often proceeds by studying a range of species, which then enables it to draw conclusions or construct new models that are both widely applicable and also amenable to local variation (cf. Darwin, Mendel, the discoverers of the structure of DNA and such ecologists as E.O. Wilson). There is a lesson here for biology education research: we surely want to engage in fine-grained research that is true to the particularities of a particular situation; we also want to be able to extrapolate to broader horizons.

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

If one starts with education, then one starts with what has sometimes been described not as a discipline but as a field. Like medicine and engineering, education draws on a wide range of more fundamental disciplines to make its advances. This is an epistemological point about knowledge production in education. But there is another way of starting with education and that is to do so not from an epistemological standpoint but from a normative one. With John White, I have argued that the aims of education are to equip each learner to lead a life that is personally flourishing and to help others to do so as well (Reiss & White, 2013). If one accepts this approach, then biology education research can be seen as serving to contribute to such flourishing (indeed, 'others' would include non-humans).

I have deliberately started with biology and education because in my experience, certainly of supervising doctoral students and researchers, including biology education researchers, often start with research. We are expected to identify a gap in the literature, formulate research questions and then derive a methodology that allows us to address those research questions. However, while such an approach is efficacious for producing findings that add to the literature, and so are publishable, such findings are unduly constrained by the accidents of history-what has previously been researched-more than by what needs to be researched.

2. What is important?

About 10 years ago I wrote a paper entitled 'Teacher education and the new biology' (Reiss, 2006). In it I argued that recent years have seen a growth in not only biological knowledge but also, and more significantly for teacher education, in the types of knowledge manifested in biology. No longer, therefore, is it adequate for teachers to retain a Mertonian or Popperian conception of science. Today's teachers of science also need to be able to help their students discuss bioethics and the societal implications of biology, even when these are controversial and contested. Moreover, practical work can no longer be confined to 'pure', 'safe' and 'confined' activities. These are increasingly rejected by students, validly, as boring or irrelevant. Instead, we need to help students undertake a range of activities that will help them develop criticality and the potential for action.

I think this holds even more strongly for biology education research. We need to bear in mind the purpose of our research (cf. Kincheloe & Steinberg, 2004, who encourage researchers to ask the research questions that will make a difference to students' lives). As Karl Marx said “The point is not merely to understand the world but to change it”. In the UK, there has been more emphasis in recent years on the impact of scientific research, on knowledge transfer and on public engagement with research. Some commentators have understood that this shift is a result of a naïve, politician-driven understand of knowledge production, and fear that it may lead to a narrowing of research and a consequent loss of quality. But another way of reading this new emphasis is to see it as a healthy desire for research to make a difference. Given how many of the world's major issues-climate change, species extinction, human well-being, our use of the environment, animal welfare-are ones in which biology, education and research all play a key role, there is a tremendous scope for the next generation of biology education research to be intellectually stimulating and also of great social impact.

3. Implications for biology education researchers

The implications of the above are that biology education researchers should be encouraged to undertake research that is likely to make a difference. However, in the UK, as in a number of other countries in Europe and elsewhere, such noble sentiments are somewhat overshadowed by the realities. Biology education research is in trouble in the UK for a number of reasons:

1. For all that the present and previous governments are genuinely committed to the notion that school science education is important, their focus is primarily on physics and chemistry as these are the subjects for which there are shortages of specialist teachers.
2. Department for Education (i.e. government) funding for research has largely been channelled into random controlled trials undertaken under the aegis of the Education Endowment Foundation. An examination of their website (https://educationendowmentfoundation.org.uk/projects/) shows that the projects they fund are far more likely to be on topics such as reading, numeracy and character development than biology.
3. There has been a collapse in recent years in education funding by the UK Research Council (the Economic and Social Research Council) that funds educational research. Success rates for education grant applications in recent years have been running at about 3–4%!
4. There has been a long tradition of biology education researchers developing their expertise while working in initial teacher education. However, in England since 2010, there has been a persistent government-driven move towards initial teacher training that makes little or no use of higher education. As a result, education posts are being cut back at universities.

Of course, not everything is doom and gloom and some of these trends may well reverse in the coming years. My advice to those at the start of their biology education research careers is first and foremost to find an area of research about which they feel passionately and then to begin to research it in ways that require little or no funding, ideally in cooperation with others, whether in their own country or internationally. We are fortunate that it is still possible to publish unfunded work in strong science education research journals to a far greater extent than in medicine or the pure sciences. In addition, we have a professional organisation-ERIDOB-that I have always found to be wonderfully supportive, ever since I went to my first ERIDOB conference back in 1998 in Gothenburg.

My second bit of advice-and here I return to Feyerabend (1993)-is for biology education researchers simply to use every possible method they can to help them answer their research questions. In my brief career as an academic scientist (Reiss, 1989), I found that this is what the best scientists did. Let me end by commending the work of the prolific science educator Wolff-Michael Roth (http://web.uvic.ca/~mroth/) who embodies the same tendency in his own research.

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17 "BIOLOGY DIDACTICS": A DISTINCT DOMAIN OF EDUCATIONAL RESEARCH

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"Biology Didactics" or "Biology Education Research" is research aimed at highlighting and facilitating the process of teaching and learning about the biological world. Since the biological world is part of the natural world and thus the biological sciences are part of the natural sciences, one might consider "Biology Didactics" as *just* a part of "Science Didactics", the research field better known as "Science Education". In fact, a number of research questions addressed by "Biology Didactics" can be approached through theoretical constructs that have emerged within "Science Didactics" (Lewis, 2008). Nevertheless, the epistemological and psychological lines of thought that need to be taken into account when conducting research on the process of teaching and learning biological sciences in particular seem to differ from those considered when conducting research on the process of teaching and learning other natural sciences. I will briefly consider some epistemological and psychological issues that, in my opinion, seem to influence the teaching and learning of biological concepts and give rise to research questions that are to be asked in the context of "Biology Didactics" as a distinct domain of educational research. Finally, I outline the current state of biology education in Greece.

1. Some epistemological issues

Reaching our current understanding of living organisms has been a difficult task that has taken many centuries. Difficulties in understanding living beings might be attributed to many factors. For instance, if we are to understand structures and functions of living organisms, we have to study structures and functions some hierarchical levels below. The micro–macro conception problem characterizes other, non-biological entities, as well. However, in the case of living beings, this problem acquires additional significance due to their organization complexity. Living beings consist of chemical substances but cannot actually be thought of as simply chemical structures. They are self-organized at different levels, each of which shows different functions that contribute to the survival of the organism as a whole (Mayr, 1988, 2004). This complexity is traditionally troubling to both students and those concerned with

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designing syllabi or writing textbooks. What level of explanation is most appropriate for understanding biological phenomena: molecular or evolutionary, organismic or ecological, or all of these together? Moving between these different levels is difficult but it is a prerequisite for a synthesis of the whole picture and an ultimate understanding of living beings. The above may pinpoint some very interesting research questions concerning the development of systems thinking in the context of biology education (Verhoeff et al., 2008).

Biological knowledge includes a long series of concepts with different degrees of complexity, abstraction and importance. Our effort when teaching biology should aim at providing students with the means to grasp concrete and descriptive concepts before they go on with the theoretical ones. Can we do this? The concept of gene, for instance, has been altered many times since it was first introduced as a theoretical construct and it is still under modification (Gericke & Hagberg, 2007). How, then, do we teach about genes? Is it good to start with the Mendelian view of the gene and then move on to its molecular conceptualization, mirroring the progression of scientific thought? Would it be better if we just focused on the molecular conceptualization of the gene as a piece of a DNA molecule—a chemical structure with a specific base sequence—and forget about the Mendelian view? And how can we help the younger students start building a solid understanding about it? Can our research produce pedagogical theories that concern teaching and learning of key biological concepts? In this respect, the Dutch school has actually led the way (Boersma & Waarlo, 2008; Knippels et al., 2001).

Apart from teaching science concepts, we are also interested in teaching the methods of construction and evaluation of knowledge. Biology is a very complex science in terms of research methodology. Its diversity is reflected in its many different scientific fields which have actually developed into separate biological sciences. Characteristics of their research methods are reflected in the way we teach some topics, especially when we try to adopt the inquiry-based teaching and learning model. The pluralism of methods through which scientists construct knowledge has been recently highlighted by Duschl and Grandy (2008) in the context of science-teaching practices. In fact, the so-called "scientific method" differs according to the discipline in question. Experimentation may work for disciplines such as cell and molecular biology, genetics and physiology, physics and chemistry. However, when it comes to evolution or even ecology, for instance, knowledge construction may rely on observing or comparing information that is not necessarily provided by experiments. In biology education, we have the chance to discuss issues such as the role and explanatory power of the reductionist approach in experimental biology. In addition, we can discuss issues such as the difficulties involved in generalization or the different-level explanations that can be given to account for a certain phenomenon (see "functional" and "historical/evolutionary" explanations). It seems that research about the ways to support students in understanding all of this diversity in scientific practice is of key importance and interest (Duschl & Grandy, 2013; Windschitl et al., 2008).

Finally, last but not least is the issue of teleology in biology (Mayr, 1988, pp. 38-66). Our natural tendency is to consider that the biological world, as a part of the natural world, functions with a final cause (i.e. in order, harmoniously, in balance), and not to accept that "randomness" and "contingency" are integrated in its function; this induces another specificity concerning the construction of biological knowledge. Garvin-Doxas and Klymkowsky (2008) indicated that the spontaneous assumption that "randomness" seems to be incompatible with the extremely effective "biological systems", may undermine our understanding in many contexts, since "probability" runs through a very wide range of biological processes at different levels of organization. Indeed, in contexts of ecology, genetics and molecular biology, as well as evolution, the challenge for biology education is destabilization of the deeply rooted assumption of "no randomness—but purpose" (Ergazaki & Ampatzidis 2012; Kampourakis & Zogza, 2008, 2009).

2. The psychology of learning biological concepts

2.1 Is there an autonomous intuitive biology?

Although there is no agreement among cognitive psychologists about when intuitive biology emerges (age 4–5 years or 7–8 years) (Carey 1985, 1988; Inagaki & Hatano, 2002, 2006; Keil et al., 1999), they all suggest that intuitive biology is a separate domain, distinct from those of intuitive psychology and intuitive physics. In practice, this means that we have different ways of thinking about living things. It has been suggested that the emergence of a distinct domain of biology cognition could be evolutionarily favored, since knowledge of animals and plants (potential food sources) (Wellman & Gelman, 1992), as well as knowledge of bodily functions (Hatano & Inagaki, 1994) might be crucial to human beings' survival.

Intuitive biology is characterized by the developing ability to make some key ontological distinctions, for instance the "mind–body" distinction, as well as by the activation of special reasoning devices with regard to the biological world. According to Inagaki and Hatano (2002), these are (a) the "personified" predictive device which gives young children the opportunity to make rational predictions about attributes of living entities according to how much they look like humans, (b) the "teleological–vitalistic" explanatory device that leads to intention-free explanations about why several bodily functions occur, and (c) the "essentialist" reasoning device that leads children to categorize living entities on the basis of their unique, internal "essence" which remains intact throughout life. Intuitive biology shifts to more advanced, school biology when "mechanistic" or even "evolutionary" reasoning can be performed. However, elements of intuitive biology can even be traced in lay adults, especially when it comes to demanding, theoretically laden phenomena such as inheritance or evolution.

2.2 What does this mean for biology didactics and biology education?

Biology didactics can be thought of as a separate domain of research not only on epistemological grounds, but also by appealing to the psychology of acquisition of biological knowledge. The latter may guide the formulation of research questions concerning the development of age-bound learning environments regarding the biological world. In particular, it seems that we can start education in special topics of biology from the early years (age 4–5) and ask questions about children's shift from one way of thinking to another (e.g. from intentional to vitalistic and mechanistic, or from analogical human-based to category-based). The development of more advanced conceptual structures may be pursued more effectively later on, if work on children's intuitive ways of thinking about biological phenomena has already been explored.

2.3 Contemporary biological issues and everyday life

The phenomenal development of biological sciences and biotechnologies has affected our personal and social life to a great extent. A popularized version of new knowledge about science and technology that is related to health, environment or economy becomes available to lay people very quickly, without of course having the chance to be integrated in "school science". This happens through more or less traditional media such as the press or the internet, under the pressure of interested groups of citizens (France & Gilbert, 2006). The consequence of this is that lay people are increasingly asked to decide about issues that are critical to their lives by evaluating new scientific knowledge that was never actually addressed through their traditional education.

The need to educate such citizens is another great challenge for biological education and another context of asking research questions that combines understanding of biological concepts with decision-making processes. In this context, the development of learning environments that favor the construction and evaluation of arguments with biological content drawing upon knowledge, cultural/ethical considerations and the nature of biological sciences and technology is crucial (Erduran & Jiménez-Aleixandre, 2008; Simonneaux, 2002).

3. Biology education in Greece today

Biology education research was introduced in pedagogical departments for future primary teachers by academics who were initially engaged with research in biological sciences. Thus, the focus of this newly born research domain was initially defined by their previous interests in human health/health education or ecology/environmental education. The idea of developing biology didactics under the unifying ideas of science education was eventually developed at the University of Patras and it was somehow propagated with the development of post-graduate education programs in Greek universities. Research in biology education is mostly presented at Science Education conferences around the country. Today, there are courses of biology didactics in biology departments, but they are still offered by staff of pedagogical departments.

Biology education in primary and secondary schools is informed by international trends. Biology concepts' introduction begins at kindergarten. Curricula and textbooks are influenced by the implications of biology education research and especially of research on students' conceptions. In the interdisciplinary curriculum developed in 2003, the aim of scientific literacy was included to improve students' achievement in assessment tests such as PISA; moreover, the importance of providing students with opportunities to realize the usefulness of scientific knowledge in everyday life and in accordance to their own interests was recognized. Special aims in the case of biology in upper secondary schools are organized around three axes: "scientific knowledge and methodology", "science and technology in everyday life" and "communication and collaboration skills".

4. Coda

Biology didactics seems to be a distinct domain of educational research that can be enriched by taking into account these special aspects of biology:

- Its epistemological basis, which gives biology education the privilege of introducing important concepts (e.g. teleology or randomness) as well as different levels of explanation for biological phenomena.
- Its special background in terms of naïve biology that intermingles with conceptual understanding (essentialist thought and inheritance, teleology and evolutionary thought, etc.)

Moreover, although not discussed in detail here, I think that the following are quite interesting as well:

- Biology and culture: research about the relevance of biology in everyday life, taking into account reported cultural influences in biology understanding.
- Biology, technology and society: education for scientific literacy and the socio-scientific issues has been a great area for research and we should continue our effort to find unexplored issues.

In any case, linking research with practice needs to be among our priorities.

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18 THE EMERGENCE AND AFFILIATIONS OF CURRENT RESEARCH IN SCIENCE EDUCATION IN FRANCE

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We can have no claim to completeness about the affiliations and orientations of current research in the teaching of science and technology in France. Research in science education was initially established based on other fields in the humanities (developmental psychology, social psychology, sociology, anthropology, epistemology, philosophy, etc.). Teaching was built on matters of disciplinary learning and the sharing of constructivist and socio-constructivist approaches. Work in teaching science (biology, physics and chemistry) and methods has relied on the didactics of mathematics, whereas others are more inspired by social psychology (Giordan, Girault & Clement, 1994; Astolfi & Develay, 1989), some have opted to develop a curricular analysis (Lebeaume, 1999), and yet others are based on Bachelard's approach to developing the current problematization (Orange, 1997, Fleury & Fabre, 2005). In this article, we situate these trends as well as that of the socially acute questions (SAQ) to which we contribute, and the affiliations that have enriched them at the national and international level (Fig 1.).

Initially in maths education, Chevallard (1985), who developed the Théorie Anthropologique du Didactique (TAD), coined didactic transposition (DT), which is the activity of transforming an object of scholarly knowledge produced at an academic level into an object of knowledge to be taught. There is external transposition where the knowledge to be taught in a formal or prescribed curriculum is selected, and an internal DT of knowledge which is done by the teachers. Quessada and Clément (2007) defined the didactical transposition delay (DTD), which measures the time between the emergence of a concept in the scientific community and its appearance in school curricula or handbooks. In relation to TAD, Sensevy, Mercier and Schubauer-Leoni (2000) developed another model of analysis of joint action (TACD) based on management of chrono-, meso- and topogenesis. They defined ‘mesogenesis’, the genesis of the medium, as the development of a common system of meanings between the teacher and the students in didactic transactions that determine their meaning. Chronogenesis management is related to developing knowledge objects on a time axis.

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Topogenesis (land management) is related to the space occupied by the teachers and students throughout the teaching/learning process, and the sharing of responsibilities in the advance of knowledge.

The "Problematization" framework was developed by Orange (1997) and Fleury and Fabre (2005) based on Bachelardian and Popperian approaches. In it, scientific activity is not confined to describing reality or enumerating facts, it is an attempt to explain phenomena by articulation between two registers: the models and the empirical facts being considered. Understanding scientific knowledge is understanding the problem at its origin.

The analysis of students' social representations/conceptions (alternative conceptions, preconceptions, etc.) was inspired by the work of Moscovici (1961) in social psychology. Clement (1994) suggested the term 'situated conceptions' for concepts expressed in a given context. With his colleagues, Clément analysed conceptions with the KVP model: K (knowledge), V (values) and P (social practices).

Curricular analysis (Lebeaume 1999; Coquidé, Lasson & Fortin, 2010), inspired by Anglo-Saxon approaches, sets out to analyze the aims and objectives of an educational program in the context of its implementation (sociological, political and educational dimensions). The purpose of the curricular analysis is to examine the consistency between the required tasks, the educational goals, and the epistemological and social meanings.

The Socially Acute Questions (SAQ) current studies the process of teaching and learning in buoyant objects of controversy and debate in the scientific sphere, society and media, and therefore in the classroom (Legardez & Simonneaux, 2006). This takes into account:

- The epistemological question in teaching, especially in the wake of the current Anglo-Saxon view of Nature of Science (Lederman, 1992), emphasizing the social dimension of science in connection with the current science–technology–society–environment (STSE) approaches. Anglo-Saxon socio-scientific issues (SSI) (Sadler, Chambers & Zeidler, 2004; Zeidler, Walker, Ackett & Simmons, 2002). Current teaching of SSI has become one of the main trends in research in science education. SSI education focuses on the social consequences of the applications of science and technology. There are similarities and differences between the SSI and SAQ trends (Simonneaux, 2013).

The structuring and restructuring of didactics around disciplines certainly continues, but it is also changing simultaneously to a cross-over with different didactics. Moreover, the didactics of experimental science has drawn heavily on the didactics of mathematics, be it the TAD or the TACD. The emergence of SAQ is involved in this cross-over, because these questions are inter-disciplinary in nature. This is amplified by the emergence of "education for", especially in education for sustainable development and citizenship education, or education for health, in which SAQ are involved. "Education for" incorporates inter-disciplinary and multi-reference didactic questioning, which partially removes the disciplinary division (Simonneaux et al., 2009). Didactics remains defined by disciplinary inputs and has been legitimized in a form of "veneration of the discipline" (Chevallard, 2006). Now we are witnessing a paradigm change in education: from an inventory of knowledge based on a pedagogy of exposure of knowledge towards a questioning of the world based on a pedagogy of inquiry (Ladage and Chevallard, 2010).

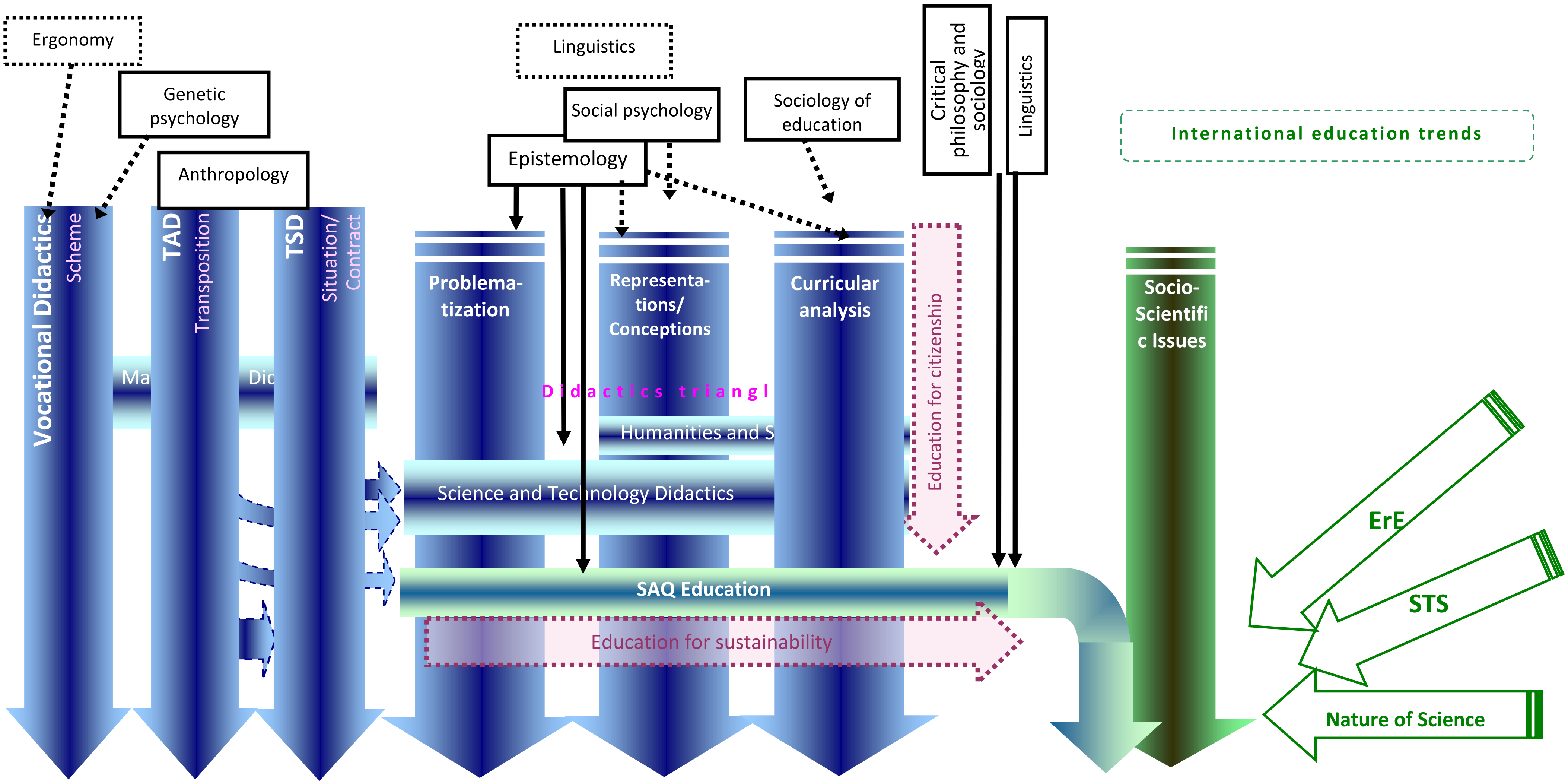

Figure 1. The main trends of science education in France and their affiliations.

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19 THE NATURE OF RESEARCH IN DIDACTICS OF BIOLOGY: A DUTCH PERSPECTIVE

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1. Introduction

The question about the essence of research in didactics of biology is comparable to the question 'What is life'? Biologists do not answer the latter. Instead, they seek to describe and explain life phenomena. 'What is…?' is a philosophical question and as a researcher in the didactics of biology, I can express my view on this issue by reflecting on 40 years of personal work experience in didactics of biology. Didactics essentially studies both what is valuable and what is learnable for different abilities and age groups in schools, and how this should be aligned in the curriculum. *Valuable* refers to the normative task of didactics: the Why and What questions to be answered from three relevant perspectives (biology, student and society). *Learnable* concerns the instrumental task: the How question.[1] The ultimate aim of research in didactics of biology is to contribute to understanding and improving contemporary teaching and learning of biology, which includes curriculum rethinking, and empowering and facilitating teachers through research-informed pedagogies. Didactics shares a meta-perspective with the history and philosophy of biology; from different angles, these contribute to understanding the nature of biology. Let me start with some Dutch historical and contextual details.

2. Professionalization and scientification of teaching biology

Until the 1970s, in the Netherlands, you were either born a teacher or had to learn the art of teaching by simply imitating your favourite teacher or your teaching supervisor. Over the past decades however, teacher education has been professionalized with a focus on reflective

1 The Proceedings of the First Conference of ERIDOB in 1996 were entitled What – Why – How? Research in Didaktik of Biology. Both the title and the use of the German term 'Didaktik' reveal the difference between the continental and Anglo-Saxon tradition. The Constitution of ESERA starts with the following preamble: "Wherever the English phrase 'science education' appears in this document, it has a meaning equivalent to 'didactique des sciences' in French, 'Didaktiken der Naturwissenschaften' in German, 'Didáctica de las Ciencias' in Spanish, or the equivalent in other European languages (see Appendix)". This was the outcome of a heated debate about the naming of the new association during the foundation of ESERA in 1995. The English 'didactics' has a connotation of imposing and thus is not equal to 'Didaktik'. In the mid-1980s, Shulman coined the term 'Pedagogical Content Knowledge (PCK)' which does not fully cover the continental meaning of didactics either.

practice and developing a personal teaching style (self-development model: teachers as self-regulating learners). This tendency toward professionalization gradually became informed by two related research fields: teacher education research and research in didactics of school subjects. The latter field, emerging in the 1980s, had and still has a strong focus on concept formation, development of subject-specific attitudes and skills, and curriculum issues. Unfortunately, these two research fields became more and more autonomous at the cost of synergy. In addition, researchers and teacher educators became separate groups, which until recently contributed to the theory–practice gap. Ideally, a researcher in didactics of biology should have working experience as a teacher and as a teacher educator.[2] A promising development is that since 2007, Dutch teachers can apply for a part-time PhD position and combine work in school with qualifying as a researcher in didactics.[3]

3. Programmatic research in didactics of biology

The only Dutch chair in didactics of biology, hosted by Utrecht University, provided a strong impetus for research from its inception in the 1990s until it was recently cancelled due to budget cuts. Research in didactics of biology has now become almost fully dependent on external funding[4], which severely interferes with the performance of programmatic research. In its heyday, the Dutch research programme in didactics of biology, which is now fading, focused on (a) transforming *domain-specific*[5] *meta-cognitions* into learning and teaching strategies (LTs) and (b) *context-based biology education*. Systems thinking is central to the life sciences and this was elaborated into the yo-yo LT (genetics), modelling LTs using multiple representations (cell biology, ecology), and molecular mechanistic reasoning LT (genomics). Next to systems thinking, the perspective of form and function, i.e. taking a designer´s view, is central to biological (and technological) thinking, and this was elaborated into learning by designing LTs (immunology). Context-based LTs addressed the problem of transferring concepts between contexts (recontextualizing cellular respiration) and acquiring a

2 Cf. Van der Zande, P.A.M. (2011). Learners in dialogue. Teacher Expertise and Learning in the Context of Genetic Testing. Utrecht: Utrecht University (PhD thesis). In this research project, research in didactics of biology and in teacher education was integrated. The researcher is an experienced biology teacher and teacher educator, which is the best guarantee for implementation of research findings in practice.

3 Reasons to start this programme were to facilitate the implementation of context-based science education and to provide career opportunities for teachers.

4 It is true that external funding is available, but for curriculum development and implementation rather than for research.

5 Research in didactics can be pragmatically demarcated by its focus on the domain of life sciences and the corresponding school subject. Subject-specific concepts and scientific ways of thinking and acting are central. Subject knowledge is crucial in developing skills and attitudes. In addition, applications and implications of life sciences co-define the domain of research in didactics, mindful to situated learning in contexts such as health, environment and agriculture. Since the late 1980s, we have gradually extended the field of didactics of biology to informal learning settings and have started educating health and environmental education professionals. With the introduction of the bachelor–master system at the beginning of the 21st century, we also added science communication, of which health and environmental education became a part. Due to budget cuts, didactics of biology was forced to narrow its scope, i.e., back to the core business of teacher education and school biology. Our pragmatic demarcation is still problematic. The sciences and technologies are converging. For example, synthetic biology, the engineering approach to biology, builds on life sciences, engineering and informatics.

coherent understanding of biological concepts (cellular metabolism). Another strand in context-based research is genomics education for citizenship: socio-scientific learning. These studies share the *design research approach*, which has some common ground with the German didactic reconstruction approach. In design research, designing, studying, optimizing and reflecting/theorizing are interwoven. Case studies, using multi-method triangulation, are an important component of design research. Although small-scale, familiarization with design research has turned out to be quite time-consuming; moreover, it is difficult to publish and its theoretical output is modest and debatable.[6] On the other hand, design research provides theory-based and empirically tested educational designs for use in the classroom and teacher training. The practical and theoretical outcomes are communicated through a website for teacher educators so as to promote the implementation of research findings into teacher education.[7] In addition, through participation of researchers in curriculum projects, syllabus review committees and examination boards, research findings may eventually affect classroom practice.

4. Organizational context of research as success factor

A new and valuable experience for us in the last decade has been the participation in genomics-related education and communication activities, supported by grants from the *Centre for Society and Genomics* and the *Cancer Genomics Centre*, both genomics centres of the *Netherlands Genomics Initiative (NGI)/Netherlands Organisation for Scientific Research (NWO)*. We started by developing and implementing mobile DNA laboratories, then rethought science curricula in the genomics era, and concluded with international consensus building on genetics literacy needed by a 21st century citizen. The DNA laboratories were successful in providing new science content and skills in different application contexts, but underperformed in discussing the social and moral implications. In response to this, more emphasis was placed on techno-scientific citizenship education and informed decision-making (socio-scientific issues-based education). Many science teachers lack the support and confidence to address value-laden issues in their classrooms, so we also started research and in-service education to empower and facilitate them. Another research project focused on connecting molecular knowledge to phenomena at the higher level of cells, organs and organisms; a learning trajectory based on molecular–mechanistic reasoning was designed and tested. Unfortunately, the *NGI* ended in 2013. Being part of a national multidisciplinary genomics network enabled us to learn a lot from genomics, humanities and social science researchers and from science communicators, which was inspiring and helpful in updating biology education in schools.[8]

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6 Boersma, K.Th. &Waarlo, A.J. (2009). On the theoretical input and output of 'design research' in biology education. In Hammann, M., Waarlo, A.J. &Boersma, K., The Nature of Research in Biological Education. Old and New Perspectives on Theoretical and Methodological Issues. ERIDOB Conference 2008. Utrecht: CD-β Press, FIsme-series on Research in Science Education, No. 60.

7 See www.ecent.nl (in Dutch).

8 CSG Next 2008-2013: Harvesting results & Preparing for the future http://www.society-lifesciences.nl/fileadmin/user_upload/docs/Publicaties_PDFs/Rapporten/CSG-next_2008-2013_web.pdf

5. Nature of research in didactics of biology

Didactics of biology is *transdisciplinary* in nature, meaning that multiple academic disciplines contribute to it, as do practitioners with their practice knowledge and expertise. Delivering disciplines are the history and philosophy of life sciences, pedagogical and educational sciences, communication sciences, and science and technology studies, including bioethics. It can also be partly characterized as *translational research*. In the genomics network, findings from multidisciplinary basic research were made useful for practical applications towards improving biology education (cf. translational medicine: from bench to bedside). Doing research is an effective way of having a *lasting or sustainable reflective conversation* on the what, why and how of teaching and learning biology informed by theoretical notions and empirical data and thus challenging stubborn beliefs. Developing a *common language* among members of the ERIDOB community will be important in facilitating effective communication. What has struck me over the years is that my expertise is somewhat embodied and 'emminded', rather than available in an *external knowledge base*. In my supervising and consulting activities, relevant expertise is activated that enables tailor-made comments. However, novices in the field have an urgent need for an appropriate and comprehensive textbook, which we cannot yet offer them. Up until now we have referred to articles or book chapters in readers.[9] Gradually, an *integrated practice-oriented discipline of its own* should emerge, characterized by autonomous, domain-specific theory development on learning and teaching biology, and by an eclectic set of appropriate research methods. Although the extent of research has increased considerably since ERIDOB was established, re-inventing the wheel is quite common and *domain-specific knowledge accumulation*, the aim of doing research, is still modest. The research culture of 'publish or perish' might account for paying insufficient attention to valuable publications of the past decades. *Gradual research-informed improvement* rather than hypes and hopes presented as renewal or change in biology education should be our mission.

6. Final remark

As for the Dutch situation of research in didactics of biology, the warning slogan in advertisements for investment funds seems applicable: "Results achieved in the past are no guarantee for the future". Although we have meanwhile been successful in acquiring two EU projects, PARRISE and SYNENERGENE, these projects are not research-oriented and bring with them a large administrative workload. Our tenured staff has been reduced substantially, the only Dutch chair in didactics of biology has been eliminated, and the changing research-funding regime is undermining programmatic research. Sharing and learning from the threats and opportunities of national policies and strategies concerning research in didactics of biology in the ERIDOB research community are needed more than ever.

9 A Delphi study amongst ERIDOB participants could be helpful in reaching consensus on key publications in our field to be included in a research knowledge base for graduate and PhD students.

20 MEANING OF THE TERM "RESEARCH IN DIDACTICS OF BIOLOGY"

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Toward the 10th conference of ERIDOB we were asked to define the term "Research in Didactics of Biology" and to highlight questions that should be addressed in this research area. Herein we attempt to provide answers to those two tasks, from the Israeli perspective.

1. Defining the term "Research in Didactics of Biology"

We initiated our thinking about the definition of "Research in Didactics of Biology" with an examination of the current ERIDOB documents: the ERIDOB policy paper and the call for proposals. A careful examination of the policy paper revealed that the term "Research in Didactics of Biology" has not been defined since the ERIDOB organization was established 20 years ago in Kiel, Germany. Nor did an examination of the current ERIDOB strands, which are listed in the recent ERIDOB calls for papers (from 2010, 2012 and 2014), reveal the meaning of this term, as most of the strands are general, rather than specific for research in biology didactics (Table 1). It appears that only strands 7 and 8 refer to specific content, namely "environmental education and biology education" and "health education and biology education", whereas all of the other strands are general to science education research and do not specify biological content. Thus, we believe that raising this question in this symposium is timely.

In T. Tal & A. Yarden (Eds.) Proceedings of the 10th Conference of European Researchers in Didactics of Biology (ERIDOB), Haifa, Israel, 2014.

Table 1. Current ERIDOB strands.

1.	Student conceptions and conceptual change
2.	Student interest and motivation
3.	Student values, attitudes and decision-making
4.	Student reasoning, scientific thinking and argumentation
5.	Teaching: teaching strategies, teaching environments
6.	Teaching and learning with educational technology
7.	Environmental education and biology education
8.	Health education and biology education
9.	Social, cultural and gender issues
10.	Practical work and field work
11.	Research methods and theoretical issues concerning research in biology education

The essence of research in biology didactics obviously stems from the actual teaching and learning of biology in formal and informal contexts. It relies on every nation's educational frameworks and opportunities for the teaching and learning of biology. We found the recently published US framework for K–12 science education (National Research Council [NRC], 2012) to be suitable for the general framework of the formal biology curriculum in our country, and we believe it is probably suitable for the syllabi in other countries as well. The framework is built around three major dimensions: core ideas, crosscutting concepts, and scientific practices. If we take as an example the curriculum for high-school biology in Israel (10^{th}–12^{th} grades, 16–18 years of age), it includes: (a) core ideas in biology that are expressed in three obligatory core topics (homeostasis in the human body, the living cell, and ecology) and in a few elective topics (inheritance, reproduction); (b) eight crosscutting concepts, or main principles that are emphasized in every topic studied (i.e., homeostasis, structure-function relationships, evolution, organization of biological systems); (c) practices (i.e., asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, communicating information) that are expressed in an inquiry project carried out by the students, in laboratory experiments, in papers students are requested to read, and throughout the learning of the various core ideas. The three dimensions are embedded one within the other in such a way that learners are engaged with the core topics, the crosscutting concepts and the practices simultaneously (Israeli Ministry of Education, 2011). Accordingly, we see research in biology didactics as focusing on each of those three dimensions and on their integration, with the aim of promoting biology education. This is carried out by examining all facets of the teaching and learning of biology, including the learners, the teachers and the settings in which they both act. Due to various queries that were raised at the recent ERIDOB 2012 conference in Berlin, we would like to emphasize our belief that research that is focused only on the practices and/or crosscutting concepts while learning and teaching contents other than biology cannot be considered research in biology didactics.

We hereby suggest modifying the current ERIDOB strands to reflect the way in which biology is taught and learned in the field, while placing more emphasis on the biological aspects. We base our suggestion on the strands of the National Association of Research in Science Teaching (NARST) with adaptations to our field (Table 2).

The following main modifications were incorporated into the newly suggested strands:

1. The newly suggested strands do not include strands 7 and 8 of the current ERIDOB strands (Table 1). We suggest that the related fields that are more interdisciplinary in nature, such as environmental education and health education, be integrated within the other strands rather than standing out independently of the other strands. It is not that we think that those strands should not be represented in ERIDOB; on the contrary, current research in biological sciences is interdisciplinary in nature and this should be reflected in the educational programs and educational research. However, we suggest allowing those strands to be represented along with the other topics.
2. Current ERIDOB strands 1–4 were regrouped and are not represented in the newly suggested strands 1 and 2, which are focused on various aspects of the leaning of biology.
3. Current ERIDOB strand 5 is now represented in the newly suggested strands 2 and 3, which are focused on learning biology (strand 2) and on teaching biology (strand 3).

Table 2. Suggested ERIDOB strands

1. **Biology learning, understanding and conceptual change** How students learn biology for understanding and conceptual change, student reasoning, scientific thinking and argumentation
2. **Biology learning: contexts, characteristics and interactions** Learning environments, teacher–student and student–student interactions, factors related to and/or affecting the learning of biology, including interest and motivation to learn biology
3. **Biology teaching: characteristics and strategies** Biology teacher cognition, content knowledge, pedagogical knowledge, pedagogical content knowledge, instructional materials and strategies
4. **Biology learning in informal contexts** Biology learning and teaching in museums, outdoor settings, community programs, using communications media and in after-school programs
5. **Biology teacher education** Pre-service and in-service professional development of biology teachers, pre-service and in-service biology teacher education programs and policy, continuing professional development of biology teachers
6. **Biology curriculum, evaluation, and assessment** Biology curriculum development, change, implementation, dissemination and evaluation, including alternative forms of assessment of teaching and learning of biology
7. **Cultural, social and gender issues** Equity and diversity issues, sociocultural, bioethical, multicultural, bilingual, racial/ethnic, gender equity studies related to biology education
8. **Teaching and learning biology with educational technology** Computers, interactive multimedia, video and other technologies used for biology education
9. **History, philosophy, and sociology of biology** Historical, philosophical and social issues related to biology education

4. The newly suggested strand 3 also focuses on teachers' knowledge, i.e., pedagogical content knowledge, which is missing from the current strands and has been extensively discussed at recent ERIDOB conferences.
5. Current strands 10 and 11 were eliminated as they are represented in the other suggested strands, and also since there have been no accepted submissions to those strands in recent ERIDOB conferences.

We suggest putting the newly suggested strands up for discussion among ERIDOB members and reaching a consensus on a new list of strands representing our community research work in the field of "Research in Biology Didactics" for future ERIDOB conferences.

2. What research questions should be addressed in didactics of biology?

We believe that the foundations for research into the didactics of biology consist of the two intertwined elements of content and scientific reasoning. Research into content alone would be no more than biology research; research into science reasoning alone would be general science education research. Accordingly, research in biology didactics should incorporate a biological element with a scientific reasoning element. Figure 1 shows the sub-components of each element (content and scientific reasoning). Research in biology didactics offers a variety of interesting and creative connections between these sub-components and others being developed in the fields of science and education. For example, research into the connections between:

- Understanding the nature of science and teaching the theory of evolution
- Developing scientific literacy by reading primary literature in genetics supported by ICT
- Developing critical thinking and systems thinking by doing open inquiry on plant hormones
- Professional development of biology teachers experiencing open inquiry themselves, on the subject of homeostasis in prokaryotes
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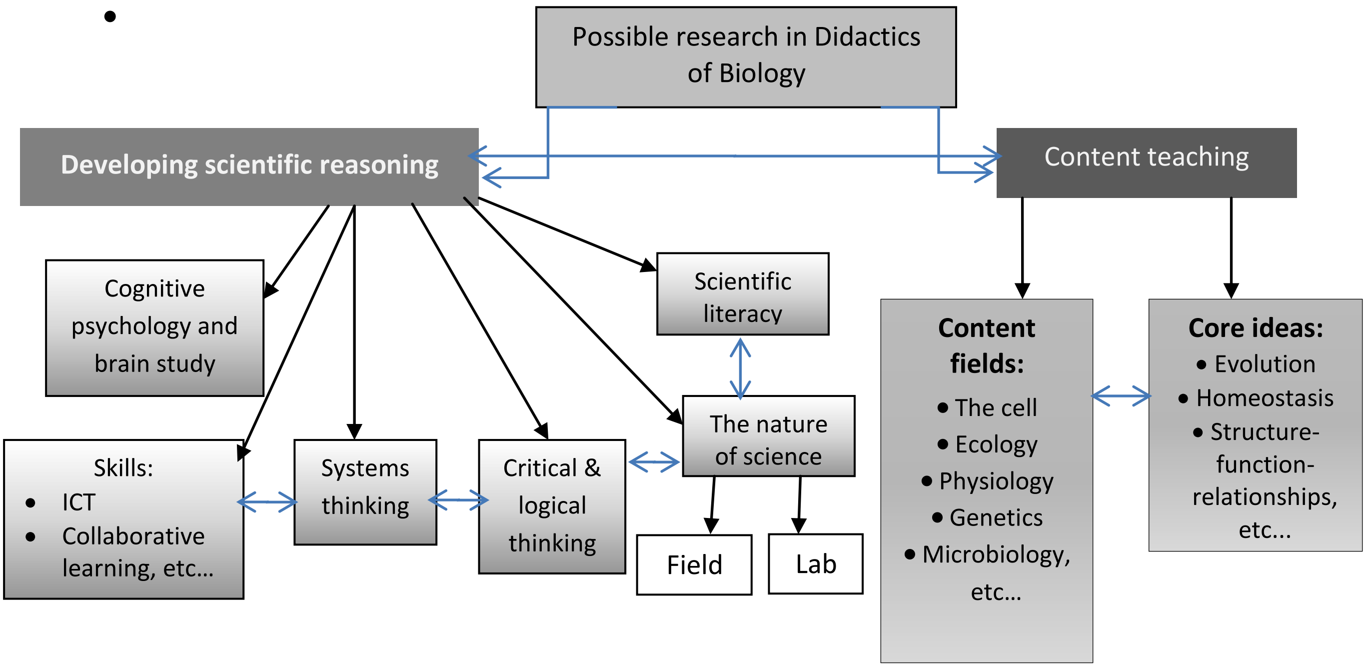

Figure 1. Emphases of research in didactics of biology.

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