HIGH-SCHOOL TEACHERS' APPROPRIATION OF AN INNOVATIVE CURRICULUM IN BIOINFORMATICS

Yossy Machluf*, Hadas Gelbart* and Anat Yarden
The Department of Science Teaching, Weizmann Institute of Science (Rehovot – Israel)
machluf.yossy@weizmann.ac.il
* These authors contributed equally to this work

Keywords
Authentic science education; Bioinformatics curriculum; Teachers' development program; Assessment; Domain-specific knowledge

Abstract
One of the goals of curriculum developers is to provide learners with opportunities to engage in activities that resemble authentic scientific research. A learning environment (LE) aimed at introducing bioinformatics into a high-school biotechnology majors curriculum through engaging learners in authentic research practices served as the context for this study. A teachers' program aimed at establishing a community of biotechnology teachers who collaborate in implementing the LE was established. One of the goals of the teachers' program was to design an assessment tool for the LE. In this study, we examined how the teachers designed the assessment tool, as a means of probing their knowledge and beliefs in adopting contemporary scientific research into their classroom. The analysis of the assessment tool revealed questions that require the use of conditional knowledge, which is at the heart of performing authentic scientific research. Most of these questions called for coordination between various scientific reasoning practices. The teachers perceived research as combining laboratory experiments and bioinformatics approaches. Thus, the assessment tool represents characteristics of authentic modern scientific research and the teachers' appropriation of the new bioinformatics curriculum, by extending its roots to the 'traditional' curriculum. We envision that an analysis of the rationale and design of the assessment tool developed by the teachers, may not only be applicaple for the characterization of other scientifically authentic assessment tools, but also can serve as a means of exploring teachers' knowledge and beliefs.

1. Introduction

1.1 Authenticity in science education

One of the fundamental goals of curriculum developers is to provide learners with opportunities to engage in scientifically authentic practices. Here we refer to the canonical perspective of authentic science education (following (Buxton 2006)), namely practices that resemble authentic scientific research as they are carried-out by the scientific community. This perspective on authenticity is aligned with both the Western scientific canon and the canon for science education standards in the US (National Research Council [NRC] 1996, 2012), Europe (European Union 2006) and elsewhere (Yarden and Carvalho 2011). Such practices represent important discipline-specific aspects of science, and may therefore enhance cultivation of students' scientific habits of mind and can contribute to the contextualized understanding of how scientific knowledge is acquired, evaluated, and developed (Samarapungavan *et al.* 2006). These practices can offer students opportunities to develop a deep understanding of scientific knowledge (Abrams 1998; Lee and Songer 2003) and to invoke the reasoning that scientists employ and the epistemology underlying authentic inquiry (Chinn and Malhotra 2002); they may also lead to a proper conception of the nature of scientific inquiry. Engagement in authentic scientific research practices can foster student participation in practices of inquiry (Chinn and Malhotra 2002; Falk *et al.* 2008), and requires continuous coordination between various intervening events of the scientific practice (Chinn and Malhotra 2002; Falk and Yarden 2009).

The overall greater complexity of authentic scientific research requires continuous application of conditional knowledge and coordination of declarative and strategic knowledge, while reasoning scientifically and making decisions (Gelbart and Yarden 2011). Declarative knowledge has been defined as knowing "what" the factual information is, procedural knowledge as knowing "how" to use this knowledge in certain processes or routines, and conditional knowledge as understanding "when and where" to access certain facts or employ particular procedures (Alexander and Judy 1988). Usage of conditional knowledge, and coordination of facts, procedures and strategies, are not typical of regular school tasks and rarely appear in school learning materials (Chinn and Malhotra 2002; Yarden 2009).

1.2 The emergence of bioinformatics

Massive growth in information, due to experimental and technological advances, has led to "an absolute requirement for computerized databases to store, organize, and index the data and for specialized tools to view and analyze the data" (National Center for Biotechnology Information [NCBI] 2011). Bioinformatics is an emerging interdisciplinary field, drawn from fields as diverse as mathematics, physics, computer sciences, engineering, biology, and behavioral science. It applies principles of information sciences and information technologies to make the vast, diverse, and complex life sciences data more understandable and useful, and help to realize its full potential (National Institutes of Health [NIH] 2000). Bioinformatics has revolutionized and redefined how research is carried out, and has had an enormous impact on biotechnology, medicine, industry and related areas (Attwood *et al.* 2011).

While bioinformatics is increasingly important in modern life sciences, it plays almost no role in high-school science classes. To mirror today's research trends and keep science curricula current, considerable resources are now being devoted to integrating this exciting field and its related databases, tools and technologies into science classrooms (Gallagher *et al.* 2011; Gelbart and Yarden 2006; Lewitter and Bourne 2011; Wefer and Sheppard 2008) mainly through inquiry-based activities. Incorporation of bioinformatics in education, mainly at the high-school level, presents great opportunities and major challenges for students and teachers, as well as at the curriculum and logistics levels (Cummings and Temple 2010).

We recently developed a web-based learning environment (LE) (Machluf *et al.* 2011) that is aimed at introducing bioinformatics into a high-school biotechnology majors curriculum in Israel. The biotechnology curriculum includes obligatory subjects such as genetic engineering and biochemistry, and the elective topics of immunodiagnostics and immunotherapy, tissue culturing, environmental biotechnology, bio-nanotechnology and advanced laboratories, as well as bioinformatics (Israeli Ministry of Education 2005). In the LE, both pedagogy and technology were recruited for educational purposes aimed at engaging students with scientifically authentic inquiry activities that bring the fruits of bioinformatics to bear on human health quality and expectancy (see http://stwww.weizmann.ac.il/menu/personal/anat_yarden/abstracts/Bioinformatics.pdf). Learners are invited to take part in five authentic inquiry activities in biotechnology using eight different bioinformatics tools and databases. The activities were developed based on primary research articles selected according to (i) the relevance of the scientific context to students' interests; (ii) a clear biotechnological application; (iii) use of a variety of bioinformatics tools and databases that are suitable for the high-school students' cognitive level; (iv) high-impact subjects that are broadly covered in the popular scientific literature and in the public media, and (v) clear connections to principles and techniques in the biotechnology syllabus. In each multistep activity, the students are introduced to the rationale and main goals of the research at hand, and learn how to utilize the bioinformatics tools and databases, similar to the original research plan. The selected bioinformatics tools are basic yet fundamental; they are commonly used by scientists and enable acquisition of central bioinformatics principles and approaches. To proceed in the investigation, the students experience different scientific practices, they are required to coordinate their acquired procedural knowledge, declarative subject-matter knowledge, context-dependent conditional knowledge and prior content knowledge, and also to reason scientifically and make decisions following the strategic plan.

1.3 Teachers' professional development program

Integrating scientific practices, crosscutting concepts and core ideas (following (National Research Council [NRC] 2012)) into real-world inquiry-based activities for bioinformatics learning and instruction is necessary but not sufficient. We believe that successful implementation of bioinformatics as an elective topic in the biotechnology syllabus is greatly dependent on the teachers, who should become agents of change (Fullan 1993). Therefore, a teachers' professional development program was established during the 2010-11 academic year. To develop teachers' identities as reform-minded science teachers, the program provides opportunities for participation in scaffolded series of experiences that will build their personal vision and mastery of knowledge and skills, as well as recognition by self and others as reform-enhancing teachers (Luehmann 2007). The design of the teachers' program stems from a theoretical perspective that views teachers' training, similar to students' learning, as a combination of the constructivist learning perspective (Greeno 1998) —which encourages active learning that allows opportunities to build one's own knowledge, and the situated learning perspective—which views learning as a process of enculturation into a community of experts by using authentic activities (Brown *et al.* 1989). The rationale of the program is based on the following guidelines: (i) designing and developing a curriculum, or assessing it, can serve as a vehicle for teachers' professional development and as a driving force for transforming science teaching (Parke and Coble 1997); (ii) experienced teachers have valuable and unique kinds of knowledge and skills (Shulman 1987); (iii) the assessment tool is a curriculum requirement that can be recognized by professionals (e.g., the teachers themselves, other teachers, supervisors, educators and developers in bioinformatics) as a meaningful product of the teachers participating in the program.

This study examined how high-school biotechnology teachers design and develop an assessment tool for an innovative LE in bioinformatics, as a means to probe their knowledge and beliefs in adopting contemporary scientific research into their classrooms. Specifically, we asked:

(I) What are the characteristics of the assessment tool developed by the teachers?

(II) What was the teachers' rationale behind the development of the assessment tool?

2. Research design and method

2.1 Research context

A teachers' professional development program aimed at establishing a community of teachers who collaborate in adapting the new LE and promoting its implementation was launched at the Weizmann Institute of Science. Four highly qualified in-service biotechnology teachers, from four different high schools across the country, with only limited knowledge in bioinformatics but with experience in implementing innovative learning materials and preparing students for the matriculation exams in biotechnology, were selected to participate in the program (Table 1). The main rationale of this program was to develop teachers' identities as reform-minded teachers, pioneers at the forefront of high-school bioinformatics education, who recruit their knowledge and experience to mutually design and develop bioinformatics instructional means and assessment tools.

Table 1. Participants characteristics

Teacher	**Gender**	**Degree**	**Years of teaching experience (biotechnology)**	**Experience in writing matriculation exams**	**Other duties**
1	Male	Ph.D.	30 (13)	Yes	
2	Female	Ph.D.	31 (14)	Yes	National advisor
3	Female	M.Sc.	24 (10)	No	Regional advisor
4	Male	M.Sc.	6 (6)	No	

The program curriculum ran for eight hours weekly over the course of one academic year (37 meetings). Each semester, the teachers participated in a biology course and in seminars in science education research, while most of their time was devoted to collaborative workshops in bioinformatics. These workshops introduced the teachers to the bioinformatics world of research and education while they designed and developed instructional means and assessment tools. The program meetings were instructed and guided by the first two authors of this study, together with science teaching experts and in collaboration with researchers from the field of bioinformatics. During the first part of the program, emphasis was placed on acquisition of theoretical content knowledge, experiencing firsthand practical skills in using bioinformatics tools and databases, and judicious integration of bioinformatics tools alongside experimental techniques in biological reseach. As expected, it was in this phase that teachers exhibited resistance and antagonism to the new materials in bioinformatics, as they claimed to "be afraid of the unfamiliar [bioinformatics] tools" and to "feel like students." In this phase teachers were engaged primarily in understanding the procedures and technical aspects of utilizing the bioinformatics tools, rather than in the broader scientific reseach view. They then became fully familiarized with the LE and its activities, prepared teaching materials, instructed their own students while enacting LE activities, and collaboratively analyzed and reflected on their experiences. In this phase, teachers' attitudes changed into more positive responses toward the LE, and they became less skeptical and more convinced that the bioinformatics LE demands are in line with high-school students' abilities. Then, teachers collaboratively designed and developed an assessment tool that could serve as a model for the national bioinformatics matriculation examination.

2.2 Research design

The assessment tool was designed, developed and refined collaboratively by the teachers over three sessions. Following each session, brain storming was performed with the instructors and the assessment tool was then revised solely by the teachers. The three versions of the assessment tool, and more specifically the questions embedded in them, were analyzed according to three criteria (see below) in order to characterize the assessment tool developed by the teachers, and to uncover tacit knowledge and their perception of bioinformatics research. Furthermore, teachers were interviewed at the end of the year to reveal their rationale behind the development of the assessment tool.

2.3 Data analysis

We examined how the teachers designed and developed an assessment tool for the LE. To study the characteristics of the assessment tool, the questions it included were classified based on three different criteria:

I) Domain-specific knowledge: questions were categorized according to the type of knowledge required to answer them, namely *declarative*, *procedural*, or *conditional* knowledge (following (Alexander and Judy 1988)). This knowledge classification framework is of particular relevance to the bioinformatics field and the curricular themes of understanding the theoretical principles underlying each bioinformatics tool, its proper operational use, and the considerations of research-derived selection of bioinformatics tool, its integration and its contribution to experimental research, respectively. For example, in bioinformatics education, understanding the principle of sequence alignment is declarative knowledge, while using a bioinformatics tool to perform sequence alignment is procedural knowledge, and realizing when to align which sequences to what goal is conditional knowledge.

II) Scientific reasoning (following (Chinn and Malhotra 2002)): *research questions*—questions that require coordinating different research questions, *methods*—selecting methods and examining their suitability to the research questions, *results*—analyzing the results, and *theoretical explanations*—generating explanations and conclusions. Authentic scientific inquiry involves various processes; the main ones were selected and gathered into these categories.

III) Scientific approach: questions that stem from a biological approach, bioinformatics approach, or a combination of both. Modern bioinformatics-integrated research includes steps that combine both approaches, as well as steps that stem from each approach.

All of the questions were classified independently by two researchers and discussed until 100% agreement was achieved. The frequencies of questions classified into each category were calculated, and a Chi-square test was used for comparisons among groups.

At the end of the year, teachers were interviewed; the interviews were recorded, transcribed, and analyzed bottom-up using classification into episodes and subsequently into categories (following

(Shkedi 2005)). The teachers were asked to review the significant phases in the training program, the professional goals, educational achievements, implications and their recommendations for the future.

3. Results

3.1 Description of the process

Three main phases were observed in the process of teachers' collaborative design and development of the assessment tool:

I) Topic selection: Initially teachers turned to the scientific literature, seeking papers describing investigations in which advanced experiments and bioinformatics approaches had been combined and recruited to solve current biotechnological questions. This phase was clearly a bottleneck in the process, a "frustrating" phase in the teachers' own words, as they lacked the experience to realize how bioinformatics is integrated into scientific research, the mode of its implicit description in scientific papers, and its contribution. Given a choice of various candidate authentic papers proposed by the program's instructors, teachers selected the article by Gupta *et al.* (2010).

II) Processing: Teachers met one of the investigators conducting the research to gain insights into the research process, including its experimental and bioinformatics steps. Design principles of the assessment tool were determined, the scientific outline was set, and the relevant bioinformatics information (data records, nucleotide sequences, proteins structures, etc.) was gathered under the instructors' supervision. The outline was composed of a short introduction and three experimentally based sections in which the resultant data were represented using a graph and tables, combined with three sections in which bioinformatics tools were used.

III) Design, development and revision: The teachers focused on designing, developing and refining the assessment tool over three sessions. Following each session, brain storming was conducted with the instructors to analyze the assessment tool as a whole. Theoretical frameworks for analyzing the questions embedded in the assessment tool were discussed, and the assessment tool was then examined and revised solely by the teachers.

3.2 Characteristics of the assessment tool

The questions embedded in the assessment tool were analyzed according to the three criteria used to characterize the assessment tool. During the development and revision of the assessment tool, questions were mainly added (7 in the second version and 1 in the third version) and modified (12 and 9, respectively). Most added questions (5) required the use of conditional knowledge. Only 3 questions were modified such that their characteristics changed. The three versions of the assessment tool were similar, therefore only the analysis of the last version is presented.

The frequency of each of the question types in the assessment tool was calculated using the three criteria (Table 2). The frequency of questions that require the use of declarative knowledge was half that of the questions requiring either procedural or conditional knowledge. Similarly, the frequencies of questions dealing with either a biological approach or a bioinformatics approach were almost equal within each session, whereas the frequency of questions dealing with a combined approach was about twofold lower. Analysis of the frequencies of questions dealing with scientific reasoning revealed that most deal with *results* (57%), while much fewer deal with the *research questions* (14%).

Table 2. Frequencies of questions embedded in the assessment tool classified according to three criteria: Domain-specific knowledge, Scientific approach and Scientific reasoning

Scientific criteria	**Categories**	**Total number of questions (percentage)[b]** (n=28)
Domain-specific knowledge	Declarative	5 (18%)
	Procedural	11 (39%)
	Conditional	12 (43%)
Scientific approach	Biology	12 (43%)
	Bioinformatics	11 (39%)
	Biology and Bioinformatics	5 (18%)
Scientific reasoning[a]	Research questions	4 (14%)
	Methods	7 (25%)
	Results	16 (57%)
	Theoretical explanations	8 (29%)

a The sum of questions classified as scientific reasoning is above the overall number of questions due to multiple attributions of several questions.
b The number of questions within each category and their percentage of the total number of questions is presented.

A comparison of the frequency of the three types of domain knowledge within questions calling for specific scientific reasoning revealed significant differences in their distribution (Table 3). Questions dealing with *results* called mainly for procedural knowledge and to a lesser extent for conditional knowledge. Questions dealing with either *research questions* or *methods* called almost exclusively for conditional knowledge. In questions calling for *theoretical explanations*, a non-significant over-representation of questions requiring the use of conditional knowledge was observed. Four questions (14%) that required the use of declarative knowledge were not assigned to any of the scientific reasoning categories. Rather, they were based on prior knowledge or on textual information provided in the assessment tool. Conversely, 10 questions (36%), most of them requiring the use of conditional knowledge, were assigned to multiple scientific reasoning categories.

Table 3. Distribution of questions calling for a particular scientific reasoning according to the domain-specific knowledge criterion

Scientific reasoning	**Domain-specific knowledge**		
	Declarative (n = 5)	**Procedural** (n = 11)	**Conditional** (n = 12)
Research questions	0	0	4*
Methods	0	1	6*
Results	1	10	5**
Theoretical explanations	1	2	5
Not assigned to any scientific reasoning category	4	0	0
Assignment to a single scientific reasoning category	0	9	5
Assignment to multiple scientific reasoning categories	1	2	7

*$0.01 < P < 0.05$; ** $0.001 < P < 0.01$

3.3 Teachers' rationale

During the interviews broad agreement was expressed by the teachers. The teachers found the development of the assessment tool as the most meaningful activity in the program, and elaborated on the rationale and the design principles underlying its development.

They perceived their 'mission' through their annual and diverse activities as "to speak on behalf of our students and to adapt the learning materials and assessment tool to their level" while making it "relevant to students…challenging yet not frightening" (Teacher #2). They were all satisfied with the assessment tool, and described the process they had gone through as interesting, creative and educational. The assessment tool's format was developed by the teachers with the aim of demonstrating "a clear [biotechnological] research approach, following the sequence of the [original] research, and making clear the rationale behind this sequence… the goal [of the research] should be very clear to the students and it should take them directly to the [bioinformatics] tools" (Teacher #1). The teachers particularly emphasized their attempts to integrate questions calling for application of prior knowledge in biotechnology, mainly key concepts in the biotechnology curriculum, and general inquiry skills while using the bioinformatics tools: "It's great that we could integrate scientific concepts, connect between something in biochemistry like an enzyme activity, and what we see using the Jmol [bioinformatics tool]" (Teacher #1). They also mentioned their attempts to include general scientific skills: "We peppered the questions with more skills such as reading graphs…that are learned in the [school] lab" (Teacher #1). In the same line, the teachers referred to the importance of selecting bioinformatics tools that match the biotechnology curriculum: "It is also important that the bioinformatics tools suit the curriculum…Sequence alignment, for instance, is a central theme in the curriculum, while finding motifs in the gene is not, so I prefer to use the alignment tools" (Teacher #2).

A similar representation of questions calling for either biological or bioinformatics approaches, as well as inclusion of questions that coordinate both approaches, reflect teachers' acquired perception of a research approach as combining laboratory experiments and bioinformatics. This coordination between the research approaches in the assessment tool can be considered another aspect of the authentic scientific research, namely the way scientific knowledge is created and evaluated in the current era of biological sciences. Furthermore, this coordination may reflect teachers' desire to adapt the new curriculum by linking it to the existing 'traditional' one. These interpretations are supported by the analysis of the teachers' interviews. The inclusion of questions that coordinate biological subject matter and the bioinformatics approach was explained as "the whole issue here is to connect the biological approach and what you get by using the bioinformatics tools and biological knowledge!…the integration just jumped out at me! We must find out where the bioinformatics contributes" (Teacher #2). Another teacher explained that "actually we should place a hyphen connecting bioinformatics to biology" and added that "integration should be performed between the biological part, which is seemingly more external and extrovert, and the understanding of [bioinformatics and research] processes. If we'll limit the scenario to 'an enzyme was found' – why would the students think it is interesting?...the synapse [of biology and bioinformatics] should be discussed" (Teacher #1). Another teacher explained that "the hypothesis of the experimental approach is clear to me, but here we integrate a bioinformatics approach, so we have to be very accurate, to show the contribution of the integration" (Teacher #3), and added "the use of the bioinformatics tools did not scare us, but there is a need to connect what you find using the [bioinformatics] tools with the biological

knowledge that is deeply established in us…this is the way I’d like to teach it in class" as the other teachers nodded in agreement.
While reflecting on the process of developing the assessment tool, the teachers concurred that it was a long and enjoyable journey, during which they realized how difficult the process of developing authentic research-based materials is, while at the same time learning how to develop such a tool, what and how to assess, and by what means to analyze and classify the questions. Importantly, in the development of the assessment tool, each teacher could "express one's creativity, motivation, desire to contribute, and innovative ideas" (Teacher #2).

4. Discussion

A teachers' professional development program aimed at establishing a community of biotechnology teachers who collaborate in implementing the bioinformatics LE served as the context of this study. Teachers' knowledge and beliefs toward adopting contemporary bioinformatics-integrated research into their classrooms were assessed by both analysis and characterization of an assessment tool for the LE, which was constructed by the teachers, and by interviews to uncover the rationale behind the assessment tool's design and development. The analysis of the questions embedded in the assessment tool revealed that the teachers had integrated a considerable number of questions that require the use of conditional knowledge, a type of knowledge which is at the heart of performing authentic scientific research. Most of these questions require the coordination of multiple scientific reasoning practices. Similar representation of questions stemming from either biological or bioinformatics approaches, as well as inclusion of questions coordinating both approaches, reflected teachers’ acquired perception of a research approach as combining laboratory experiments and bioinformatics. These features indicate that the assessment tool represents characteristics of modern authentic scientific research (Chinn and Malhotra 2002; Falk and Yarden 2009; Gelbart and Yarden 2011), namely the way scientific knowledge is created and evaluated in the life sciences today. In this view, the assessment tool represents the teachers’ appropriation of the new curriculum in bioinformatics, through adoption of its authentic scientific research characteristics, and through expansion of its roots to the ‘traditional’ curriculum. Although these aspects of authentic and modern scientific research, namely the application of conditional knowledge as well as coordination between biological and bioinformatics approaches respectively, were part of the training program, the teachers intentionally adopted them as central to the design of the assessment tool. Evidently, these features are more abundant in the assessment tool as compared to the LE activities. The assessment tool developed by the teachers was in accordance with the goals of the bioinformatics curriculum; at the same time it comprehensively integrated and presented unique features of the bioinformatics field, which is rich in diverse procedural skills coupled with the declarative knowledge and analytical thinking required to understand and master bioinformatics approaches and applications (Wefer and Anderson 2008).
The design and development of an assessment tool for an innovative curriculum by teachers can serve as an appropriate means of linking and integrating contemporary and pioneering materials into existing scientific curricula. It can also support teachers' association with the new curriculum and expand their knowledge. Since the process of assessment tool development was central to the teachers program, it probably had a substantial impact on teachers' decision to adapt the new curriculum in bioinformatics and instruct their own students toward the matriculation examination. It may also have affected their orientation toward educational reforms and

professional development programs, as one teacher noted "I'm interested in being part of future programs of developing [educational] initiatives…from the perspective of my standards, I always want to be at the forefront, I do not want to lag behind…this is how I see myself!" (Teacher #4). Thus, it is recommended that key steps of the design and development of assessment tool or learning materials be integrated into professional development programs or training workshops for teachers.

References

Abrams, E. D. (1998). Talking and doing science: import ant elements in a teaching-for-understanding approach. In J. J. Mintzes W. J. H. Wandersee & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view* (pp. 307-323): San Diego, CA: Academic Press.

Alexander, P. A. and Judy, E. J. (1988). The interaction of domain-specific and strategic knowledge in academic performance. *Review of Educational Research*, 58 (4) 375-404.

Attwood, T. K. Gisel, A. Eriksson, N.-E. and Bongcam-Rudloff, E. (2011). Concepts, Historical Milestones and the Central Place of Bioinformatics in Modern Biology: A European Perspective, Bioinformatics - Trends and Methodologies, Dr. Mahmood A. Mahdavi (Ed.), ISBN: 978-953-307-282-1, InTech, DOI: 10.5772/23535. Available from: http://www.intechopen.com/books/bioinformatics-trends-and-methodologies/concepts-historical-milestones-and-the-central-place-of-bioinformatics-in-modern-biology-a-european-.

Brown, J. S. Collins, A. and Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher*, 18 (1) 32-42.

Buxton, C. A. (2006). Creating contextually authentic science in a "low performing" urban elementary school. *Journal of Research in Science Teaching*, 43 (7) 695-721.

Chinn, C. A. and Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, 86 175-218.

Cummings, M. P. and Temple, G. G. (2010). Broader incorporation of bioinformatics in education: opportunities and challenges. *Briefings in Bioinformatics*, 11 (6) 537-543.

European Union. (2006). Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning. *Official Journal of the European Union*, 30-12-2006 L 394/310-L 394/318.

Falk, H. Brill, G. and Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education*, 30 (14) 1841-1866.

Falk, H. and Yarden, A. (2009). "Here the scientists explain what I said." Coordination practices elicited during the enactment of the Results and Discussion sections of adapted primary literature. *Research in Science Education*, 39 (3) 349-383.

Fullan, M. G. (1993). Why Teachers Must Become Change Agents. *Educational Leadership*, 50 (6) 12-17.

Gallagher, S. R. Coon, W. Donley, K. Scott, A. and Goldberg, D. S. (2011). A First Attempt to Bring Computational Biology into Advanced High School Biology Classrooms. *PLoS Comput Biol*, 7 (10) e1002244.

Gelbart, H. and Yarden, A. (2006). Learning genetics through an authentic research simulation in bioinformatics. *Journal of Biological Education*, 40 (3) 107-112.

Gelbart, H. and Yarden, A. (2011). Supporting learning of high-school genetics using authentic research practices: the teacher's role. *Journal of Biological Education*, 45 (3) 129-135.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, 53 (1) 5-26.

Gupta, R. D. Goldsmith, M. Ashani, Y. Simo, Y. Mullokandov, G. Bar, H. Ben-David, M. Leader, H. Margalit, R. Silman, I. Sussman, J. L. and Tawfik, D. (2010). Directed evolution of hydrolases for prevention of G-type nerve agent intoxication. *Nature Chemical Biology*, 7 120-125.
Israeli Ministry of Education. (2005). Syllabus of biotechnological studies (10th-12th Grade). Jerusalem, Israel: State of Israel Ministry of Education Curriculum Center.
Lee, H. S. and Songer, N. B. (2003). Making authentic science accessible to students. *International Journal of Science Education*, 25 (8) 923-948.
Lewitter, F. and Bourne, P. E. (2011). Teaching Bioinformatics at the Secondary School Level. *PLoS Comput Biol*, 7 (10) e1002242.
Luehmann, A. L. (2007). Identity development as a lens to science teacher preparation. *Science Education*, 91 822-839.
Machluf, Y. Dahan, O. Shpalter-Avidan, C. Mitchel, A. and Yarden, A. (2011). Bioinformatics in the service of biotechnology, A web-based learning environment for biotechnology majors, http://stwww.weizmann.ac.il/g-bio/bioinfo. Rehovot, Israel: The Amos de-Shalit Israeli Center for Science Teaching.
National Center for Biotechnology Information [NCBI]. (2011). At http://www.ncbi.nlm.nih.gov/About/primer/bioinformatics.html (accessed 15 June 2011).
National Institutes of Health [NIH]. (2000). NIH working definition of bioinformatics and computational biology. Available: http://www.bisti.nih.govJuly 17, 2000].
National Research Council [NRC]. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
National Research Council [NRC]. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.
Parke, H. M. and Coble, C. R. (1997). Teachers designing curriculum as professional development: A model for transformational science teaching. *Journal of Research in Science Teaching*, 34 (8) 773-789.
Samarapungavan, A. Westby, E. L. and Bodner, G. M. (2006). Contextual epistemic development in science: A comparison of chemistry students and research chemists. *Science Education*, 90 (3) 468-495.
Shkedi, A. (2005). *Multiple case narrative: A qualitative approach to studying multiple populations.* Amsterdam: John Benjamins.
Shulman, L. (1987). Knowledge and Teaching: Foundations of the New Reform. *Harvard Educational Review*, 57 (1) 1-23.
Wefer, S. H. and Anderson, R. O. (2008). Identification of Students' Content Mastery and Cognitive and Affective Percepts of a Bioinformatics Miniunit: A Case Study With Recommendations for Teacher Education. *Journal of Science Teacher Education*, 19 (4) 355-373.
Wefer, S. H. and Sheppard, K. (2008). Bioinformatics in high school biology curricula: a study of state science standards. *CBE Life Sci Educ*, 7 (1) 155-162.
Yarden, A. (2009). Guest Editorial - Reading Scientific Texts: Adapting Primary Literature for Promoting Scientific Literacy. *Research in Science Education*, 39 (3) 307-311.
Yarden, A. and Carvalho, G. S. (2011). Authenticity in biology education: benefits and challenges. *Journal of Biological Education*, 45 (3) 118-120.