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CHARACTERIZING AND SCAFFOLDING THE ENACTEMENT OF ADAPTED PRIMARY LITERATURE BASED HIGH-SCHOOL BIOLOGY CURRICULA

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תודות

- למנחה שלי, פרופ' ענת ירדן שידעה לכוון, לדרוש ולהציב גבולות מבלי להגביל ולקצץ כנפיים, תודה על ההנחיה החכמה והקפדנית והליווי המקצועי ברמה הגבוהה ביותר במשך שמונה שנים מדהימות.

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- למורים שהסכימו להסתכן ולהתנסות בחומרים חדשים ולתלמידיהם שהשתתפו בשלבים הראשונים של הוראת הנושאים מבוססי ה-APL – תודה על האומץ והנכונות להיחשף בראיונות ובמהלך ההוראה.

- למשפחתי: אימי, בעלי וילדי, תודה על העידוד והתמיכה לאורך הדרך.

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ABSTRACT

Primary literature is a genuine text genre of science communication, written by scientists in order to communicate their findings to the scientific community. Adapted primary literature (APL) is an educational text genre that retains the characteristics of primary literature while adapting its content to the comprehension level of high-school students.

My work is the first comprehensive study of the enactment of APL in the naturalistic settings of the classroom, focusing at the same time on both students and teachers. I have developed an APL-based Biotechnology curriculum and a curriculum guide supporting the enactment of an APL-based Developmental Biology curriculum. My study aimed to characterize the class enactment of these curricula and the factors that influence it and are influenced by it. Teachers' instructional strategies and students' benefits and challenges were investigated in the context of the APL-based enactment. An additional important aim was to scaffold the enactment process at the teachers' and students' levels by designing educative curricular materials for teachers, which contain written and visual case studies. The development of these educative materials and the investigation of their impact on the enacting teachers was an additional, practical, aim of this study.

Teaching sessions of different teachers [n=20] enacting the Biotechnology curriculum were video-recorded and transcribed. The class discourse was analyzed at several resolution levels. Post-enactment interviews were performed with the teachers enacting the two APL-based curricula and group interviews were performed with the students of some of their classes [n=97]. The interviews were analyzed using a narrative constructivist procedure for multi-case analysis. I focused my analysis on different samples of teachers enacting each of the two APL-based curricula and possessing different levels of content knowledge and inquiry experience.

My findings indicate that a complex interaction of factors, namely teachers' pedagogical content knowledge, the APL genre and the content of the curriculum, shaped the outcomes of the enactment. The Conversational model developed in the course of this study was found adequate for the enactment of APL and for promoting learning by inquiry. Teachers used diverse instructional strategies depending, among the others, on the part of the curriculum and on the section of the article enacted. A

main characteristic of primary literature and of APL is the different scope and style of the different article sections. The teachers seem to have been able to draw on this characteristic and enhance it by varying their strategies, sometimes reaching a synergistic effect. Even for the enactment of the same article sections, teachers used different enactment models in order to support the different benefits and minimize the respective limitations of each model.

Cognitive and affective engagement, active learning and inquiry thinking were among students' main benefits in the context of APL enactment, as remarked by teachers, students and by our own observations. During the lessons enacted by exemplary teachers, students exhibited different inquiry aspects: they designed an experiment, predicted the experimental results, discussed their practical aspects, they explored the role of the presented methods and their components and suggested alternative methods, and they analyzed the theoretical basis of methods, analyzed graphs and drew conclusions. The students applied a copious number and a high diversity of coordination practices by which they connected elements possessing different epistemic status or located in different contexts: theory, data, experimental stages, text. The coordination practices had an important role in the process of students' meaning-making of the APL text and were associated with the display of inquiry aspects and with students' expressed claims of difficulty.

Students' difficulties were mainly linked to the comprehension of complex, multi-stage, molecular processes and methods that are abundant throughout the curriculum and required the use of previous knowledge in new contexts. Coordination practices were applied both in the context of utterances exposing the difficulties and in the context of discussions that attempted to solve the difficulties. It seems that complex educational contexts like APL, because of the challenges posed, carry the promise of promoting beneficial gains like the performance of coordination practices and inquiry aspects. However, in order for these gains to occur, teachers have to use adequate instructional strategies, thus, stressing the importance of developing suitable scaffolding tools, for both students and teachers. We showed the usability of the curriculum guide for the Developmental biology curriculum and the benefits incurred to teachers by the video-taped case studies included in the guide.

סיכום

מאמרי מחקר (ספרות ראשונית) מהווים סוגה אותנטית של כתיבה מדעית. מאמרי מחקר נכתבים על ידי מדענים, על מנת לפרסם את ממצאיהם לעמיתיהם בקהילה המדעית. מאמרי מחקר מעובדים (Adapted APL –primary literature) שייכים לסוגה שפותחה למטרות לימודיות. הם משמרים את המאפיינים של מאמרי המחקר, תוך התאמת התכנים לרמת ההבנה של תלמידים בחטיבה העליונה.
העבודה שלי חוקרת לראשונה הפעלת חומרי למידה המבוססים על APL בסביבה הטבעית של הכיתה, תוך התמקדות בתהליכי ההוראה והלמידה. פיתחתי תוכנית לימודים בביוטכנולוגיה המבוססת על APL ומדריך למורה התומך בהפעלת תוכנית לימודים בביולוגיה התפתחותית המבוססת על APL. מטרת המחקר הנוכחי היא לאפיין את הפעלת שתי תוכניות הלימודים הללו בכיתה, תוך התמקדות בגורמים המשפיעים על הפעלה זו ומושפעים ממנה. במסגרת בחינת הפעלת תוכניות הלימודים מבוססות ה-APL, התמקדתי הן באסטרטגיות ההוראה של המורים והן בתרומת ההפעלה לתלמידים ובקשיי ההתמודדות שלהם. מטרה חשובה נוספת של המחקר הייתה לסייע לתהליך ההוראה והלמידה, באמצעות פיתוח חומרים קוריקולריים עבור מורים. החומרים כללו קטעי הוראה (case studies), המוצגים באופן מילולי וחזותי. פיתוח חומרי העזר הללו והבנת אופני השפעתם על המורים המפעילים את התוכנית, היוו פן יישומי נוסף של המחקר שלי.

איסוף הנתונים התבסס על תיעוד מצולם בווידאו של מורים (N=20) המפעילים את תוכנית הלימודים בביוטכנולוגיה בכיתותיהם. השיח הכיתתי שוקלט במלואו ונותח בכמה דרגות הפרדה. בנוסף, נערכו ראיונות עומק עם המורים לאחר הפעלת התוכנית בכיתותיהם, וראיונות קבוצתיים עם חלק מתלמידי מורים אלו (N=97). ניתוח הראיונות בוצע במתודולוגיית נרטיבית קונסטרוקטיביסטית לחקר מקרים מרובים. מיקדתי את הניתוח במדגמים שונים של מורים, הנבדלים זה מזה בתוכנית שהופעלה, ברמת הידע הפורמלי של המורים ובניסיונם במחקר.

הממצאים שקיבלתי מצביעים על כך שישנו מערך מורכב של גורמים המשפיעים על תוצאות ההפעלה. מערך זה כולל את הידע הפדגוגי-תוכני של המורים (Pedagogical content knowledge – PCK) , מאפייניו הייחודיים של סוגת ה-APL והתוכן של המאמרים. מודל הדו-שיח שפותח במהלך המחקר נמצא מתאים להפעלת החומרים המבוססים על APL ולקידום למידה בדרך החקר. המורים השתמשו גם באסטרטגיות הוראה נוספות, באופן התלוי, בין היתר, בחלקים של הקוריקולום ושל המאמר שהם הפעילו באותו שלב. אחד המאפיינים העיקריים של מאמרי המחקר ושל ה-APL הוא ההבדל ביעד הנרטיבי ובסגנון הכתיבה של חלקי המאמר השונים. המורים התבססו על מאפיין זה והתאימו אליו את אסטרטגיות ההוראה שלהם, בדרכים שהבליטו את ההבדלים בין החלקים, וכפועל יוצא אף השיגו לעיתים אפקט סינרגיסטי. המורים השתמשו באסטרטגיות מרובות גם במסגרת חלקים ספציפיים של המאמר, וזאת על מנת לקדם תרומות מגוונות עבור התלמידים, ועל מנת למזער את המגבלות הכרוכות בכל אסטרטגיה מופעלת. בהסתמך על דיווחי המורים והתלמידים ועל התצפיות שלנו, התרומה העיקרית של ה-APL לתלמידים הייתה גירוי קוגניטיבי (Cognitive engagement), יצירת מעורבות רגשית, למידה פעילה ופיתוח חשיבת חקר.
במהלך שיעורים שהופעלו על ידי מורים לדוגמא, תלמידים הפעילו היבטים שונים של חקר: הם תכננו

ניסויים, ניבאו את התוצאות שלהם ודנו בהיבטים היישומיים של התוצאות. כמו כן, הם חקרו את התפקיד של שיטות העבודה השונות שהוצגו במאמר ושל המרכיבים שלהם ואף הציעו שיטות חלופיות. הם ניתחו את הבסיס התיאורטי של שיטות העבודה, ניתחו גרפים והסיקו מהם מסקנות. התלמידים הפעילו מספר רב ומגוון של קואורדינציות, בהן קישרו בין מרכיבים בעלי מעמד אפיסטמי שונה או ממוקמים בהקשרים שונים: תיאוריה, תוצאות הניסוי, שלבי המחקר והטקסט. לקואורדינציות שהופעלו על ידי התלמידים היה תפקיד חשוב בתהליך הבנת מאמרי ה-APL והקניית המשמעות לתוכנם. הן היו מקושרות עם הצגת היבטי חקר ועם ביטויים של הבעת קושי מצד התלמידים. הקשיים של התלמידים היו בעיקר קשורים להבנתם של שיטות ותהליכים מולקולריים רב-שלביים ובעלי מורכבות גבוהה. במאמרים מוצג מספר גבוה יחסית של שיטות מסוג זה ולשם הבנתם נדרש ישום של ידע קודם בהקשרים חדשים. הקואורדינציות הופעלו על ידי התלמידים הן כדרך לבטא את הקשיים שהתעוררו והן במהלך הדיונים שנועדו לפתור קשיים אלו.

באופן כללי, נראה שדווקא בזכות הקשיים שהם מעוררים, בחומרי למידה בעלי מורכבות גבוהה כמו ה-APL יכולות להיות תועלות רבות עבור התלמידים, כגון הפעלת קואורדינציות והפגנת היבטי חקר. אולם, על מנת שתרומות אלו יבואו לידי ביטוי, על המורים להשתמש באסטרטגיות הוראה מתאימות. תובנה זאת מדגישה את הצורך בפיתוח חומרים התומכים בתהליכי הלמידה וההוראה. הראנו את הישימות של מדריך למורה עבור תוכנית הלימודים בביולוגיה התפתחותית המבוססת על APL, ואת התועלות המוקנות למורים בקטעי ההוראה המצולמים שנכללים במדריך.

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Structure of the Ph.D. thesis

The thesis consists of four parts:

Part 1 begins with a general introduction including the rationale of the research, its theoretical background, main goals and research questions. They are followed by an overview of the research context and by the presentation of the research methodology.

Part 2 consists of five papers preceded which together form the main body of this study:

- Three articles - two of them published (Papers 1 & 4) and one submitted (Paper 2) to peer reviewed journals.
- A peer reviewed conference proceeding published in a conference proceedings book (Paper 3)
- A conference synopsis describing an ongoing project (Paper 5).

The papers are ordered according to the rationale of the thesis, as presented below, which is sometimes different from the chronological order of their submission or publication.

This part starts with an overview and a scheme presenting the two main directions of my research.

Paper 1

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

Paper 2

Falk, H. & Yarden, A., Stepping into the unknown: three enactment models for the opening sections of scientific articles (*submitted to The American Biology Teacher*).

Paper 3:

Falk, H., Brill, G., & Yarden, A. (2005). Scaffolding learning through research articles by a multimedia curriculum guide. In M. Ergazaki, J. Lewis, & V. Zogza (Eds.), *Proceedings of the Fifth Conference of European Researchers in Didactic of Biology (ERIDOB).* Patras, Greece.(pp 175-192)

Paper 4

Falk, H., & Yarden, A., (2009a). “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.

This article is included in a Special Issue devoted to the adaptation of primary literature for promoting scientific literacy. Collective rejoinders of the authors to two commentary articles included in the same issue are attached as appendices.

Paper 5

Falk, H., & Yarden, A., (2009b). Inquiry aspects in the context of adapted-primary-literature (APL) enactment discourse. (Paper presented at the European Science Education Research Association – ESERA conference, Istambul).

Part 3 includes a general discussion on the main findings of the thesis, followed by the presentation of a summarizing model of the APL-based enactment, the limitations of the study and its educational and research implications.

Part 4 includes several appendices related to the developed APL-based curricula and to the investigational context of my research.

PART 1 - INTRODUCTION

1-1. Rationale

Since primary literature is a genuine genre of science communication (Mallow, 1991; Beall & Trimbur, 1999), reading and analyzing primary literature are authentic scientific cognitive activities (Dunbar, 1995; Chinn & Malhotra, 2002). Schwab (1962) previously suggested that studying using primary literature could promote "enquiry into enquiry" and recommended the adaptation of articles posing comprehension difficulties.

Adapted primary literature (APL) is a novel educational text genre that retains the characteristics of inquiry articles while adapting their contents to the comprehension level of high-school students (Yarden, Brill & Falk, 2001). APL-based curricula are authentic-context inquiry curricula, dealing with cutting edge biological research. They have been incorporated as an elective subject into the new syllabus for high-school biology majors in Israel, in order to enhance students' inquiry skills and their understanding of the nature of science (Israeli Ministry of Education, 2003). A significant gap has been described between scientists' research and school inquiry and specific types of educational interventions have been suggested to contribute to closing this gap (Chinn & Malhotra, 2002). Therefore, viewing science learning as a process of epistemic apprenticeship, through which students appropriate scientists' criteria of evaluating knowledge, i.e. adopt scientifically authentic epistemic practices, is gaining support in science education (Kelly, 2008). The fact that APL-based curricula provide students with a scientifically authentic context, does not necessarily imply that they promote students' reasoning and discursive practices of scientists. An important question seems to be if and in what manner APL-based curricula can indeed promote scientifically authentic inquiry.

In the process of enacting APL-based curricula, teachers are required to cope both with new content knowledge and with the promotion of inquiry learning and application of authentic scientific practices. The challenges expected for APL enactment at the students' and the teachers' levels call for appropriate scaffolding of both. Two types of scaffolding are relevant for the promotion of the educational goal of APL-based curricula: teachers' scaffolding of their students during the enactment and the curriculum developers' scaffolding of the enacting teachers.

Several years ago, we developed an APL-based curriculum in developmental biology:

"The secrets of embryonic development – study through research" (Yarden & Brill, 1999; Yarden et al., 2001), further referred herein as the Developmental Biology Curriculum. Subsequently, we developed another APL-based curriculum on biotechnology topics: "Gene tamers – studying biotechnology through research", further referred herein as the Biotechnology Curriculum (Falk, Piontkevitz, Brill, Baram & Yarden, 2003). Both curricula are based on molecular biology knowledge.

My research is the first multidimensional study of the class enactment of APL-based curricula. Its major analytical objectives focus on the characterization of interactions prevalent in the context of the enactment between the teacher, the students and the curricular material and the outcomes of these interactions. Its major applied objectives focus on the scaffolding of the APL-based curricula enactment at the students' and teachers' levels.

The broad scope of my research was associated with:

- the novelty of the APL genre and its enactment
- the multidimensionality of class studies as opposed to controlled experiments
- our need for multilevel enactment data in order to design students' and teachers' scaffolding tools

1-2. Theoretical background

1-2-a Overview of the theoretical background

The broad scope of my study required the consideration of a similarly broad array of theoretical perspectives. The characterization of the enactment process was based on both cognitive (Ausubel, 1968) and socio-cultural (Greeno, Collins & Resnick, 1996) learning theories. We adopted the view that these theories should be used in a complementary rather than competitive manner when analyzing learning processes in the social setting of classrooms (Cobb, 1994; Driver, Asoko, Leach, Mortimer & Scott, 1994; Leach & Scott, 2003).

My research on students' science learning in the context of APL is based on three interrelated theoretical dimensions**.** The first dimension refers to scientific literacy, in its fundamental and derived senses (Norris & Phillis, 2003). The second dimension refers to the two aspects of inquiry learning, learning science as inquiry and learning by inquiry (Tamir, 1985a). The third one refers to the role of authentic inquiry interventions in closing the gap between real-world science and school inquiry (Chinn

& Malhotra, 2002). The possibility that the scientifically authentic context of APL can promote students' authentic inquiry is a benefit of the APL-based curricula to be assessed and promoted in the course of this study.

My research on the teaching aspects emerging in the context of APL is based on components of pedagogical content knowledge (PCK) (Shulman, 1986; van Driel, Verloop & de Vos, 1998) in general, and of inquiry-based teaching in particular (Crawford, 2000; Crawford, 2007). Theories analyzing the characteristics of the classroom discourse (Lemke, 1990; Mortimer & Scott, 2003) have been addressed as well.

The analysis of students' scaffolding by their teachers when enacting an inquiry intervention was based on theories referring to distributed scaffolding between the teacher and the inquiry tools (Puntambekar & Kolodner, 2005).

Finally, the theories of Ben-Peretz & Tamir (1981) and Shkedi (1995) were considered for the design of teachers' scaffolding by educational materials.

1-2-b Scientific literacy

Scientific literacy is one of the main goals of the contemporary effort to educate the citizens of tomorrow towards decision-making (American Association for the Advancement of Science (AAAS), 1993; National Research Council, 1996; Norris & Phillis, 2003). The multiple aspects of scientific literacy have been extensively studied, as reviewed by (DeBoer, 2000; Laugksch, 2000). Norris and Phillips (2003) suggested two distinct meanings of scientific literacy: the fundamental sense, which is the ability to read, interpret and write a scientific text, and the derived sense, which is the knowledge of scientific ideas and the ability to use them in a scientific manner. These two meanings of scientific literacy are not concurrent but dialectic, as they support and complement each other (Norris & Phillis, 2003). The emerging idea is that the fundamental sense, often neglected, is critical in supporting the derived sense. This neglect stems from the strong apprehension about the use of texts in school science, particularly in the inquiry science tradition (Cervetti, Pearson, Bravo & Barber, 2006); therefore, text has not typically been situated in the context of science curriculum and pedagogy (Palincsar & Magnusson, 2000). The opposite is also true because: “How, for instance, can we imagine interpreting a science text by making interconnections throughout the text (an activity we have associated with the fundamental sense) without being knowledgeable of the substantive content of science (literate in the derived sense)?” (Norris & Phillis, 2003).

One of the aspects of the derived sense of scientific literacy is the ability to think scientifically (DeBoer, 2000). Since, from an epistemological perspective, inquiry is simply the process of doing science (cf., Schwab, 1962), we regard inquiry thinking as one aspect of the derived sense of scientific literacy.

1-2-c Inquiry learning

Inquiry refers to "the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Linn, Davis & Bell, 2003).

Inquiry learning has been established as one of the main goals of school science (National Research Council [NRC], 1996)**.** It has been classified as learning science as inquiry and learning by inquiry (Tamir, 1985a). Learning science as inquiry has been suggested as learning about the way in which the scientific endeavor progresses, and analyzing the inquiry process performed by others, sometimes using historical perspectives (Schwab, 1962; Bybee, 2000). When learning science as inquiry, students use scientific reports and analyze various stages of the investigation process, in order to learn about some of the conclusions of science ‘in the framework of the way they arise and are tested’ (Tamir, 1985a). This aspect is similar to what have been often referred as understanding the nature of science (NOS), and is found at the core of scientific literacy (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; Schwartz, Lederman & Crawford, 2004).

Learning by inquiry (Bybee, 2000), or learning ‘the abilities necessary to do scientific inquiry' (National Research Council, 1996), involves the learner in performing inquiry activities, similar to those of scientists. Although no complete agreement exists on what are these activities, the inquiry aspects emerging from an up-to-date scientists' and educators' compilation include (Grandy & Duschl, 2007): posing, refining and evaluating questions; designing, refining and interpreting experiments; making observations; collecting, representing and analyzing data; relating data to hypotheses/models/theories; formulating hypotheses; learning and refining theories and models; comparing alternative theories/models with data; providing explanations; giving arguments for/against models and theories; comparing alternative models; making predictions; recording, organizing and discussing data; discussing and explaining theories/models; writing and reading about data/ theories/models. These authors emphasize the fact that in contrast to more traditional definitions of inquiry (Tamir, 1985a; National Research Council, 1996; Zohar, 2000), the inquiry aspects included above focus on epistemic and social tasks as well, in addition to the cognitive aspects. This aspect will be further referred to when discussing the dimensions of authenticity to be pursuit in educational settings.

More than 40 years ago, Schwab suggested 'enquiry into enquiry' meaning combining the two aspects of inquiry learning, learning science as inquiry and learning by inquiry as an optimal approach to promote inquiry learning, claiming that: "The complete enquiring classroom would have two aspects. On the one hand it would exhibit science as enquiry. On the other hand, the student would be led to enquire into these materials" (Schwab, 1962).

Different types of educational interventions have been designed in order to promote students' inquiry learning; most of them can be categorized into firsthand and second-hand investigations (Palinscar and Magnusson, 2000). First-hand investigations allow students to solve problems themselves, via hands-on projects (Zion et al., 2004), laboratory work (Kanari & Millar, 2004), or computerized simulations (Lee & Songer, 2003). Second-hand investigations present students with results that have been obtained by scientists (Hug & McNeill, 2008): most of these interventions are presented through software resources and only a few make use of texts (Hapgood, Magnusson & Palincsar, 2004).

In spite of the diverse inquiry-based curricula designed and investigational efforts invested, even today the aim of inquiry learning seems far from being accomplished, as 'most evidence indicates that science teaching is not now, and never has been, in any significant way, centered on inquiry whether as content or as a technique' (Bybee, 2000). Several interrelated challenges seem to impede the large scale enactment of inquiry learning. I will refer to the challenges associated with the need to implement new, inquiry-based curricula by inquiry-based teaching and with the existent gap between school inquiry and authentic scientific inquiry. I will look into these two aspects in order to later explore the way by which APL-based curricula enactment could address and alleviate some of the challenges related to them.

1-2-d Implementation of inquiry-based curricula by inquiry-based teaching

The usability of new inquiry-based curricula is challenged by factors like the capability of local settings, the policy and management climate and the culture prevailing in the specific school or class (Fishman and Krajcik, 2003). In addition, inquiry curricula, have in many cases been considered "boutique projects" supported by their developers and implemented in suitable settings only by maverick teachers, who are considered as self starters and risk taking (Squire, MaKinster, Barnett, Luehmann & Barab, 2003). Therefore, recent curricular studies persistently require educational reforms in order to move beyond this stage, by promoting the diffusion of inquiry curricular innovations to many diverse classrooms (Songer, Lee & McDonald, 2003).

Teachers play a crucial role in the diffusion of curricular innovations (Remillard, 1999; Barab & Luehmann, 2003; Songer et al., 2003). Maximum success is achieved when teachers "reinvent" the curriculum in ways that are consistent with the developers' rationale (Fishman & Krajcik, 2003). At the same time, imposed reforms run the risk of failing if teachers do not accept or understand the innovation, because commitment to change cannot be prescribed from outside, it must come from inside (Pinto, 2005). Teachers' ways to respond to an innovation are influenced by their knowledge and beliefs about the subject matter, by their beliefs about their own identity, about studying and teaching and by contextual constrains (Pinto, 2005). Implicit or explicit comparison between the innovation and the previous curriculum and acceptance of change is seen by the teachers in the perspective of their students' interests and difficulties (Pinto, 2005).

An additional reason that new inquiry-based curricula are challenging for teachers, is because they require inquiry-based teaching, based on a high level of PCK (Crawford, 2000). Teachers' PCK encompasses their interpretations of subject-matter knowledge in the context of facilitating students' learning, as well as their beliefs, aims, instructional strategies, and understanding of students' conceptions and challenges (Shulman, 1986; van Driel et al., 1998). The PCK necessary for inquiry-based teaching requires a deep understanding of the NOS, of disciplinary content knowledge and of inquiry learning, and the ability to coach and collaborate with students (Crawford, 2000; Anderson, 2002; Schneider, Krajcik & Blumenfeld, 2005). To enact science as inquiry requires that teachers model actions of scientists, develop approaches that situate learning in authentic problems and support students in making sense of data and develop their personal understandings of science concepts (Crawford, 2000). To this aim, teachers' discourse and communicational approach are important as well. For example, specific types of teachers' questions like the reflective toss (van Zee & Minstrell, 1997) and the alternation between teacher's authoritative and dialogic communicational approach (Scott, Mortimer & Aguiar, 2006) have been found to be associated with the promotion of inquiry learning. While the discourse sequence of Initiation-Response-Evaluation (IRE) prevails in traditional authoritative enactment (Mehan, 1979), inquiry-based teaching is mainly associated with different discourse patterns like Initiation-Response-Response (I-R-R-R) (Scott et al., 2006) or Initiation-Response-Follow-Up (I-R-F) with no explicit evaluation, similar to the discourse taking place in scientific communities (Chin, 2006).

There is a growing consensus that students involved in inquiry learning require a significant support (Edelson, Gordin & Pea, 1999; Linn & Hsi, 2000; Tabak & Baumgartner, 2004). Scaffolding refers to the titrated support that helps learners perform tasks that are outside their independent reach and consequently develop the skills necessary for completing such tasks independently (Rogoff, 1990). Some of the inquiry-based teaching strategies involve teachers' scaffolding the students' use of inquiry promoting interventions. The scaffolding process can structure the intervention by simplifying it (Reiser, 2004), for example by dividing it into simpler to comprehend segments. A different, seemingly opposite scaffolding pattern is by problematizing, when the teacher is presenting a more complex picture, for example by requiring the students to perform an inquiry process not necessarily required by the intervention itself (Reiser, 2004).

Considering the complexity of the above described requirements for inquiry–based teaching, it is not surprising that less experienced teachers claim to be unable to promote it, even after specifically coached to do so (Blanchard, Southerland & Granger, 2008).

Israel can be credited with some examples of successful implementation of inquiry curricula due to the high level of openness to innovations that shaped also the policy of the Ministry of Education that initiated and promoted the innovative ideas (Tamir, 2004). Since the implementation of the Biological Sciences Curriculum Studies curricula in Israel in the early 1970s, the Israeli syllabus for high-school biology majors has emphasized, in addition to the acquisition of content knowledge, the acquisition of inquiry-thinking skills (Tamir, 1985b). For example, activities such as laboratory exercises, research projects and analysis of unfamiliar excerpts from scientific articles (Tamir, 2004; Zion et al., 2004) have become an integral part of both the curricula and the assessment of biology majors (Tamir, 1985b). Nevertheless investigations in Israeli high-school biology classes have shown that although inquiry elements are prevalent among teachers' declared statements, and inquiry questions permeate assessment tools and homework assignments, inquiry is not as salient in the classroom discourse (Zohar, Schwartzer & Tamir, 1998). In order to remediate this situation it was suggested to introduce more inquiry-based curricula (Zohar et al., 1998). In this context, it is important to establish what conditions are necessary in order to allow teachers to reinvent these inquiry-based curricula as intended by their developers, by inquiry-based teaching? Since we consider APL-based curricula to be inquiry oriented, this question is relevant for their enactment.

The burden of increasing flexibility and adaptability of a curriculum in order to encourage the curriculum ownership and reinvention by the teachers, its adopters, lies with the developers (Squire, MaKinster, Barnett, Luehmann & Barab, 2003). Educative curriculum materials for teachers as well as workshops and community models of learning may provide a suitable scaffolding for "faithful reinvention" of the curriculum (Ball & Cohen, 1996; Loucks-Horsley, Hewson, Love & Stiles, 1998; Davis & Krajcik, 2005).

1-2-e The gap between science and school inquiry

Another important aspect affecting inquiry learning is the gap that has been observed between real-science inquiry and school inquiry. "Most students, in the course of ten or more years of what is called "science education" in school, never meet a scientist, never observe science being done in the laboratory or the workplace, never see samples of professional scientific or technical writing, never hear the language of science in use for its normal social functions, never come into contact with the equipment, processes, practices, and social and economic realities of science as a human activity. They encounter simulacra of the subjects and objects of science:

science teachers in place of working scientists and technologists, textbook discourse in place of the spoken and written language of working science … school laboratory exercises in place of professional investigative practices; efforts to solve problems that have no real contexts, no real parameters, no realistic complications; study of examples that are idealized, oversimplified, decontextualized." (Lemke, 1993)

Moreover, the cognitive processes needed to succeed in many school inquiry tasks are often qualitatively different or even antithetical to the cognitive processes and epistemology needed to engage in real scientific research (Chinn & Malhotra, 2002). The analysis of scientists' practices indicates several interconnected attributes: complexity (Chinn & Malhotra, 2002), application of coordination between data and theory (Perkins & Simmons, 1988; Hogan & Maglienti, 2001; Chinn & Malhotra, 2002), use of argumentative rhetoric (Latour & Woolgar, 1986) and reading and writing as an integral component of the scientific research (Dunbar, 1995; Norris & Phillips, 2003; Norris & Phillips, 2008). These and additional epistemic frameworks used when developing and evaluating scientific knowledge and the social processes and contexts that shape how knowledge is discovered are almost ignored in school inquiry (Grandy & Duschl, 2007). For example, as compared to the complexity of real-world science, school usually oversimplify the nature of observations and theory (Chinn & Malhotra, 2002; Grandy & Duschl, 2007).

1-2-f Scientific texts as components of inquiry–based curricula

The aforementioned theories pointed some of the problematic at the students and teachers levels, affecting inquiry learning. Since it was suggested that the fundamental sense of science literacy, reading and meaning-making of science texts, is affecting its derived sense (Norris & Phillis, 2003), could the enactment of curricula based on scientific texts promote some of the benefits of inquiry learning and alleviate some of the challenges? What genre of scientific texts could achieve this aim and how should they be used?

Scientific texts serve scientists, the general public, science educators and students (Goldman & Bisanz, 2002). While scientists are mainly reading and writing research articles (primary literature), in order to communicate their findings to the scientific community (Mallow, 1991; Beall & Trimbur, 1999; Chinn & Malhotra, 2002), textbooks are the prevalent genre of scientific communication in educational contexts

(Yarden, 2009). The use of media scientific reports has also begun to diffuse into the school science curricula (Jarman & McClune, 2002; Kachan, Guilbert & Bisanz, 2006). In contrast to text-books, the different genres of scientific articles offer specific examples of up-to-date research and do not follow the hierarchy of the relevant knowledge domain.

Schwab claimed that genuine and excerpted primary literature texts can be an optimal intervention for promoting inquiry learning (Schwab, 1962). "Papers by scientists reporting scientific research have two major advantages as materials for the teaching of science as enquiry. One advantage is obvious. They afford the most authentic, unretouched specimens of enquiry that we can obtain … The second advantage of original papers consists in the richness and relevance of the problems they pose for enquiry into enquiry. The papers which pose an excessive problem of reading can be edited, excerpted and 'translated'".

Several characteristics of primary literature seem to be relevant for assessing its possible contribution to inquiry learning. Reading and analyzing primary literature is an authentic scientific cognitive activity, as scientists' conclusions are grounded in the theoretical and empirical work of other scientists (Dunbar, 1995; Chinn & Malhotra, 2002). The canonical structure of the primary literature genre (Abstract, Introduction, Methods, Results, Discussion) reflects the discipline's norms, values and ideology (Yore, Hand & Prain, 2002). The sections of research articles have different rhetoric roles (Swales, 2001): while the Results section belongs, together with the Methods, to those sections of an article that deal with the particulars of the study, the Introduction and the Discussion connect between the claims of the specific research and previous experiments, in the context of the general knowledge domain (Swales, 2001). A central communicative feature of primary literature is the use of multiple representations, including graphical ones (Lemke, 1998), to display the experimental results that are often ambiguous or anomalous (Myers, 1992), and can contradict each other or the investigators' hypothesis, unlike the 'clean' data that students are usually exposed to in text-books (Chinn & Malhotra, 2002).

Learning through primary literature at the university and college level has indeed been shown to have many benefits, the main ones being exposure to the nature of scientific reasoning and communication, critical reading, practice in writing and analytical skills, improved design of the students' own research projects and gained confidence in their ability to reason, research and apply knowledge (Epstein, 1970; Janick-Buckner, 1997; Bandoni Muench, 2000). At the same time, attributes of primary literature contribute to make learning through it a challenge and a difficult task for novices, requiring adequate adaptation in order to be employed as a basis for high school curricula (Yarden et al., 2001).

Adapted primary literature (APL) refers to an educational genre specifically designed to enable the use of research articles for learning biology in high school. The adaptation process of APL maintains the original structure of the articles, while adapting the contents to the cognitive and knowledge level of high-school students (Yarden et al., 2001). Briefly, the Introduction is modified to give the novice reader basic background information that was either omitted from or simply quoted in the original paper; the main principles of the Methods are described, while details of amounts, solution compositions, and so on, are omitted; the Results are kept authentic, although offshoots of the main research question are omitted; the main figures are kept, with slight modifications; and, finally, the Discussion is expanded so that students can understand it more easily (Yarden et al., 2001). Since reading, writing and analyzing primary literature are authentic scientific practices, learning through APL provides an authentic scientific context. At the same time, since APL presents students with data obtained through others' research, it can also be ascribed to text-based second-hand inquiry (following Palinscar & Magnusson, 2001).

The syllabus for biology major studies in Israel includes three compulsory core topics (Systems in the human body, Ecology, and Cell biology). In addition, students are required to learn two elective topics. One of the elective topics that teachers can choose is based on APL and is entitled Research Topic (NOSE MEHKARI) (Israeli Ministry of Education, 2003). Congruent with the recommendations of the syllabus, we developed two APL-based curricula:

the Developmental Biology curriculum, "The secrets of embryonic development: study through research" (Yarden & Brill, 2000) and the Biotechnology curriculum, "Gene tamers – studying biotechnology through research" (Falk et al., 2003). While the Developmental Biology curriculum employs a basic scientific approach, the Biotechnology curriculum deals with the application of molecular biology knowledge to problem solving.

1-2-g Closing the gap between scientific research and school inquiry – the possible role of APL enactment

Epistemic practices are defined as cognitive and discursive practices that are central to the processes of constructing, analyzing, communicating and appropriating knowledge (Sandoval & Reiser, 2004). These are the specific ways by which members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework (Kelly, 2007). Therefore, in order to attempt to close the gap between scientific research and school inquiry, it is important to engage the students in authentic scientific tasks promoting scientifically authentic epistemic practices (Dewey, 1964; Edelson et al., 1999; Chinn & Malhotra, 2002).

Coordinating between data and theory is a key epistemic practice associated with authentic scientific inquiry (Perkins & Salomon, 1989; Chinn & Malhotra, 2002). Therefore, the promotion of data-theory coordination is considered an important aspect of science instruction (Sandoval, Bell, Coleman, Enyedy & Suthers, 2000). Nevertheless, it is a problematic epistemic practice for students: it has been shown that graduate students are challenged by the need to apply data-theory coordination in the context of their laboratory practice (Havdala & Ashkenazi, 2007). Coordination is also a challenging requirement of reading scientific articles, since much of the difficulty in interpreting scientific text may lie in a failure to grasp the implied connections between one statement and the next (Myers, 1991). Although the term coordination (Chinn & Malhotra, 2002) is used extensively in the science education literature, several other terms are also used when referring to similar cognitive processes: e.g., interconnection (Norris & Phillis, 2003), relation building (Myers, 1991), and ‘linking’ between theory and data (Havdala & Ashkenazi, 2007). We have unified and widened the scope of this term by defining "coordination practices" as including the connections made between elements belonging to different epistemic status (data, theory, experimental stages, biotechnological applications, text) or between the same elements situated in different contexts.

Although, as presented above, an important aspect of participating in science is learning the epistemic practices of the scientific community (Kelly, 2007), the school setting is inherently different from the world of science, the differences laying, among others, in the students' discipline content knowledge, their motivational goals, commitment, resources and social organization (Edelson, Gordin & Pea, 1999; Chinn

& Malhotra, 2002; Lee & Songer, 2003). Therefore, it is important to understand which of the practices attributed to scientific research should be used in educational interventions and how to design authentic curricular contexts to be used in the non-authentic school setting, in order for students to reach scientifically authentic learning outcomes. Past calls for promoting the acquisition of inquiry skills using hands-on activities are now being replaced by calls to promote the rhetoric of science based on criticism and argumentation when seeking evidence and reasons for the ideas or knowledge claims i.e. (Jimenez-Aleixandre, Buggalo Rodriguez & Duschl, 2000). It has been suggested that practical experimental work should be mainly valued in school science for the role it plays in providing evidence for knowledge claims (Millar & Osborne, 1998), since "manipulating the material world and gathering experimental data is always a subsidiary scientific activity to the rational activity of constituting knowledge claims" (Driver, Newton & Osborne, 2000). Thus, the contribution of second-hand investigations, which present students with the results that have been obtained by others (Palincsar & Magnusson, 2000), is enforced by the concept that much of what scientists know has been acquired through the thoughts and experiences of others – that is through learning in a second-hand way.

Could APL, as an authentic scientific genre, presenting text-based second-hand inquiry, yield students' scientifically authentic practices like coordination practices? Could this genre yield different aspects of inquiry learning and answer the two senses of scientific literature? If this is the case, what conditions are required for their emergence?

Several investigations have been performed on the reading and enactment outcomes of the APL genre. Based on class observations in the context of the Developmental Biology curriculum enactment, it was observed that high-school students tend to pose questions that reveal a higher level of inquiry thinking and uniqueness (Brill & Yarden, 2003). It was also observed that high-school biology students who read an APL text understood better the nature of scientific inquiry and raised more scientific criticism on the researchers' work compared with students who read a popular scientific text on the same subject (Baram-Tsabari & Yarden, 2005).

On the basis of these initial results, I began a comprehensive study of students' and teacher's enactment aspects of APL, in whole-class setting.

The whole-class setting, still the most prevailing educational setting, is a complex and messy environment graphically described as a situation where "teachers and students work together in the thick psychological soup of the classroom" (Shuell, 1996). The aforementioned theoretical aspects of inquiry learning and teaching might bear different levels of impact on the analysis of APL-based enactment in whole-class setting.

Enactment research, using diverse methodologies and grain size of analysis, address both the action dimension of enactment and its linguistic aspects (Schoenfeld, 1998; Stigler, Gonzales, Kawanaka, Knoll & Serrano, 1999; Crawford, 2005; Schneider et al., 2005). Adapting some of these investigation tools to the analysis of APL-based enactment (as further detailed in the Research Methodology section) may aid in revealing learning and instructional aspects and the factors affecting them. Since authentic scientific activity is to a great extent associated with rhetoric and argumentation (as mentioned above), the class discourse in the context of APL enactment might prove itself informative for the analysis of students' inquiry processes and of the scientific authenticity of their epistemic practices. Discourse analysis can also shade light on teachers' instructional strategies and their curricular adaptations.

1-3. Main goals and research questions

My research has focused on three main goals: the characterization of teachers' beliefs and goals, the characterization of class enactment and providing scaffolding tools for students and teachers.

1. Characterization of teachers' beliefs and goals: To characterize the beliefs and goals of high-school biology teachers following the enactment of APL based curricula in order to further understand how the teachers grasp the importance of this teaching genre as part of the high-school biology syllabus.

I focused on the following research question:

1-a. What is the extent of agreement between the enacting teachers' beliefs and aims and their motivation to teach the APL-based curricula?

2. Characterization of class enactment**:** To characterize class enactment of APL-based curricula by different teachers in order to better understand teachers' instructional strategies, students' benefits and challenges and the characteristics of the enactment discourse.

The following research questions were addressed:

2-a. What are the pedagogical strategies employed by the teachers when enacting the APL-based curricula?

2-b. What are the characteristics of the class discourse during the enactment of different sections of the adapted articles?

2-c. What coordination practices are displayed by students during the enactment? With what other epistemic practices and inquiry aspects are they associated?

2-d. What are the outcomes (benefits and challenges) of the enactment at the students' level?

3. Providing scaffolding tools for students and teachers: To use the characterization of the enactment process and of students' and teachers' challenges, in order to develop a variety of scaffolding tools to be used for different types of enactment.

The main research questions I focused upon were:

3-a. What are the teachers' attitudes toward the scaffolding tools?

3-b. How do the scaffolding tools offered by us affect the enactment process?

Several of the research questions were central to my work, and I focused on them using different curricula and different samples. The findings emerging in the context of one curriculum or in the initially analyzed sample promoted my efforts to further study the same question at a later stage, using a different sample, using similar or different data sources. I consider this experimental approach to fit the novelty of the APL genre and of the class-enactment of APL-based curricula.

Table 1 on page 20 provides the summary of the main research goals and questions investigated, the APL-based curriculum in which context they were studied, the research tools and the enacting teachers' sample that has been studied.

1-4 Context of the research

1-4-a Designing the biotechnology curriculum (Falk et al., 2003a)

The biotechnology curriculum 'Gene Tamers—Studying Biotechnology through Research' (Falk et al., 2003a) was designed for 11th-grade and 12th-grade students. The estimated time required for teaching the curriculum ranges between 30 and 35 hours.

When designing the biotechnology curriculum, we recruited several characteristics of this disciplinary domain: problem–solving orientation, novelty, direct social implications, and ability to be connected to innovations and initiatives of local scientists (Leslie & Schibeci, 2003). Prior to the publication of this curriculum, biotechnology curricula were not part of the Israeli high-school biology majors' syllabus.

The curriculum includes a student's book and teacher's guide.

The student book contains an Introductory Unit and three adapted research articles. The Introductory Unit lays the groundwork for learning the APL articles. It presents basic concepts and processes in molecular biotechnology. To avoid a systematic presentation of biotechnological methods, its contents were organized around three main case studies: genetically engineered human erythropoietin, the cloning of human growth hormone in bacteria, and genetic engineering of transgenic plants that are resistant to insects. Each case study gradually describes several biotechnological processes. In parallel to presenting biotechnology as a practically oriented, problem-solving endeavor, we stress the fact that many biotechnological solutions, although beneficial, raise new problems; and students are often invited to expose the possible drawbacks of present solutions and to suggest theoretical designs of better ones.

The three adapted research articles, all from leading peer-reviewed professional literature, deal with three different topics: Detection of genotoxic materials in water by bacterial biosensors (Davidov et al., 2000); Promotion of plants' resistance to pests by expressing a bacterial toxin (De Cosa, Moar, Lee, Miller & Daniel, 2001); and Gene therapy of an immunodeficiency in humans (Aiuti et al., 2002).

The articles were chosen for several reasons: a variety of the organisms used; a variety of stages in the biotechnological process, from basic research to field and clinical applications; presentation of biotechnological principles that can be used towards understanding other articles and can be transferred to the design of other biotechnological products; adaptability of the original research article to the APL genre (i.e., clear presentation of results, possibility of choosing a limited number of figures without altering the main meaning of the research, scientific background that is compatible with students' prior knowledge); leading-edge, high-impact subjects that are broadly covered in the popular scientific literature and in the public media; and articles based on research by local scientists.

The Design edition of the students' book [MAHADURAT YTZUV] contained more demanding contents than the 2nd edition that is used in schools since the 2004-2005 scholar year, e.g.:

i. the number of pages and of graphs for each article was 30-40% higher,
ii. the Results sections of the articles were more detailed and complex,
iii. more biotechnological processes were presented in the Introductory Unit of the curriculum,
iv. Less student's scaffolding tools were provided in the student's book.

Hence, the study of the enactment according to the Design Edition is actually the study of the enactment process of a prototype APL-based curriculum, with more pronounced genre and content characteristics than the 2nd edition. Therefore, the enactment of the Design Edition is more informative for me as a researcher whose aim is to analyze the enactment of this novel type of curricula.

The teacher's guide includes guiding questions to the research articles, elaborations on the developers' aims and rationale, and suggested instructional strategies.

1-4-b Designing the Curriculum guide for the Developmental Biology curriculum (Falk, Brill & Yarden, 2003b)

A CD-ROM format was chosen for the curriculum guide because it enabled us to present the teachers with: authentic teaching episodes, visual models of molecular processes and a pool of activities and questions to the Introductory Unit and to the articles. In addition, the guide contained remedial measures to the difficulties encountered by the students and a list of the main biological ideas of the articles.

The video taped teaching episodes, lasting from 3 to 10 minutes were subtitled and accompanied by the following texts:

1. description of the background of the recorded episode: school, class grade, previous articles studied by the students, the aim of the study session and the teaching sequence of the session including the recorded episode;

2. description of the episode: stage-by-stage description of the events occurring during the episode, without any comments (e.g. "The teacher waits for a long time before the first student answers");

3. pedagogical comments on some of the main didactic and cognitive processes which occurred in the episode. The teachers are explicitly told that these comments solely reflect the authors' view and they are prompted to elaborate upon their own

interpretation of the events whenever they feel it is necessary.

4. open questions, asking the teachers to compare the interventions in two or more episodes, or to elaborate on alternative teaching strategies.

The questions included in the pool addressed: knowledge organization, inquiry skills, highlight of the main biological ideas of the articles and their application in other contexts.

1-4-c Designing and running teachers' professional development (PD) workshops

Curriculum focused professional development can be promoted using educative curriculum materials (Ball & Cohen, 1996; Davis & Krajcik, 2005) as well as by workshops and community models of learning (Loucks-Horsley et al., 1998). Various teachers' development workshops have been carried out in order to familiarize biology teachers with the curriculum and with its developers' rationale.

i. Short acquaintance workshops (3 h) presenting the rationale of this genre, its possible benefits and challenges and part of one article

ii. Summer workshops during three subsequent days (24 h), presenting the scientific background of each of the APL articles, and diverse enacting models, part of them suggested by the teachers themselves

iii. Follow-up workshops (32 h), for teachers during their first year of implementation of the curriculum. These workshops were mainly focused on creating a supportive community, discussing enactment challenges and answering questions raised by the teachers, as well as presenting several case studies of enactment of APL in classrooms.

One of the main goals of the summer and follow-up workshops was to collaboratively design assessment tools at different levels. This practical goal presented a good opportunity to discuss the different aspects of the curriculum rationale, particularities and expectations.

1- 5. The research methodology

1- 5-a Overview of the research methodology

Table 1 provides the summary of the main research goals and questions investigated, the APL-based curriculum in which context they were studied, the research tools and the enacting teachers' sample that has been studied.

Table 1: Research goals, questions and tools

Research goals	Research questions	Curriculum context	Teachers' sample	Research tools	Relevant Paper
1. Characterization of teachers' beliefs and goals when enacting an APL-based curriculum	1-a What is the extent of agreement between the enacting teachers' beliefs and aims and their motivation to teach the APL-based curricula?	Biotechnology	4 teachers enacting the Biotechnology curriculum (sample B)*	Teachers' interviews	Paper 1
2. Characterization of the class enactment in the context of APL-based curricula	2-a What are the pedagogical strategies employed by the teacher when enacting the APL-based curricula?	Developmental Biology	4 teachers enacting the Developmental Biology curriculum (sample A)*	Teachers' interviews	Paper 3
		Biotechnology	4 teachers (sample B)*	Teachers' interviews Students' group interviews Enactment sessions	Paper 1
			3 teachers enacting the opening sections of an article (sample C)*	Enactment sessions	Paper 2
			1 teacher enacting the Methods and Results sections (sample E)*	Enactment sessions	Paper 5
	2-b What are the characteristics of the class discourse during the enactment of different sections of the adapted articles?	Biotechnology	1 teacher (sample E)*	Enactment sessions	Paper 5
			1 teacher enacting the Results and Discussion sections (sample D)*	Enactment sessions Teacher's interviews	Paper 4

	2-c What coordination practices are displayed by students during the enactment? With what other epistemic practices and inquiry aspects are they associated?	Biotechnology	1 teacher (sample D)*	Enactment sessions Teacher's interviews	Paper 4
			1 teacher (sample E)*	Enactment sessions	Paper 5
	2-d What are the outcomes (benefits and challenges) of the enactment at students' level?	Developmental Biology	4 teachers (sample A)*	Teachers' interviews	Paper 3
		Biotechnology	4 teachers (sample B)*	Teachers' interviews Students' group interviews Enactment sessions	Paper 1
3. Analysis of the scaffolding tools for the enactment of APL-based curricula	3-a What are the teachers' attitudes toward the scaffolding tools?	Developmental Biology	4 teachers (sample A)	Teachers' interviews	Paper 3
	3-b How do the scaffolding tools offered by us affect the enactment process?	Developmental Biology	4 teachers (sample A)*	Teachers' interviews	Paper 3
		Biotechnology	4 teachers (sample B)*	Teachers' interviews Students' group interviews Enactment sessions	Paper 1

* As further detailed in Research samples

1- 5-b Research samples

The enacting teachers that were studied for collecting the research data were divided into several research samples, according to their formal academic knowledge and research experience, enacted curriculum and enacted sections of article [during the recorded enactment sessions]. The data collected from different samples were used for answering the research questions, as detailed in Table 1. In some cases, the data were collected from their students as well, as further detailed.

Sample A: This sample includes four "expert" teachers with previous formal knowledge in molecular biology and laboratory research, enacting the Developmental Biology curriculum (for answering the questions 2-a. 2-d, 3-a, 3-b).

Samples B-E belong to a larger pool 20 teachers enacting the Biotechnology curriculum during the years 2003-2005.

Sample B: This sample includes four "non-expert" teachers, with no previous formal biotechnology knowledge, (for answering questions 1-a, 2-a, 2-d and 3-b). Data collected from their students (n=98) were used for answering questions 2-a and 2-d.

Sample C: This sample includes three "expert" teachers, with previous formal knowledge in molecular biology and laboratory research, enacting the opening sections (Title, Abstract, Introduction) of the same APL article from the Biotechnology curriculum (for answering question 2-a).

Sample D: This sample includes one exemplary teacher with extensive biotechnology knowledge enacting the Results and Discussion sections of an article from the Biotechnology curriculum, (for answering questions 2-b and 2-c).

Sample E: This sample includes one exemplary teacher with extensive research knowledge, enacting the Methods and Results section of an article, (for answering questions 2-a, 2-b and 2-c).

Sampling rationale

The enactment sessions observed and recorded for each teacher included in samples B-E was a convenience sample, since I visited the schools following teachers' explicit invitation. Since my declared aim was improving the Gene Tamers experimental edition of the students' book and designing a curriculum guide, no selection was performed between the teachers or the enactment sessions before entering the classrooms. Because the Biotechnology curriculum was enacted mainly in the 12th grade, under the psychological pressure of the approaching Matriculation examination, I considered each such invitation as a rare opportunity of glimpsing into the enacted curriculum. No suggestions were offered to the teachers regarding the contents or the structure of the lessons observed. This approach enabled me to observe the most naturalistic whole-class enactment and to observe the largest possible variety of enactment models. I considered this approach to fit the very first stages of enactment of a new curriculum.

The enactment sessions of all the teachers observed (n=20) were used in order to alter the experimental edition (MAHADURAT YITZUV) of the biotechnology curriculum. Toward this aim, students' and teachers' challenges were analysed in a superficial and additive manner, and text changes were performed in order to address them in the final edition. These practical aspects of my work have not been part of my research.

Following the class observations, and a first analysis of their transcripts, I reached the conclusion that the variability between the different teachers, topics of the sessions (the articles taught and their sections) and the emerging enactment models was too extensive in order to allow for a fruitful comparison between all of them. Therefore, out of the 20 teachers enacting the Biotechnology curriculum, I focused on the lessons of eight teachers. Choosing them out of the whole pool was directed by the aims of my research as stated above, and their fitness to a specific characteristic aimed by the research, as specified above in the samples description. Different samples, including other or additional teachers, could have been grouped, in order to answer some of the questions.

1-5-c Research tools

Since both the theoretical and practical aspects of the APL enactment are multidimentional, multiple sources of data were required in order to triangulate toward reliable results. Most of the research tools used in this investigation provided answers for more than one question, most questions were answered using data provided by a variety of tools. A qualitative research methodology (Guba & Lincoln, 1998) was adopted because of the priority given to the characterization questions and the complexity of the observed features.

Interviews

Semi-structured (following Britten, 1995), post enactment interviews, 60-90 minutes long, were performed with the teachers of all samples. They were asked to elaborate on their beliefs, goals and motivations, teaching strategies and on the particularities of the APL-based enactment compared to other biology curricula. The teachers of sample A were subsequently, exposed to a videotaped teaching episode from the curriculum guide and were asked to comment on it. Post enactment, semi-structured students' group interviews, 30-45 minutes long were performed with the students of the teachers included in sample B.

The teachers' interviews were audio-recorded, the students' interviews were audio-taped and video-taped and transcribed by me. The transcripts were analyzed using the narrative constructivist procedure for multiple-case analysis (Shkedi, 2005). Internal validity was established at the mapping stage of the analysis.

Enactment sessions

Two or four (45 min each) enactment sessions were observed and fully recorded for each of the teachers, at least two of them while the class studied an APL article. For some teachers, enactment sessions dedicated to the Introductory Unit of the Biotechnology curriculum were observed as well.

The recordings of the enactment sessions were fully transcribed by a neutral transcriber.

The class discourse was analyzed in two manners: when serving as a secondary source, for answering questions 2-a and 2-d, low resolution analysis was performed, scanning the text for episodes illustrating the main categories resulting from the focused categorization of the interviews.

For answering the questions related to the class discourse 2-b and 2-c, high resolution analysis of the class discourse was performed by dividing the text into topic/action episodes according to transitions in the main discussed topic or enacted activity (e.g., a change in episode such as an event or specific activity, or a shift in focus to a different discussion question). The analysis focused several aspects:

- Students' inquiry aspects
- Students' coordination practices. A coordination event occurred when students made the connection between elements belonging to different epistemic levels (theory, data, research stages and text).
- Students' claims of difficulty
- The teacher's communication approach (van Zee & Minstrell, 1997; Mortimer & Scott, 2003) and her interventions associated with specific students' inquiry aspects and epistemic practices.

PART 2 – THE PAPERS

2-1 An overview of the research

Initial efforts to characterize the enactment of the APL-based biotechnology curriculum in a holistic manner, at both "non-expert" teachers' and students' level (Paper 1), were followed by two divergent investigational directions. The teacher-oriented direction focused the teachers' instructional strategies in the context of different APL sections of the biotechnology curriculum (Paper 2) and the analysis of the impact promoted by the scaffolding tools for the Developmental Biology curriculum (Paper 3).

The student-oriented direction focused the students' coordination practices as reflected in the context of the class discourse of two classes enacting the Biotechnology curriculum and the inquiry aspects applied in one of them (papers 4 and 5).

Nevertheless, the teacher/student orientation of the papers is not always a clear-cut. Paper 3 includes aspects belonging to students' scaffolding and paper 5 includes aspects belonging to the teacher enactment.

Figure 1 is summarizing the two investigational directions, the teacher-oriented direction and the student-oriented direction, and the papers belonging to each.

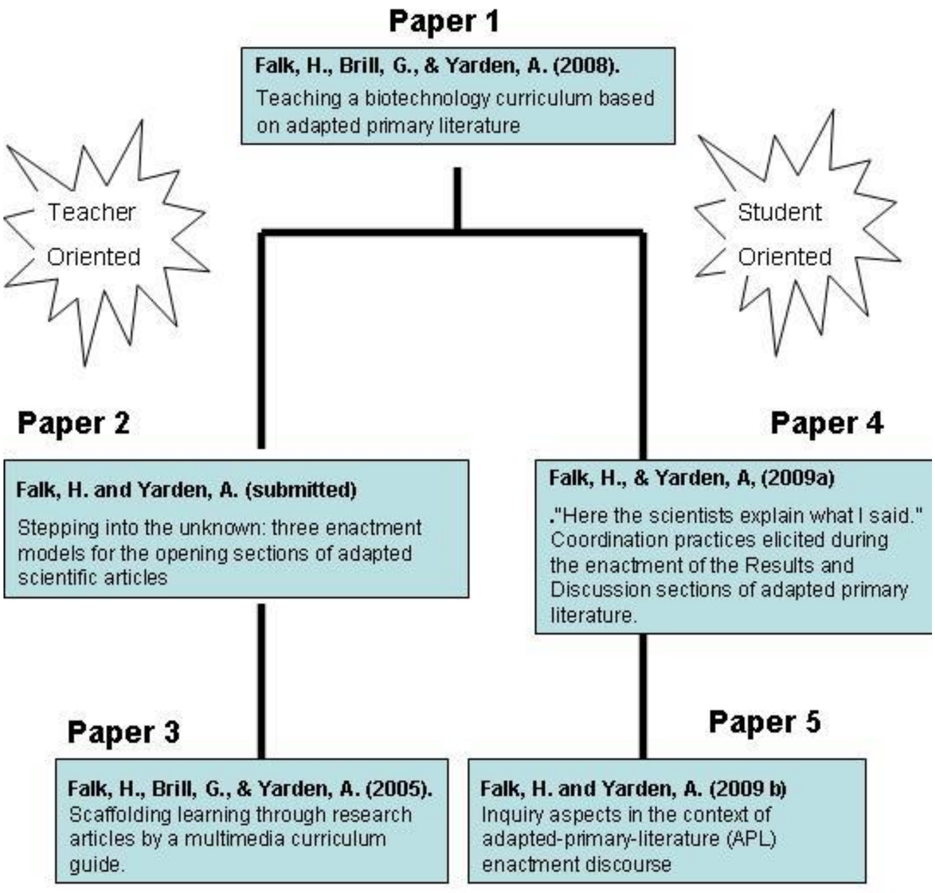

Figure 1: The teacher-oriented and student-oriented investigational directions

Paper 1 (Falk, Brill & Yarden, 2008) focuses on both the enacting teachers' PCK and their students' performances and challenges when enacting the APL-based biotechnology curriculum. At the teachers' level, we analyzed the aims and beliefs of four teachers and the instructional strategies they used during the enactment of the curriculum. The teachers expressed a strong commitment to inquiry learning, which they view as a main attribute of high-school biology studies. Their instructional strategies were different for the Introductory Unit and for the articles and differed for different sections of the articles. At the students' level, the enactment was associated with cognitive and affective engagement, active learning, inquiry thinking, and understanding of the nature of science. Students' challenges were mainly linked to the comprehension of complex, multi-stage, biotechnological processes and methods that are abundant throughout the curriculum and required the use of previous knowledge in new contexts. We found that the benefits and challenges were influenced by a complex interaction of factors: teachers' PCK, the APL genre and the biotechnology content. In some cases, these factors acted concurrently, in other cases they acted in an opposite manner. Learning by inquiry was strongly related to teachers' PCK.

The findings of this article, the first one to analyze the class enactment of APL, lead us to further address our efforts in two directions:

1. the analysis of teachers strategies employed for specific sections of the article
2. the analysis of the class discourse, performed at a finer resolution, during specific article sections

Paper 2 (Falk & Yarden, submitted) analyses three enactment models for the opening sections of the same article belonging to the APL-based biotechnology curriculum. Not only, as reported by the findings of Paper 1 teachers use different instructional strategies for the enactment of different article sections, we detected as well different models for the enactment of the same sections. By analyzing teachers' and students' utterances during the enactment, we could point the relative advantages of each model and its conformance to the opening stage requirements of the learning cycle (Lawson, 1988). Besides the analytical value of this article, the presentation and analysis of these models is expected to scaffold teachers during the enactment of different genres of scientific articles.

Paper 3 (Falk, Brill & Yarden, 2005) focuses on the characterization of a teacher's guide and its impact on the teachers' enactment of APL.The novelty of the teaching strategies required for APL enactment, stems from the fact that besides coping with new content knowledge, teachers are concomitantly faced with the promotion of skills which are associated with learning through research articles. To assist the enacting teachers and to convey them our perspective on the pedagogical content knowledge (PCK) that we considered adequate for the enactment process of APL we developed a teacher's guide for the developmental biology curriculum (Falk et al., 2003b). The paper describes the main characteristics of the teacher's guide and analyses the enacting teachers' stances on APL enactment and on the efficacy of the curriculum guide materials.

Paper 4 (Falk & Yarden, 2009) is included in a Special Issue focusing on the reading of scientific texts, in general, and on the adaptation of primary scientific literature for promoting scientific literacy among high school science students, in particular. Collective rejoinders to two discussion articles to appear in the same issue (Ford, 2009; Osborne, 2009) are attached as appendices.

This paper is the first of two focusing the students' epistemic practices as emerging in the context of the class discourse, during the enactment of the APL-based biotechnology curriculum. It focuses the enactment of two distinct sections of an article; the Results and the Discussion. The findings described both enforce the findings of Paper 1 and Paper 3 concerning students' benefits and challenges during enactment and deploy a high resolution analysis on the authentic scientific practices that are emerging.

Paper 5 This final stage of my work (still in process) is focusing again, similarly to Paper 1, on both students' and teacher's aspects of enactment, this time at the finer resolution of discourse analysis.

At the students' level, I am characterizing the inquiry aspects performed during the enactment of the Methods and Results sections, as the extent by which students perform learning by inquiry when enacting APL texts was questioned (Osborne, 2009). The scope of the analysis is to enforce our previous claim (paper 1 and paper 4) that when students enact text-based learning they are indeed performing many recognized aspects of inquiry. We also show that most inquiry aspects performed are associated with coordination practices.

At the teacher's level, we investigate discourse characteristics associated with the emergence of inquiry aspects and with the coordination practices.

PAPER 1:

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

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RESEARCH REPORT

Teaching a Biotechnology Curriculum Based on Adapted Primary Literature

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Adapted primary literature (APL) refers to an educational genre specifically designed to enable the use of research articles for learning biology in high school. The present investigation focuses on the paedagogical content knowledge (PCK) of four high-school biology teachers who enacted an APL-based curriculum in biotechnology. Using a constructivist qualitative research approach, we analysed those teachers' aims and beliefs, the instructional strategies they used during the enactment of the curriculum, as well as the outcomes of the enactment as perceived by the teachers and their students, and as reflected in the class observations. Some of the teachers' strategies applied during the enactment, such as the conversational model, were specifically designed for teaching APL-based curricula. We found that the instructional strategies applied for the adapted articles were associated with cognitive and affective engagement, active learning, inquiry thinking, and understanding of the nature of science. Suitable teacher PCK promoted learning by inquiry in addition to learning on inquiry. Students' challenges were mainly linked to the comprehension of complex, multi-stage, biotechnological processes and methods that are abundant throughout the curriculum and required the use of previous knowledge in new contexts. A complex interaction of factors, namely teachers' PCK, the APL genre, and the biotechnology content of the curriculum, shaped the instructional strategies of the new curriculum and the outcomes of its enactment

Theoretical Background

Inquiry learning has been classified as learning on inquiry and learning by inquiry (Tamir, 1985a). Learning on inquiry has been suggested to be learning about the way in which the scientific endeavour progresses, and analysing the inquiry process performed by others, sometimes using historical perspectives (Bybee, 2000; Schwab, 1962). When learning on inquiry, students use scientific reports and analyse various stages of the investigation process, in order to learn about some of the conclusions of science 'in the framework of the way they arise and are tested' (Tamir, 1985a).

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Learning by inquiry (Bybee, 2000), or learning 'the abilities necessary to do scientific inquiry' (National Research Council, 1996), involves the learner in raising research questions, generating a hypothesis, designing experiments to verify that hypothesis, constructing and analysing evidence-based arguments, recognizing alternative explanations, and communicating scientific arguments. All of these processes have been previously defined as inquiry thinking (National Research Council, 1996; Tamir, 1985a; Zohar, 2000). Schwab suggested 'enquiry into enquiry' as an optimal approach to promote inquiry learning, claiming that: 'The complete enquiring classroom would have two aspects. On the one hand it would exhibit science as enquiry. On the other hand, the student would be led to enquire into these materials' (Schwab, 1962, p. 65).

Since the implementation of the Biological Sciences Curriculum Studies curricula in Israel in the early 1970s, the Israeli syllabus for high-school biology majors has emphasized, in addition to the acquisition of content knowledge, the acquisition of inquiry-thinking skills. Activities such as laboratory exercises, research projects (Biomind), ecological field projects (Biotop), and analysis of unfamiliar excerpts from scientific articles (Tamir, 2004; Zion et al., 2004) have become an integral part of both the curricula and the assessment of biology majors (Tamir, 1985b). Investigations in Israeli high-school biology classes have shown that although inquiry elements are prevalent among teachers' declared statements, and inquiry questions permeate assessment tools and homework assignments, inquiry is not as salient in the classroom discourse (Zohar, Schwartzer, & Tamir, 1998). The remedial treatment suggested for this situation is the integration of more inquiry-oriented pedagogies into the classroom practice (Zohar et al.).

Schwab (1962) previously suggested that:

> Papers by scientists reporting scientific research have two major advantages as materials for the teaching of science as enquiry. One advantage is obvious. They afford the most authentic, unretouched specimens of enquiry that we can obtain … The second advantage of original papers consists in the richness and relevance of the problems they pose for enquiry into enquiry. The papers which pose an excessive problem of reading can be edited, excerpted and 'translated'. (p. 81)

Despite this unequivocal recommendation, in the course of nearly 40 years we have found no other evidence of curricula that use the primary literature genre for high-school science learning.

Primary literature (namely research articles) is a genuine genre of science communication, having been written by the scientists who conducted the research in order to communicate their findings to the scientific community (Beall & Trimbur, 1999; Mallow, 1991). Reading and analysing primary literature is an authentic scientific cognitive activity, as scientists' conclusions are grounded in the theoretical and empirical work of other scientists (Chinn & Malhotra, 2002; Dunbar, 1995). Therefore, learning through primary literature may be beneficial for students' acquisition of a realistic understanding of the nature of science (NOS), by exposing them to the authentic inquiry activity of reading scientific texts, which has been reported to have many benefits (Bandoni Muench, 2000; Epstein, 1970; Janick-Buckner, 1997). However, learning through research articles is both a challenge and a difficult task for novices, requiring adequate adaptation in order to be employed as a basis for high-school curricula (Yarden, Brill, & Falk, 2001). Adapted primary literature (APL) refers to an educational genre specifically designed to enable the use of research articles for learning biology in high school. The adaptation process maintains the canonical structure of the research article and some of the original results, while adapting its contents to the high-school biology students' comprehension abilities, as previously described (Yarden et al.). Briefly, the Introduction is modified to give the novice reader basic background information that was either omitted from or simply quoted in the original paper; the main principles of the Methods are described, while details of amounts, solution compositions, and so on, are omitted; the Results are kept authentic, although offshoots of the main research question are omitted; the main figures are kept, with slight modifications; and, finally, the Discussion is expanded so that students can understand it more easily (see Yarden et al. for additional information).

A few characteristics have been previously identified for learning using the APL genre: High-school students tend to pose questions that reveal a higher level of inquiry thinking and uniqueness during and following learning through APL (Brill & Yarden, 2003; Falk, Brill, & Yarden, 2005); A deeper level of comprehension of an APL text was reached when high-school students answered scaffolding questions (Brill, Falk, & Yarden, 2004); High-school biology students who read an APL text better understood the nature of scientific inquiry and raised more scientific criticism on the researchers' work compared with students who read a popular scientific text (Baram-Tsabari & Yarden 2005); and Students' comprehension difficulties were related to the complexity and ill-structured knowledge of APL texts (Falk et al.).

Following the requirements of a newly published syllabus for biology majors in Israel (Israeli Ministry of Education, 2003), we recently designed a curriculum based on APL entitled 'Gene Tamers—Studying Biotechnology through Research' (Falk, Piontkevitz, Brill, Baram, & Yarden, 2003). The curriculum is aimed at enhancing students' inquiry-thinking skills and their understanding of the nature of research practices in biological sciences, and is expected to represent contemporary biological research, which is only seldom used for science learning in secondary schools (Israeli Ministry of Education, 2003).

Three characteristics of biotechnology make it an ideal subject for school curricula: it is a cutting-edge field suitable for innovative science and technology, it has direct social implications, and it can be connected to innovations and initiatives of local scientists (Leslie & Schibeci, 2003). Until recently, biotechnology curricula were not part of the Israeli high-school biology majors' syllabus and very few genetic-engineering topics were integrated into other topics; that is, cell biology or genetics (Israeli Ministry of Education, 1991).

Inquiry curricula, designed to promote inquiry-thinking skills, have been shown to be challenging for teachers as they require a relatively high level of paedagogical content knowledge (PCK) (Crawford, 2000). Teachers' PCK encompasses their interpretations of subject-matter knowledge in the context of facilitating students' learning, as well as their beliefs, aims, instructional strategies, and understanding of students' conceptions and challenges (Shulman, 1986; van Driel, Verloop, & de

Vos, 1998). The PCK for inquiry teaching includes a deep understanding of the NOS and of inquiry learning, and the ability to coach and collaborate with students (Anderson, 2002; Crawford, 2000; Schneider, Krajcik, & Blumenfeld, 2005). Teachers' PCK is not a static entity. On the one hand, teachers' awareness of their students' achievements and challenges, and its impact on their instructional strategies during the enactment process, are critical components of their PCK (Schoenfeld, 1998; Shulman, 1986; van Driel et al., 1998). On the other hand, teachers' criteria, when judging the outcomes of the enactment process, are usually influenced by both their values and their beliefs about teaching (Tamir & Jungwirth, 1972). For instance, we can expect that a teacher whose beliefs are focused on subject matter will teach, monitor, and report on different strategies and outcomes than a teacher who believes that acquiring inquiry thinking is crucial for learning science (Squire, MaKinster, Barnett, Luehmann, & Barab, 2003).

The study described here was designed to present teachers' PCK as related to the enactment of the APL-based biotechnology curriculum within the high-school biology majors' studies in Israel. We analyse several dimensions of teachers' PCK: teachers' beliefs, aims, established PCK and motivation to teach this novel curriculum, their instructional strategies during the enactment, and their interpretation of the outcomes of the enactment. We support our analysis of teachers' reports with students' comments and class-enactment observations.

Design and Methodology

Israeli High-school Biology Majors' Syllabus

At the end of the 10th Grade, students in Israel choose to major in at least one scientific or non-scientific topic, which is evaluated in a national matriculation examination at the end of 11th and 12th Grades (16–18 years old). The syllabus for biology-major studies (300 hrs of teaching; Israeli Ministry of Education, 2003) includes three compulsory core topics (Systems in the human body, Ecology, and Cell biology). In addition, students are required to learn three elective topics, each designed for 30–45 hours of teaching. One of the elective topics that teachers can choose is based on APL and is entitled Research Topic. The biology matriculation examination is aimed at assessing knowledge related to the core and elective topics, comprehension of content, and high-order thinking skills or inquiry skills. Between one-third and one-half of the national matriculation examination is aimed at assessing students' inquiry skills (Zohar et al., 1998). In this respect, students are also assessed for inquiry laboratory skills and on an ecology-based research project (Tamir, 1998; Zion et al., 2004).

Curriculum Design and Characterization

The biotechnology curriculum 'Gene Tamers—Studying Biotechnology through Research' (Falk et al., 2003) was designed for 11th-grade and 12th-grade students. The estimated time required for teaching the curriculum ranges between 30 and 35 hours. The curriculum material includes a student's book and teacher's material that mainly contains guiding questions to the research articles, elaborations on the developers' aims and rationale, and suggested instructional strategies. In addition, various teachers' development workshops have been carried out in order to familiarize biology teachers with the curriculum and with its developers' rationale. Additional teacher's materials were developed during these workshops.

The student book contains an Introductory Unit and three adapted research articles. The Introductory Unit lays the groundwork for learning the APL articles. It presents basic concepts and processes in molecular biotechnology. To avoid a systematic presentation of biotechnological methods, its contents were organized around three main case studies: genetically engineered human erythropoietin, the cloning of human growth hormone in bacteria, and genetic engineering of transgenic plants that are resistant to insects. Each case study gradually describes several biotechnological processes. Throughout the Introductory Unit, a large number of questions and assignments are distributed. Some of them ask the students to find relevant information toward solving a certain transfer problem and suggest a solution. Others require finding additional applications for a given method or analysing the possible social implications of a biotechnological process. In parallel to presenting biotechnology as a practically oriented, problem-solving endeavour, we stress the fact that many biotechnological solutions, although beneficial, raise new problems; and students are often invited to expose the possible drawbacks of present solutions and to suggest theoretical designs of better ones. The three adapted research articles, all from leading peer-reviewed professional literature, deal with three different topics: Detection of genotoxic materials in water by bacterial biosensors (Davidov et al., 2000); Promotion of plants' resistance to pests by expressing a bacterial toxin (De Cosa, Moar, Lee, Miller & Daniel, 2001); and Gene therapy of an immunodeficiency in humans (Aiuti et al., 2002). The abstracts of the three adapted articles, translated back to English from the Hebrew version of the original APL articles, appear in the Appendix.

The articles were chosen for several reasons: a variety of the organisms used; a variety of stages in the biotechnological process, from basic research to field and clinical applications; presentation of biotechnological principles that can be used toward understanding other articles and can be transferred to the design of other biotechnological products; adaptability of the original research article to the APL genre (i.e., clear presentation of results, possibility of choosing a limited number of figures without altering the main meaning of the research, scientific background that is compatible with students' prior knowledge); leading-edge, high-impact subjects that are broadly covered in the popular scientific literature and in the public media; and articles based on research by local scientists.

To provide teachers with an adequate instructional strategy for the enhancement of inquiry learning, we developed the conversational model and suggested it as suitable for APL-based teaching (Yarden et al., 2001). The model is based upon an iterative process involving a constructivist discourse between the students and the article, which includes three steps: the students read one section of the article together in the classroom; they then raise questions about the part they read, and the teacher writes the questions on the board or on a transparency; and, finally, the students propose hypotheses or predict the outcomes of suggested experiments, in order to answer at least some of the questions. By repeating those steps in the subsequent sections of the article, the students can obtain answers to their questions, and can verify their predictions in the class discussion that follows. This strategy is described in detail elsewhere (Yarden et al.).

Research Design

Research population. The research population included teachers that volunteered to implement the APL-based curriculum 'Gene Tamers—Studying Biotechnology through Research' (Falk et al., 2003) in their classrooms during the 2003–2005 academic years. Here we focus on four teachers—Sara, Rona, Tal, and Naomi (not their real names)—and their classes (for details see Table 1). All four teachers participated in an introductory teachers' development summer workshop that took place over three consecutive days (8 hours a day), and three teachers (Tal, Rona, and Naomi) also participated in a professional development workshop lasting four non-consecutive days (8 hours a day), during the academic year, which was aimed at teachers who implement the curriculum in their classrooms. The teachers could address questions to the curriculum developers at all times. The students of these four teachers (n = 98) participated in this research as well (Table 1). During the group interviews (see below) about one-half of the students in each class actively participated (Sara, 7/8 students; Rona, 12/25 students; Naomi, 13/30 students; Tal, 10/35 students). Prior to the beginning of the curriculum enactment, students in all four classes had very little, if any, prior knowledge in biotechnology.

Data collection and analysis. Three data sources were used to triangulate the factors that shape the particularities of the APL-based curriculum enactment: Teacher interviews, 60-min to 90-min semi-structured interviews (following Britten, 1995) on their beliefs, aims, instructional strategies, and students' outcomes during enactment; Group interviews with the students, 30-min to 45-min group interviews with the students that focused on the same aspects raised during the teachers' interviews were video-recorded and audio-recorded (in one case, Sara's class, data were collected only by audio-recording)—since our intention was to improve the curriculum, we explicitly encouraged and gave higher priority to the negative utterances of the students, in all classes; and Class enactment, two successive teaching sessions (45 min each) of the four teachers were observed, at least one of them while the class studied an APL article—the sample of observed sessions was chosen following an invitation from the teachers and is therefore not random.

The enactment was recorded during the whole sessions. The interviews were fully transcribed by one of the authors and the class-enactment recordings were fully transcribed by a neutral transcriber based on the audio-recordings and video-recordings. The first-order and second-order theoretical analyses of the interviews were

Table 1. Characteristics of participating teachers and their students

Characteristic	Teacher: Sara	Rona	Tal	Naomi
Biology education	MSc	MSc	MSc	BSc
Graduate domain	Ecology	Neurobiology	Plant Physiology	–
Teaching experience	> 10 years	> 10 years	> 10 years	> 10 years
Type of school	Religious, girls, rural	Secular, mixed, urban[a]	Secular, mixed, urban[a]	Secular, mixed, urban
Number of students	8	25	35	30
Students' cognitive levels as estimated by their teachers	Very high–high	Average–high	Average–high	Average–high
Student's prior topics studied in class	3 core topics, genetics	3 core topics	3 core topics	3 core topics, microbiology
Beginning of enactment of the curriculum	12th Grade	11th Grade	11th Grade	12th Grade
End of enactment of the curriculum	12th Grade	12th Grade	12th Grade	12th Grade

[a]Same school.

performed according to the narrative constructivist procedure recommended for multiple-case analysis (Shkedi, 2005). The mapped and focused categorizations were performed with the aid of Narralizer Software (Shkedi & Shkedi, 2005). Since one author is a high-school teacher herself, who enacted the APL biotechnology curriculum for two subsequent years, she could comply with the requirement of possessing a deep involvement in the participants' culture (Shkedi, 2005). Internal validity was established at the mapping stage of the analysis. An initial agreement of 92.4% was reached for the analysis of teachers' interviews and 85% for the students' interviews. Following debates, the agreement reached 97.5%. After analysis of the interviews, the recordings of the enactments served as a secondary data source (Shkedi, 2005). Thus, they were scanned for episodes illustrating the main categories resulting from the focused categorization.

Results

Teaching strategies are influenced by teachers' knowledge, beliefs, and aims (Schoenfeld, 1998). Therefore, in order to interpret the teaching strategies applied during the enactment of the APL-based curriculum, we start by characterizing the enacting teachers' beliefs, their motivation in enacting the APL biotechnology curriculum and their PCK when enacting other curricula. We then go on to analyse the main features and outcomes associated with teachers' instructional strategies when enacting the APL-based biotechnology curriculum, with reference to strategies specific to the Introductory Unit of the curriculum and to the adapted articles, and those deployed throughout the curriculum.

Teachers' Beliefs, Aims, and Established Instructional Strategies

The four teachers in this study—Rona, Tal, Naomi, and Sara—can be described as independent, inquiry-oriented, pursuing life-long learning in a broad range of professional interests, and continuously seeking new challenges. For example, they often read popular scientific articles, design experimental learning materials, develop user proficiency in computer skills, and participate in professional development workshops. Their values include a strong enthusiasm for biology and biology teaching, and they seem to be satisfied with their professional choice:

> If there is something that I really love, it's biology. I love this subject, it's wonderful and amazing, both the biology and what people accomplish by using biology. (Sara)

Due to the strong focus on inquiry skills that is prevalent in biology teaching at the high-school level in Israel, all interviewed teachers declared a strong commitment to inquiry learning, which they view as a main attribute of high-school biology studies.

> I feel that biology teaching, as it should be done, is different from teaching other disciplines, because you can't teach other disciplines by thinking and inquiry. It always was different, at least from our point of view. (Tal)

Although none of the teachers specialized, during their graduate education, in fields related to molecular biology or biotechnology, they feel motivated to choose a curriculum that is linked to modern molecular biology (i.e., genetics or microbiology).

> The main reason is because we live in a century that is involved with that, and I don't think that we can let them major without at least a taste of the real thing, the reality that surrounds them. (Tal)

In different instances during the interviews, teachers referred to their usual PCK repertoire during biology classes, highlighting their use of:

- popular scientific articles in order to promote interest and inquiry thinking, and
- class debates and argumentations, in order to promote bioethical aspects.

The four teachers never mentioned that they feel in any way different from their high-school-biology-teaching colleagues or that their life-long learning behaviour makes them feel special. The strong undertone emerging from their narratives is that many high-school biology teachers in Israel have already incorporated in their beliefs the importance of conveying scientific literacy and inquiry thinking and they attempt to base part of their teaching upon these beliefs. Nevertheless, their inquiry teaching is still compartmentalized from the routine act of teaching and therefore worth mentioning and cherishing.

Teaching Strategies Applied to the Introductory Unit

Teachers made a clear distinction between the conventional instructional strategies they employed for the Introductory Unit and the strategies they employed when teaching the articles.

> As for the Introductory Unit, it was crystal clear that I am going to formally teach them and they are going to learn. (Tal)

The similarity in teaching the Introductory Unit of the curriculum to other curricula stemmed from the 'textbook' genre of this part of the curriculum. Its main role, according to the teachers' views, was to provide an extensive overview of concepts and processes that are required to understand the adapted research articles. Teachers also felt that, by suitable reference to previously learned subjects and through the contents of the Introductory Unit, it was possible to facilitate the integration processes of previously learned topics.

> It wasn't difficult for the students. That's what is good about the Introductory Unit, is that it revises everything that one needs to know before reading the article … And then it goes like, 'Aaah, piece of cake'. If we would have mentioned it two years ago, then it would have been problematic. That's why the Introductory Unit is excellent, you don't throw them straight into the water, kind of 'take all of the biology you know and use it'. (Sara)

Teachers' reference to their traditional teaching strategies for the Introductory Unit provides us with a stance to be contrasted with their teaching strategies during the enactment of the articles.

Teaching Strategies Applied to the Adapted Articles

The promotion of four main features was associated with strategies for teaching the articles: cognitive and affective engagement, active learning, inquiry thinking, and NOS understanding. For the first three features, the association occurred at the intentional level (teachers consciously promoting these same goals), at the practice level (teachers applying specific teaching strategies), and at the outcome level (teachers' and students' declarations and class observations indicating the achievement of these outcomes). From our constructivist analysis of interviews, these three levels emerged as strongly intertwined and implicitly included within each other. The fourth feature, a more realistic understanding of NOS, was manifested only at the declared outcome level.

Cognitive and affective engagement. Throughout the interviews, teachers stressed the importance they attribute to engagement-eliciting strategies. Since one of the teachers' main reasons for volunteering to implement the curriculum was their high cognitive engagement, they felt committed to explicitly share this feeling with their students:

> I stressed it to them every time, look how wonderful it is, they (the scientists) were not satisfied with that biosensor, although it took them a long time to genetically engineer it, now they want it to be even more sensitive by altering the ion channels, it's so inspiring, it shows their depth of thinking, it shows biological reasoning. (Sara)

Teachers' strategies toward engagement elicitation stem mainly from their established PCK. For example, in the enactment episode, Naomi analyses the advantages of gene therapy over other therapeutic methods (as presented in the gene therapy article) by staging an imaginary meeting between the patient's mother and the physician involved in the treatment.

> So what I am asking you, doctor (everyone here in the class is 'the doctor'), please help me save my baby. Tell me what her chances are, what the treatment can do for her, and please do not hide the risks. OK, so now you are the doctor, I am the mother … (Naomi)

During her interview, Naomi remarked that although she uses similar engagement-eliciting strategies for other biology curricula, the elicited engagement was stronger during the enactment of the APL curriculum.

> The students were cooperative. Sometimes there are lessons that don't flow and that are boring, it didn't happen here, and it was an accomplishment from my point of view as a teacher, because the lessons flowed and they asked questions. (Naomi)

All of the teachers claimed to have used the conversational model (Yarden et al., 2001). Teachers used this model mainly for the initial stage of article learning—analysis of the title and abstract, and for predicting the contents of different sections of the article. Their focus was mostly directed to the motivational drive promoted by this model by allowing students to raise questions and find their own answers while learning through the article.

During the students' group interviews, the most prevalent category of positive responses (> 30%) referred to their engagement during the study of the biotechnology curriculum—this category was expressed by students in all four classes:

> … because articles mainly add to the level of interest one can bring to a topic. (Student in Tal's class)

> It was more exciting because that's what they (the scientists) really did, isn't it? (Student in Rona's class)

Several students reported that they were more interested in reading a research article than a textbook or the Introductory Unit of the curriculum, and even suggested using articles rather than textbooks in class because they elicit more interest. Students attributed their engagement to the contemporary nature of the curriculum contents, to the ability to solve real-world problems using school science knowledge, and to the authenticity of this curriculum genre in contrast to common biology curricula.

> That's what scientists do today and not 300 years ago. (Student in Tal's class)

> I liked the one about humans (the article on gene therapy). It was not so difficult because it was exciting. (Student in Rona's class)

The last sentence of this quotation illustrates how students' engagement can affect their proneness to learn science, as previously described (Darby, 2005; Osborne, 2003). Students' engagement was strongly cherished by the enacting teachers, because it facilitated class management, provided them with positive feedback during class enactment, and further enabled students to cope with curriculum-associated challenges.

Active learning. Active learning is manifested by knowledge being actively built up by the learner, who is responsible for his own learning (Driver, Asoko, Leach, Mortimer & Scott, 1994; Osborne, 1996) and self-regulates it (Niemi, 2002).

Both Rona and Sara felt that while teaching the articles, they demanded more than usual that the students act as active learners:

> I involved them more; they reached the things by themselves. And I let them cope on their own with the subject matter. Under my guidance, my supervision, in order to check that they understood correctly, but it's not like something else that I usually explain to them, here I let each of them explain. (Sara)

In contrast to other curricula where the teachers perform the integration and present it to the students, the study of APL prompted teachers to direct students to actively integrate knowledge by themselves.

> Something different happened here; we learned by what is called real issues. Genetics is also learned by real issues, but we get it already processed. So I deliver it to them already processed and summarized. And here, the integration had to come from them. (Rona)

Active learning was promoted in several ways:

1. Using the conversational model, students raised questions that were noted on the board or on a transparency. When students read the following sections of the article, the teachers asked which of the questions could be answered by the new information and prompted the students to find the answers by themselves.
2. Group assignments were given focusing on an analysis of the graphical representations in the Results section of the article. After each group elaborated its answers about a single graphical representation, delegates presented the group production to the whole class, while the teacher acted as a moderator.
3. Using questions such as 'What other information would you like to get in the Abstract?' (Tal) or 'What title would you give to the Results section?' (Rona), teachers emphasized the canonical structure of primary literature, which provides a clear content-organization mould, facilitating the distinction between conjecture, evidence, and implications. This content organization provided students with visible borders, leading to self-regulation of the reading and comprehension process, and guiding them toward becoming independent readers of articles.

> … the article from the student book [*Gene Tamers*] that was detailed, every section had a title, and that made it obvious what was going to happen. (Student in Rona's class).

Tal differed from the three other teachers in her inability to promote active learning among her students. She asked her students to read the article at home and write down clarifying questions, instead of applying the conversational model, in class.

> I guess that the reason I want them to read at home is because … it shouldn't be like I am coming, pouring the subject matter and they just listen … They didn't feel comfortable because this was not the way they are used to learning. … They expected me to go on teaching them, from the beginning. (Tal)

Tal's legitimate aim was to involve the students and create active learners. However, the change that she required from her students was too drastic and, at this stage, they did not seem to cooperate with the high standards she presented to them. Despite the fact that her content knowledge, declared beliefs, and aims did not seem to differ from the other teachers, the difference might lie, however, in her PCK, which did not take into account her students' difficulties when suddenly asked to become active learners 'on their own', instead of being taught the subject matter (as usual) or enacting the conversational model in class (as suggested).

Inquiry thinking. One of the major points teachers focused upon in the interviews was students' acquisition of inquiry-thinking skills while learning using APL. The fact that both students and teachers said that the curriculum provides opportunities for learning by inquiry is not a trivial one, since it might be expected that learning using adapted research articles will mainly enhance learning on inquiry.

For the analysis of the article results, teachers used questions that were designed to connect the information provided in the article with inquiry-method concepts and ideas usually applied by students during laboratory sessions and during analysis of the unseen scientific texts (i.e., what were the investigator's aims, what are the variables and constants of the experiment, what conclusions can be drawn from the results).

Complex tasks asked students to assert the consistency and validity of different results presented in the article. For instance, at the beginning of the lesson on the summary of the Results section of the article dealing with genetic engineering of plants, Sara presented the following question to her students: 'Are the advantages of introducing the Bt toxin gene into the chloroplast, as seen by the levels of the Bt toxin protein (presented in a graph in a previous section of the results), consistent with the results of the bioassay (presented as a table and images)?' Sara's rationale for raising this question was a certain discrepancy between the two kinds of results, producing ambiguous conclusions. Analysis of evidence-based arguments and critical evaluation of controversial data occurred during the students' negotiation of the answer.

> Student 1: We see that when it [the gene] was in the chloroplast the concentration of the toxin is much higher…because we see that the leaves were eaten less by the three [kinds of] caterpillars relative to when the gene was in the nucleus.
> Student 2: No, because in the last one [last picture], it was not the same …
> Student 1: Well, we've got here two things, we've got how much of the leaves they [the caterpillars] ate and how fast they died. We have two things that happened to them. So, I think that for all kinds of caterpillars, they died faster when the gene was in the chloroplast.

The ability to design experiments and methods suitable for answering research questions is also considered a demanding parameter of inquiry thinking (Zohar, 2000). The following episode presents Rona while introducing a method for the quantification of specific proteins to her class. The students had learned about the specific affinity between antigen (e.g., a protein) and antibody in the 10th Grade and had used calibration curves in a previous laboratory session on quantification of vitamin C in fruit juice. In the present lesson, Rona uses guided inquiry in order to promote the students' application of their prior knowledge in the context of the task presented in the article: determination of the Bt toxin protein level in genetically engineered plants. Rona attempts to elicit her students to predict the method before moving to the Methods section of the article and reading about it, according to the third step of the conversational model (Yarden et al., 2001).

> Teacher: When we are asking if there are any differences between genetically engineered Bt gene in the nucleus and in the chloroplast, how are we going to check it?
> Student: By comparing.
> Teacher: By comparing what? How shall we check if the engineering process succeeded?
> Student: We will check if it's [the gene] expressed in the plant.
> Student: We will use the caterpillars.
> Teacher: OK, we will use the caterpillars and we will see, here they died and there they died … Is this a qualitative or a quantitative experiment?

Student:	Qualitative …
Teacher:	But this time I do not want only a qualitative experiment to see if the caterpillar is alive or dead, I also want a quantitative experiment … How can I check the quantity of Bt protein that is expressed in the plant?
Student:	Use of a calibration curve.
Teacher:	Great! We will soon reach this subject and we are going to make the connection to what we learned during the lab session. And here we are going to learn about it again, because then we didn't succeed too well. Now, this method is presented on page 93.

Initially, the methods suggested by the students are based on information they acquired in the previous sections of the article: measuring the protein level by measuring the survival of caterpillars fed with engineered plant tissue. But this method, as reported in the adapted article and suggested by the students, is qualitative, and Rona is interested in emphasizing the need for a quantitative method. Subsequently, a student proposes a method he had used in the laboratory session—applying a calibration curve. When the students read the description of the method in the Methods section of the article, they will indeed read about the use of calibration curves as a means of obtaining quantitative results. In this instance, the teacher, instead of merely analysing and explaining the experiment presented in the article (learning on inquiry), used the framework of the article to emphasize the constraints of the experiment and promoted the design of a suitable method before addressing the Methods section of the article (learning by inquiry).

Teachers and students explicitly attributed inquiry thinking to the APL genre and to the problem-solving epistemology of biotechnology as it is reflected in the curriculum. It seems that APL conveys a pervasive feeling of inquiry that students are aware of, without always being able to explicitly elaborate upon its source.

> Like, you discover more through the article. (Student in Sara's class)

The fact that students envisage transfer of insights from the articles to the high-school inquiry laboratories also points to gains in inquiry thinking.

> Now, when we are doing an experiment in the lab session, we better understand what we are doing. (Student in Rona's class)

Among the interviewed teachers, Tal was the only one who clearly reported on students' challenges with regards to inquiry thinking. Her students could not cope with the inquiry-thinking requirements of the curriculum enactment and she was convinced that some of them could not even grasp simple graph-reading skills.

Understanding the nature of science. We anticipated that the structure and genre of the research articles would convey the scientists' voice, their conjectures, rationale, and enthusiasm, thus promoting a realistic epistemological perspective of the scientific endeavour in general, and of the biotechnologists' perspective in particular. Students' comments during the group interviews referred to the NOS aspects, emphasizing the importance they attributed to the 'authenticity' and the situational aspects of the adapted articles.

> The structure of the article, you know, the abstract, the introduction, the discussion, they emphasize the reality … it's about the experiments, the things that they really did. (Student in Naomi's class)

Teachers were enthralled by the fact that hearing the 'scientist's voice' through the article provided students with the feeling that they were sharing in a professional community with experts in biology, and that the article promoted their apprenticeship process by allowing them to become members of this community:

> And there was another student that said, and I agree with him 'Look, now we are biologists'. (Rona)

However, for students, the article became the research itself, and was regarded as 'real-world' science, rather than a mere reflection of it.

> What is really good is the organized way that they perform the research. First of all you get the 'why' they are doing this, then 'how' they are doing the experiment, the tools and stuff, the experiment itself, results. (Student in Rona's class)

This rapt, if somewhat naive belief may lead to students' viewing the nature of science as an ordered process, a faithful example of the 'scientific method', as previously observed in another research setting by Latour and Woolgar (1986).

The only structural element of the articles that raised a feeling of discomfort among the students was the Discussion section. This is probably because it contradicts the high-school student's notion of final conclusions, since it reveals, instead, the remaining open ends and uncertainties of the inquiry process.

> In my opinion, the Discussion should be shorter, because it's too long and sometimes it's confusing. After you have already understood the results, after you have already understood everything, they begin telling you about things that harm your understanding. (Student in Rona's class)

In contrast to this reaction, Rona, this student's teacher, is fully aware of the dynamic nature of science reflected in the Discussion section.

> What a student told us was that the Discussion impairs his confidence, but, in fact, this is exactly what we are interested in, from the scientific point of view. To raise new questions, new problems. (Rona)

Nevertheless, she seems unable to promote the same understanding among her students, probably because of a lack of relevant strategies for the instruction of this type of text.

Teaching Strategies Applied Throughout the Curriculum

Complex, multi-stage, biotechnological processes and methods are abundant throughout the curriculum, both in the Introductory Unit and in the adapted articles. When associating a strategy with the Introductory Unit or with the articles, we mean that it was used predominantly, but not exclusively, for the enactment of that part of the curriculum.

Students were expected not only to understand the research methods and molecular processes, but sometimes they were required to suggest them *a priori*, via assignments and the conversational model. Complying with these expectations required: integration of knowledge and its application at two levels—prior school biology knowledge integrated and applied in the context of a biotechnological method and suitable methods to be further integrated into a coherent entity and applied in order to solve a problem; and inquiry thinking—understanding the complex inter-dependency of the research question and the methods selected to investigate it and between the selected methods and the results obtained and their interpretation. Since the research methods and molecular processes presented in research articles are more detailed than in popular articles or textbook curricula, the task of teaching them became even more challenging.

> With the methods, there were difficulties from the beginning, since it's something they are not acquainted with, and they have to think harder. In spite of the fact that they know that one needs a regulatory gene and a reporter gene and a gene for antibiotics resistance, and all this stuff, it is difficult [to think about] everything, it's very complex, there are a lot of details. … and the difference between prokaryotes and eukaryotes, there are loads, loads of content knowledge that one has to consider in order to solve a problem. The integration is problematic. (Tal)

When students could not grapple with the complexity of the text, they encountered some cognitive load, leading to confusion.

> If you miss one single step, that's the end of it. (Student in Sara's class)

Teachers' incentive to face the students' challenges when learning complex contents stems from the interest elicited by biotechnological processes and by their belief that the study of methods will promote inquiry learning of biology.

> I think that biology majors should learn about methods used today. They should. The method changes, but the rationale behind it doesn't. (Sara)

Teachers tried to find the right balance along a continuum ranging from detailed descriptions of the method to outlining only the main biological principle upon which it is based. Both extremes have pitfalls, including rote learning, lack of comprehension, cognitive load, and ambiguity, and might lead to a general feeling of difficulty. The instructional strategies for the methods included: prediction or 'redesign' of the method by students; visualization techniques of molecular processes (blackboard drawings, slides, animations); use of flow charts; emphasis on the main biological principles upon which the method or process is based; and participation in wet, hands-on laboratories provided in outreach programmes for high-school students in academic research institutions.

The fact that research articles and biotechnological processes provide students with a naturalistic environment in which previously acquired biological concepts and ideas are used in a novel context, and are useful for solving problems, was also used by the teachers. Comprehension was boosted by both concretization of the previous, sometimes abstract, ideas and their application in a real situation in a way that emphasizes their relative importance.

> I think that in addition to learning biotechnology, the fact that we learned it using articles provided a very real example of the research methods. The articles illustrated all those things and it was very helpful for understanding the material. (Student in Rona's class)

> They [the articles] provide repetition of the same things, but they repeat the important things, really. They emphasize them in order to better know the theoretical aspect. (Student in Naomi's class)

Many methods are characterized by the fact that they harness prior biological knowledge (i.e., antibody–antigen complex in the case of protein quantification, DNA replication in the case of polymerase chain reaction (PCR)). But situating prior knowledge in a new context may raise also new challenges. The episode presented below illustrates the problematic nature of knowledge application in a context different from the original one in which it was constructed as well as the outcome of the instructional strategy applied. During the instruction of the article dealing with promotion of plants' resistance to pests by expressing a bacterial toxin, Rona is evoking students' prior knowledge on the structure and function of antibodies, in order to explain the quantification method enzyme-linked immunosorbent assay (ELISA), which makes use of antibodies.

Teacher:	OK, on page 93 we see the description of a method that is also suitable for the Bt toxin. This method is called ELISA. I would like to stop here and remind you of long-forgotten matters from last year that will also be useful for your next exam on the systems in the human body. An antibody. What is an antibody? We spoke about it in previous lessons.
Student:	White blood cells.
Teacher:	These are cells that are formed in the bone marrow and are connected to what? What do they fight against?
Student:	Bacteria.
Teacher:	Right, we usually speak about antibodies against pathogenic agents.
Student:	Infections.
Teacher:	We spoke last lesson, for example, about immunization against HIV or the flu virus. And we spoke about why we have to immunize against the flu every year. Why is it?
Student:	Because the anti- …
Teacher:	The anti-? The antigen is changing. Now I am going to draw [on the board] what you are looking at in your books, I am drawing an antibody.
Student:	One moment, the antibody is like destroying [the antigen], isn't it?

Rona is attempting to anchor the application of antibodies in the quantification tool to students' prior knowledge. However, her recapitulation of prior knowledge elicits students' formulation of associations that are completely unproductive in the new context.

Discussion

The study reported herein was designed to present teachers' PCK in relation to the enactment of an APL-based biotechnology curriculum within the high-school biology majors' studies in Israel. We focused on the teachers' beliefs and aims, their enacted instructional strategies, and the enactment outcomes as perceived by them and triangulated with their students' comments and with class observations. Since agreement was found between data obtained from the three different data sources used here, namely teachers' and students' interviews as well as class enactment, we believe there is a sound basis to the presented findings.

Teachers' Paedagogical Content Knowledge

The characteristics of the teachers that participated in this study, as portrayed by their narratives, allow us to conclude that, despite being inquiry-oriented, they cannot be considered mavericks in the classical sense; that is, exhibiting extraordinary behaviour that is seldom found among other teachers (Squire et al., 2003). This remark has quite broad implications for the analysis of the data, as it enables us to infer not only from the 'boutique' enactment of APL-based curricula, but from a plausible scenario fitting numerous classes, in order to anticipate the potential usefulness of such curricula.

During the curriculum enactment, teachers deployed a variety of strategies promoting comprehension of complex scientific contents, cognitive and affective engagement, active learning, and inquiry thinking. Overall, the teaching practices used by the teachers were diverse and changed according to the components of the curriculum, the sections of the article, teachers' PCK, and students' constraints. Some of these practices (i.e., the conversational model) were developed and presented to teachers by us, others (i.e., visualization of molecular processes through board drawings) were specifically designed by the teachers themselves, and yet others (use of motivational strategies) were part of their established PCK.

Adapted articles can be taught in different ways. At one extreme, one can envisage a teacher that processes the article's contents and presents them to her students using teacher-centred, conventional teaching. At the other extreme, students can tacitly read the article, comprehend it and summarize its content. Despite the significant difference between these two instructional extremes, in both strategies, students rely on an external factor, either the teacher or the article, to unfold its story in order to acquire knowledge. Similar to a caring teacher, a well-adapted article will slowly reveal its contents and present an orderly analysis of the results in the Discussion section, explaining inconsistencies, raising self-criticism, and suggesting necessary future experiments.

By reading a research article from beginning to end, students are able to learn on inquiry (following Bybee, 2000; Schwab, 1962; Tamir, 1985a); namely, how the scientists performed the research and the rationale behind it. Students are also provided with the opportunity to learn on inquiry since the learning process is based on the analysis of primary scientific communications. However, it is hard to expect that students will be able to apprentice inquiry thinking and apply it in other contexts following the reading of an article. In contrast, the conversational model succeeded in many cases to transform the article into a live inquiry process, or to learning by inquiry (following Bybee, 2000; Schwab, 1962; Tamir, 1985a): students raised hypotheses, formulated research questions based on the previous assumptions presented in the introduction of the article, attempted to design methods suitable for answering these questions, analysed the results, and drew conclusions before checking the validity of the conclusion presented in the article. Learning by inquiry was also elicited by the questions and assignments used by the teachers, both designed by them and suggested by us. Thus, learning by inquiry cannot occur without suitable instructional strategies (i.e., the conversational model). Although both learning on inquiry and learning by inquiry were observed here, only learning on inquiry is an integral part of the APL genre and learning by inquiry is dependent on teachers' appropriate instruction strategy. Overall, these instructional practices greatly conform to the PCK that has already been found to improve students' inquiry thinking: teaching 'enquiry into enquiry' (Schwab, 1962), active learning (Fisher, 2000), suitable discourse (Minstrell, 2000), or adding to task demands (Mannes & Kintsch, 1987). The inquiry-eliciting instructional strategies used by the teachers were complemented by engagement-eliciting and strategies promoting the comprehension of complex scientific contents, aimed to spur students' efforts and to support them.

Although teachers' PCK is considered a key factor in students' benefits and challenges during the enactment of the APL-based biotechnology curriculum, additional curriculum factors, such as the APL genre and the biotechnology content, may have contributed to these outcomes. Within a complex, multi-variable curricular innovation, it is hard to differentiate and find a simple causative link between the relative contributions of each curriculum factor and the enactment outcomes. Moreover, curriculum genre and content characteristics also contribute by promoting teachers' engagement and readiness to use specific instructional strategies. Using second-order analysis (Shkedi, 2005), we attempted to draw a working model that might allow us to look at the influence of the APL genre and biotechnology content on the enactment, in order to superimpose the above-discussed role of teachers' PCK.

The Adapted Primary Literature Genre

The research articles present the stories of scientific discoveries by bringing different scientific ideas in close proximity, in contrast to textbooks where knowledge is hierarchically organized according to main scientific ideas. Possessing a historical epistemology, research articles gradually reveal new content in the context of the investigation in which it was obtained. The first of these two genre's characteristics elicits integration of disciplinary knowledge, while the second facilitates its application. Repetition of the same or closely related content knowledge in different sections of the article, illuminated from several angles, creates an additional hierarchy based on the relative importance of different knowledge topics to the unfolding of the reported research, and facilitates content comprehension.

The fact that the article presents a specific scientific example, anchored in real-life science, situates biological ideas in the context of their application. Learning in a relevant context presents several advantages, such as cognitive engagement (Elster, 2006) and better application of theoretical contents (Finkelstein, 2005). Nevertheless, learning in context might impede transfer of knowledge to other contexts (Mayer & Wittrock, 1996), as students might have difficulty determining the validity of the context-embedded knowledge in new environments. Additional studies are required to sample this possible challenge.

The ordered, canonical, and uniform structure of APL texts offers an enduring and recognizable framework within which specific contents are embedded. This structure formally distinguishes between different stages of the research and between evidence and theory. Students encounter the same structure for every article they study, and the different sections are clearly annotated every time. However, this orderly structure may create confusion among the learners between the process of producing knowledge, namely 'real-world' science, and the process of communicating the research results, namely the research as it is presented in the articles, as previously suggested by Latour and Woolgar (1986).

The expository sections of the APL article, the Methods and the Results, possess the strongest genre-specific characteristics. Although in the process of adapting the Methods section most of the technical details were omitted and the theoretical fundamentals of the methods applied were emphasized, the methods were presented in more detail than previously met by students in other curricula (Yarden et al., 2001). Thus, they conveyed a dimension of reality and a glimpse of real-world science, and contributed to the concretization of previously learned abstract biological processes. The Methods section also provides examples of the different ways in which biological knowledge can be applied toward practical problem-solving. Therefore, the Methods section can create engagement and better comprehension of prior biological contents. On the other hand, the complexity of the Methods section was challenging, often leading to cognitive load, and it is plausible to assume that students' prior knowledge and cognitive abilities were constraints that influenced the enactment outcomes.

The Results section exhibits raw, empirical data, sometimes contradicting the investigators' hypothesis or each other (Chinn & Malhotra, 2002). Since raw data have a strong element of ambiguity, critically reading and analysing them is an additional source of inquiry thinking. The Discussion section was found to be challenging for students who felt that the new inquiry questions and investigators' self-criticism were interfering with the comprehension they felt they had acquired in the previous parts of the article. Those feelings among the students may represent their possible confusion between the real scientific process and the way it is described in authentic scientific communications, as already mentioned.

The Biotechnology Content

Biotechnology research is applicative and rooted in social and economic issues, as biotechnologists use scientific knowledge to design products and technologies with a practical orientation, as presented mainly in the Introduction and Discussion sections of the adapted research articles. At the same time, biotechnology is a domain that enjoys broad public relationships and embodies the essence of modern biology for teachers and students. Both of these characteristics may have elicited the students' and teachers' engagement identified here. The problem-solving framework of biotechnology research gave the students a strong sense of reality that emphasized the practical importance of the research and the utility of the scientists' efforts. This was especially evident in the gene-therapy article where the 'life-saving' message elicited students' efforts to understand the scientific contents involved, and also in the genetically engineered plants article in which students are confronted with the problem of transgene dissemination during reproduction of the nucleus-engineered plants, and the possible solution of introducing genes into the chloroplast genome. This problem-solving orientation of biotechnology is closer to a technology model (France & Gilbert, 2006) than to the classic hypothetico-deductive model of science against which students' knowledge of the nature of science is usually measured (Alters, 1997). We hypothesize that the technology model is more engaging and easier to understand and can be further applied by students, due to its similarity to real-life problem-solving models.

Solving specific problems involves extremely diverse biological knowledge. Part of the knowledge presented in the articles had been previously studied by students in their former high-school biology studies. Meeting it in a different context, in the proximity of knowledge learned in a completely different genre, offers an opportunity for integration of knowledge, and at the same time poses a serious challenge. The scientific investigations presented in the curriculum make use of a variety of methods (i.e., gene cloning, immunoassay, cell transformation, polymerase chain reaction). These methods involve molecular processes that occur in living cells (i.e., DNA replication, protein synthesis, protein–protein interaction and cell differentiation). Because molecular processes occur at the micro-molecular and cellular levels and cannot be visualized without sophisticated equipment, they are abstract for most students (Rotbain, Marbach-Ad, & Stavy, 2005). Additional comprehension challenges occur due to the complexity of the methods and because students have no previous experience in handling molecular methods (Olsher & Dreyfus, 1999; Venville & Treagust, 2002).

Concluding Remarks

In exploring the relative contribution of the main curriculum factors, we uncover complex cause-and-effect relationships. The elicitation of students' engagement is an example of the teachers' PCK acting concurrently with the genre and contents of the curriculum; thus, their positive effect is additive, or maybe even synergistic. In the case of content comprehension, where the biotechnology contents act antagonistically to the APL genre (i.e., complex molecular content challenges comprehension, genre's canonical structure boosts it), the role of the teachers' instructional strategies becomes even more important in minimizing students' challenges and tips the balance toward a favourable outcome. Sometimes, within the same curriculum factor, both beneficial and non-beneficial effects can be detected (i.e., the canonical structure boosts comprehension, but conveys a false message that real-world science is an ordered process). This dual characteristic requires the teacher's unique PCK in order to elicit the beneficial effects and avoid the non-beneficial ones. Finally, whereas the other curriculum factors mainly promote learning on inquiry, suitable teachers' PCK can promote learning by inquiry, allowing for 'enquiry into enquiry' (following Schwab, 1962).

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PAPER 2

Falk, H. & Yarden, A., Stepping into the unknown: three enactment models for the opening sections of scientific articles. (*submitted to The American Biology Teacher*)

Stepping into the Unknown: Three Enactment Models for the Opening Sections of Scientific Articles

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Abstract

Different genres of scientific articles begin to diffuse into science curricula. Adapted primary literature (APL) retains some characteristics of inquiry articles, while adapting their contents to the level of high-school students. By comparing enactment models for the opening sections of an APL article, we aim at supporting classroom use of scientific articles.

Enacting Scientific Articles

Communication of scientific information serves scientists, the general public, science educators and students (Goldman & Bisanz, 2002). Scientists read and write mainly primary literature (research articles) in order to communicate their findings to the scientific community. In contrast, textbooks are the prevalent genre of scientific communication in educational contexts. Although learning through primary literature may be beneficial for students because it represents "real science" through an authentic scientific genre, it is a difficult task for novices, requiring adequate adaptation to serve as a basis for school enactment. Adapted primary literature (APL) is a novel text genre that retains the authentic characteristics of primary literature while adapting the contents to the cognitive level and knowledge of high-school students (Yarden, Brill & Falk, 2001; Falk & Yarden, 2009).

The use of media scientific reports and APL, both based on different extents of primary-literature adaptation, have begun to diffuse into high-school science curricula (Jarman & McClune, 2001; Kachan, Guilbert & Bisanz, 2006; Falk, Brill & Yarden, 2008). In contrast to textbooks, they offer specific examples of up-to-date research and they usually do not follow the hierarchy of the relevant knowledge domain (Falk & Yarden, 2009). Their enactment requires text-based learning, which has long been neglected in science lessons as it was considered antithetical to inquiry learning (Cervetti, Pearson, Bravo & Barber, 2006). Therefore, the promotion of learning by inquiry and of gaining an understanding of the nature of science (NOS) (National

Research Council, 2000) in the context of APL and media reports could become an important aspect of enactment (Falk et al., 2008). The APL genre, initially developed by us for a developmental biology study at the high-school level (Falk & Yarden, 2009) and further applied to additional domains, (Falk et al., 2008; Norris, Macnab, Wonham & de Vries, 2009) retains the structure of the research article and some of its original results. It is therefore more similar to primary literature than the other scientific article genres used in class (Falk & Yarden, 2009). By analyzing the enactment of APL in the classroom, we can obtain a vivid illustration of the challenges presented by scientific articles and of the strategies that might be useful in overcoming them.

Opening the Enactment of an Article

The sections of research articles, and among them the opening sections—Title, Abstract and Introduction, have different rhetorical roles (Swales, 2001). While the Title and Abstract are aimed at providing a concise presentation of the specific research, the Introduction connects that research with previous experiments, in the context of the general-knowledge domain. In APL articles, pedagogical considerations promote the significant conservation of the opening sections' original role and knowledge level during the adaptation process. In contrast, the opening sections of popular reports are adapted mainly to stimulate public interest and to fit the public's common level of knowledge.

According to Lawson (1988), the opening stage of the learning cycle should promote students' exploration of a specific example by direct observations and raising questions. Another enactment model (Singer & Moscovici, 2008) suggests the initiation of constructivist instruction via an immersion stage, during which students both identify tentative patterns and explore their own knowledge as relevant to the problem at hand.

An important question is whether the pedagogical aims assigned to the opening stages of a scientific topic in class are also applicable to the opening of APL articles and if so, what models may be suitable for opening the enactment of an article? What scientific reasoning processes do these enactment models elicit at the students' level and what challenges do they present for the students and the enacting teachers? For instance, our three main interconnected concerns about the enactment of the opening sections of APL were that: a. students would be intimidated by the sudden exposure to an overwhelming amount of novel terms and ideas; b. content aspects might be given priority over aspects of inquiry and NOS understanding, due to the challenging text and the numerous questions raised; c. teachers, although agreeing to the importance of inquiry learning, would revert to teacher-centered enactment models while attempting to facilitate students' challenged comprehension.

Thus, it is important to present and explore several models for "stepping into the unknown" presented by an APL article. Each model presented below is illustrated through the case study of a teacher enacting it.

Methodology

The teachers who participated in this study are 35 to 55 years old, teaching high-school biology for more than 5 years. They volunteered to teach the APL-based biotechnology curriculum (Falk et al., 2008), which is an elective component of the biology majors' syllabus in 12th grade in Israel. The curriculum includes an Introductory Unit and three adapted articles, as previously described (Yarden et al., 2001). The teachers' and their classes' characteristics are summarized in Table 1.

[Insert Table 1 about here]

We videotaped, transcribed and analyzed the discourse emerging during the class enactment of the opening sections of one of the articles from the APL-based biotechnology curriculum (Falk et al., 2008). The article focuses on the use of genetically engineered bacteria as biosensors to monitor the level of genotoxic materials in water. Its opening sections present concepts and ideas not previously encountered by students in the high-school biology syllabus (genotoxic polluting material, bacterial biosensors, recombinant DNA). Nevertheless, these concepts are based on students' prior basic knowledge of the more general ideas of environmental risks, bacteria and DNA function.

Conversational Model

The conversational model, previously suggested by us (Yarden et al., 2001), is based on a teacher-mediated constructivistic dialogue between the students and the article. The model includes the following iterative stages:

1. A student reads the Title, a short section of the article or several paragraphs of a longer section (hereafter referred to as section 1). The teacher then asks:

   T_A: *What can we learn from the title and what questions does it raise?*

2. Students raise questions about section 1. All the questions, without discrimination according to level or to the correctness of their assumptions are recorded on the board.
3. Students make predictions about the way in which some of their questions will be further investigated by the scientists and about the sections of the article that will include the answers to their questions. This second type of prediction is preceded by an exploration of the scientific article's structure and the function of its different sections. At this stage, the teacher is to avoid supplying answers to students' questions or comments on the correctness of their predictions.

   T_A: Please, read the Title [again]. Do we expect the article to deal with this topic?

   T_A: Where [in what article section] will we find information about this question, if at all?
4. By reading the next section or paragraphs (section 2), students find answers to their previously formulated questions and compare the described research with their predictions.

   T_A: Did the Abstract answer some of your questions?

   T_A: Read again, and try to raise a question to which the answer is found in this paragraph.
5. Finally, students formulate new questions arising from section 2.
6. The process (stages 1-5) is repeated.

The roles of the teacher's questions and comments were to elicit the different stages of the conversational model and to facilitate their implementation by clarifying students' utterances, focusing the students on specific knowledge and the article's structural elements and regulating their work. Immediately after reading the Title, students' questions were simple, consisting mainly of "wh" clarifying questions referring to the concepts appearing there:

S: What is a biosensor?

Gradually, students' questions became more sophisticated and research-oriented: they explored the experiments to be described by the article with a focus on the molecular mechanisms related to the structure and function of the biosensor and the stages of its development.

S: How do they [the genotoxic materials] harm the DNA?

Students' questions about the Abstract were, in general, more elaborate than those concerning the Title.

S: Because, if they are just developing it [the biosensor], who said that it can react to all of them [genotoxic materials], maybe it will react in one place and it won't somewhere else.

Since the students expected to find the answers by further reading the article, the reading process was similar to the performance of an inquiry, the questions having a role similar to that of inquiry questions raised in the process of scientific research (Brill & Yarden, 2003).

Problem-Solving Model

The problem-solving model of enacting the opening sections of an article involves presenting the students, before their first exposure to the article, with a problem similar or tangential to the one that the scientists are exploring and asking them to suggest suitable methods and experiments to solve it. During the ongoing collaborative process, students' answers are based on both their prior knowledge and inquiry skills and new, relevant information received from their teacher, according to the advancement of the solution. Therefore, this model is to some extent similar to the enactment of "Invitations to inquiry" (Schwab, 1962). Its main stages are:

1. The teacher presents a problem similar to the practical or research problem investigated in the article. If the problem has social implications, they are explored in order to expose the students to the diverse aspects that may affect the problem-solving. Students' prior knowledge should allow them to understand the problem and equip them with the ability to offer compatible solutions.

   T_B*: We have just established the Water Management Council. You are the managers and you have all the scientific help you need. Now, you suspect contamination of a drinking-water source. How do you proceed?*
2. Students suggest different strategies for solving the problem, taking into consideration as many parameters as possible.
3. The teacher guides this process by supplying new relevant information, posing questions or suggesting alternative ways of solving, and asks the students to analyze the rationale and relative advantages of these solutions.

   T_B*: Let's try to find another way. Maybe it's possible to do it faster and at lower cost.*
4. When a tentative solution is reached (it does not necessarily have to match the solution proposed by the article), the teacher directs the students to read the

opening sections of the article.

T_B: Now, let's read the article together and for the first time you will see a scientific text that was

not written for students, but a real article.

Starting from general questions referring to the metastrategies of identifying a polluting substance, teacher B's questions gradually focused on specific strategies and the methods that could be used. He guided the students to suggest improvements for their suggested strategies, thereby reflecting a main tenet of biotechnology. He opposed some of the students' suggestions by pointing out the practical and experimental limitations (e.g. the polluting substance is unknown, therefore one cannot use a specific indicator) and wrote a summary on the board of some of the principles applied by the students to solve the presented problem.

At the beginning, students' comments were highly unfocused and based mainly on their practical experience in the school laboratory or in everyday life.

S: I would check the water.

S: [One should] see the pH level, maybe bacteria are growing.

Gradually, their comments became more specific, taking into consideration the possible limitations of their suggested solutions:

S: The question is if it's the same in humans [the reaction of animal biosensors].

In the last stage, although the students did not suggest the use of bacterial biosensors by themselves, they could support the rationale for their use, when suggested by the teacher.

S: They are smaller [the bacteria], and smaller quantities [of genotoxic materials] will affect them.

Scientific Literacy Model

The relatively narrow interpretation, which we use here, of the term of "scientific literacy" refers to knowledge about different forms of scientific communication and their uses. The scientific literacy model focuses on a comparison between different genres of articles in terms of aspects of scientific communication—the need to publish the results of one's research, their different audiences and characteristics, the information provided by each genre and their different communication styles and suitability to the relevant audience.

This model is not as rigorously structured as the previous two. It involves exposing the students to the same scientific topic presented in two or more articles belonging to different genres. Usually, the information provided is complementary: while the popular reports present ideas and concepts in a narrative genre and in a simpler language, thereby facilitating comprehension (Baram-Tsabari & Yarden, 2005), the APL articles provide more detailed information that helps elucidate the inquiry aspects. The sequence of the exposure may vary. Some teachers use the popular reports before the enactment of the APL articles: students' questions on these reports are later answered by the information provided in the APL article and the comparison between the two genres is performed after the students have accomplished the enactment of both articles.

In the case study enacted by teacher C, the students were first exposed to the Title, Abstract and most of the Introduction of the APL-based article on biosensors (using the Conversational model). Then they were presented with two popular reports: a short excerpt from a report entitled "Get the bacteria into a chip and ask them if they feel well" (Galili, 2004), and a longer, higher level report entitled "The bacteria will safeguard the water" (Zinger, 2003), both dealing with the use of bacteria as biosensors for detecting pollution in water, from popular scientific websites. The students read each report for about 10 minutes.

The teacher's role was to regulate exposure to the different texts, pointing to problematic paragraphs, asking the students to rephrase them according to the knowledge acquired from the APL article, and asking them to compare the different genres in terms of the NOS aspects related to them.

> *T_C: Well, if you were scientists, in what journal would you have published [the popular report]?*
>
> *T_{CB}: Let's underline sentences [from the popular report], there is at least one confusing, even misleading one... I would like you to try and transcribe this sentence, now, that you know more and you are the experts.*

Comparing both genres helped students understand that analogies and personifications used in popular articles as communicational teasers ["asking the bacteria if they feel well"] should not be taken literally.

> *S: Here [in the media report] in order to explain that a bacterium is in a bad state or something like this, they say that it doesn't feel well.*

In the context of the genre characterization that emerged, students even suggested the concept of open-access publishing as the best way of promoting scientific feedback to one's results:

S: But when they use the internet [to publish], they [other scientists] will be able to react. Like, I am asking for their reaction. I would like to know what their reaction is.

By finding ideas in the popular reports that they had previously suggested in the context of the opening sections of the APL, the students enforced their self-confidence as scientific readers.

Summary and Conclusions

Since the three presented models promote different desirable science-learning skills and processes, we do not suggest a preference for any one of them over the others. While the conversational and problem-solving-based models emphasize learning by inquiry, by formulating inquiry questions, designing methods and planning experiments, the scientific literacy model emphasizes a better understanding of the NOS. While the conversational model relies in part on the students' being responsible for knowledge acquisition, the other two models provide more opportunities for teachers to channel the class discourse toward aspects they consider important. While aspects concerning scientific communication can be discussed in the context of both the conversational and scientific literacy models, the problem-based model is oriented more towards discussing discipline-specific strategies and metastrategies. Both the conversational and problem-solving models take into account that even though students may suggest incorrect answers or pose questions based on wrong assumptions, the teacher does not need to immediately intervene in order to correct them, but can rely on the text to do so. The science literacy model presumes students' prior knowledge of the characteristics of another genre, based on the initial analysis of another text.

However, each model has its own main limitations: a. the conversational model has been reported as time-consuming and sometimes tedious because of its iterative stages; b. the problem-solving model may enhance the teacher's role as knowledge provider and regulator, instead of delegating this role to the article; c. the scientific literacy model may be problematic due to the difficulty involved in finding texts that belong to different genres but refer to the same topic. Indeed, most teachers that have enacted the APL-based curriculum have reported the use of a variety of models, sometimes in the context of the opening sections of the same article, in order to support their different benefits and minimize their respective limitations.

We consider all three presented models to contain the pedagogical components included in the initiation stages of different learning cycles. In the conversational model, posing questions on the article sections that have been read enables exploration of the text, the research described and prior knowledge. In the problem-solving model, the exploration of the discussed problem and the different aspects of its solution provide the same benefits. For the scientific literacy model, reading the first text provides an immersion stage to be further used as a comparison with the additional genres. This parallel can be drawn even though most learning cycles have been designed for problem-solving and hands-on inquiry, and not for science-text-based learning as in our case. An exception is the application of the learning cycle to text-based learning by Musheno and Lawson (1999) that showed that students achieve better concept comprehension by reading a text that presents examples before introducing new terms, which is a typical characteristic of scientific articles.

The reported case studies demonstrate that the three models can contribute to the enactment process of APL articles. We believe that their adoption by teachers will facilitate the use of the different genres of science articles in class, and may promote the design of additional enactment models.

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Table 1: Teacher and class characteristics

Teacher (abbreviation)	Gender	Formal scientific education	School	No. of students in class	Enactment model
A (T_A)	F	MSc (Biology)	Urban, secular	25	Conversational
B (T_B)	M	MSc (Biology)	Religious, boys only	10	Problem-solving
C (T_C)	F	MSc (Biology)	Religious, girls only	9	Scientific literacy

PAPER 3:

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SCAFFOLDING LEARNING THROUGH RESEARCH ARTICLES BY A MULTIMEDIA CURRICULUM GUIDE

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Abstract
We developed a guide for a developmental biology curriculum for high-school students based on adapted primary literature. The curriculum guide was designed on a CD-ROM, enabling us to present authentic teaching episodes and a vast pool of questions and activities to be edited by the teachers, both aimed at providing the teachers with environment-effective advice while enhancing their feeling of autonomy. To characterize the teaching process using the guide, we interviewed four implementing teachers. It seems, according to the idiosyncratic interpretation of the tools provided in the guide by the interviewed teachers, that the curriculum guide was effective in both educating and emancipating the implementing teachers.

1.Introduction

Learning biology through adapted primary literature, has been promoted as a novel requirement in the syllabus for high-school biology students in Israel. The topics to be learnt using adapted primary literature are expected to be from cutting-edge biological research, which is only seldom used in secondary schools. The aims of this curricular change are to enhance the inquiry skills of high-school students and their understanding of the nature of science and scientific communication (Israeli Ministry of Education, 2003).

Primary literature (research articles) is used by scientists in order to communicate their research work to the scientific community (Beall et al., 1999). Learning through primary literature at the university and college level has been shown to have many benefits, the main ones being exposure to the nature of scientific reasoning and communication, critical reading, practice in writing and analytical skills, improved design of the students' own research projects and gained confidence in their ability to reason, research and apply knowledge (Epstein, 1970; Janick-Buckner, 1997; Bandoni Muench, 2000). Primary literature has also been successfully used in journal club forums which serve as a tool for professional development of in-service biology teachers (Brill et al., 2003).

We predicted that the use of adapted primary literature at the high school level would enhance different aspects of scientific literacy and improve students' acquaintance with the nature of scientific research. We expected the students to improve their understanding of the rationale behind the research plan and methods, to critically assert the goals and conclusions of the scientific research and to become acquainted with the characteristic language and structure of scientific communication (Yarden et al., 2001).

It was recently shown that high-school students that read adapted primary literature better understand the nature of scientific inquiry and raise more scientific criticism of the researchers' work compared to students that read the same research presented as secondary literature (Baram-Tsabari & Yarden, 2005). Congruent with these views, we developed a curriculum in developmental biology based on adapted primary literature for high-school biology students in Israel (Yarden & Brill, 2000). The curriculum includes an introductory unit and three research articles that address central topics in the field of developmental biology: differentiation, genetic control of development and cell migration. The articles retained the basic structure characterizing primary literature (abstract, introduction, materials and methods, results and discussion) and have been processed as previously described (Yarden et al., 2001), to accommodate the cognitive level of high-school students.

Learning through adapted primary literature requires novel and challenging modes of teaching, as high-school biology teachers' use of scientific articles in class is almost exclusively limited to secondary literature (Wellington, 1991; Wade et al., 2000; Jarman et al., 2002; Brill et al., 2003). The novelty of the teaching strategies required, stems from the fact that besides coping with new content knowledge, teachers are concomitantly faced with the promotion of skills which are associated with learning through research articles. To assist the teachers that implement teaching using adapted primary literature and to convey them our perspective on the pedagogical content knowledge (PCK) that we considered adequate for the teaching process (Shulman, 1986; Shkedi, 1998), we recently developed a teacher's guide for this developmental biology curriculum (Falk et al., 2003).

When designing the guide, we took into consideration several factors found to influence the use of curriculum guides by teachers: (a) teachers' lack of motivation in using curriculum guides; (b) the variety of teachers' expectations; (c) the teacher's autonomy; (d) the context, language and system of beliefs; (e) the appropriateness of the written medium:

Teachers' lack of motivation in using guides: As a general rule teachers overlook the use of curriculum guides even though they recognize their importance (Fullan, 1991; Shkedi, 1995). It has been reported that teachers use the students' books as their guideline in teaching, thus impeding the necessary communication between the developers and the teachers expected to occur via the guide and promoting the tyranny of the textbook (Ben-Peretz, 1990).

The variety of teachers' expectations: When teachers do consider using a curriculum guide, their expectations are diverse, as they stem from previous content, pedagogical knowledge and experience of each teacher (Abulafia 2003). Some reports have found that teachers are mainly interested in class activities and subject matter, both very practical subjects; they are much less concerned about the intents of the developers (Ben-Peretz, 1981; Shkedi, 1995).

The teacher's autonomy: Another important aspect of curriculum guides is the amount of autonomy that the guide should provide to the implementing teacher. There is evidence that teachers tend to cherish their curricular autonomy, and that the autonomy feeling is an important element in facilitating the teachers' appropriation of the curriculum (Ben-Peretz, 1981; Ben-Peretz, 1990; Shkedi, 1995). The requirement for autonomy reflects the teachers' professionalism in the field and their refusal to hand it over to outside experts (Skedi, 1995). Others view the autonomy requirement as stemming from the educators' opinion that teaching is a craft in which teachers must inventively adapt general precepts to each teaching situation (Harris, 1983), hence rigid recommendations are unproductive. While Eisner's idealized vision is of good curriculum materials, that both educate and emancipate teachers (Eisner, 1990), Shkedi is convinced that, in the eyes of the implementing teachers, the curriculum guide cannot fulfill both functions simultaneously, i.e. combine a clear pedagogical content approach and autonomy (Shkedi, 1998). Shkedi's data seem to argue that there is no equal partnership between teachers and curriculum developers and that teachers do not view the suggestions and approaches of the teachers' guides as an emancipating tool for innovation and change.

The context, language and system of beliefs: It has been suggested that for a curriculum guide to fulfill its role and be used by the teachers, it should stem from the context in which the teachers work. It should advice from the teacher's point of view and use the language that teachers use in their working context. Moreover, the writer of the guide should understand, consider and use the same system of believes as the teacher (Harris, 1983; Olson, 1983).

The appropriateness of the written medium: The complexity of the class situation in which the teachers have to implement the PCK of the curriculum raises additional problems as it is difficult to train professionals for complex practice environments, and still enable flexible responses (Spiro et al., 1988; Eilam et al., 2004). Learning to function in ill-structured situations, like the classroom, cannot be achieved by the compartmentalization of knowledge that may lead to oversimplified interpretations and decision making. This compartmentalization is inherent to written media. Westbury (1983) also raises questions about the appropriateness of the written medium for the communication of practical understanding. Westburry (1983) asked "Is it possible to encode information about something that is as action oriented as is teaching within the limitations that are inherent in the static conventions of a written medium?". Similar doubt was raised by Shkedi's (1995) research that stressed the advantage of workshops compared to curriculum guides in conveying educational practices.

All of the aforementioned considerations lead us to design the curriculum guide for the unit "The secrets of embryonic development: study through research" as a multimedia guide on CD-ROM. The main characteristics of the guide are the inclusion of a pool of questions and activities that can be edited by the teachers and a collection of video-taped authentic teaching episodes. Both were aimed at providing the teachers with environment-effective advice while enhancing their feeling of autonomy. We expected the guide to provide a scaffold for the acquisition of the pedagogical and content tools provided and support the teachers in the appropriation of these tools. Moreover, we hoped that at a later stage of the process of curriculum implementation, the teachers would feel confident to devise, with the help of the teaching models provided in the guide, their own tools oriented toward the same pedagogical aims.

The specific questions we faced while designing the guide and evaluating its effectiveness were:

1. What novel teaching models and pedagogical tools could be offered to teachers, in order to facilitate the teaching of biological contents and skills associated with teaching and learning through adapted primary literature?
2. What are the most effective ways of enhancing the permeation of the provided tools into classroom practice?
3. To what extent would the teachers appropriate the tools and strategies we offer and develop self-confidence in teaching through adapted primary literature?

2. Methodology

2.1- Designing the guide

A curriculum guide to the unit "The secret of embryonic development – study through research" was gradually developed during the first three years of the unit implementation. According to the design research principles which we adopted, we developed teaching strategies and tools, used them in training workshops and circulated them among the pilot group of teachers that implemented the unit. We used different forms of inquiry, in order to establish the suitability of the strategies and tools to the class setting and the teachers' readiness to use them. Subsequently, we altered the materials provided, developed additional materials and adapted new teaching tools, which were suggested by the teachers themselves.

2.1.1- Teachers' population during the design stages

A group of eight high-school biology teachers volunteered to teach the curriculum in three iterative teaching cycles during the initial stages of development of the teacher's guide (two teachers during the first year, three teachers during the second year and three teachers during the third year – one of the teachers taught the curriculum during three consecutive years). An additional group of five teachers participated in a workshop during the last stage of the development and in parallel implemented the curriculum in their classrooms. All the participating teachers taught the curriculum in 11^{th} and 12^{th} grades, who studied towards the matriculation exam in biology, in urban high-schools in Israel. The syllabus for the biology studies in Israel includes, in addition to basic topics, advanced topics, designed for 30 hours of teaching. The matriculation exam includes open questions on these advanced topics.

2.1.2- Design stages

1. The conversational model for teaching and learning through research articles (Yarden et al., 2001), as well as additional teaching strategies, were presented to the teachers during 2 to 3-hour developers-teachers meetings.

2. A first collection of guiding questions and activities for the introduction of the curriculum and for the research articles as well as their answers was developed and given to the teachers.

3. Teaching sessions, in three different schools were video taped. The video tapes were

used during training workshops in order to follow up on the teaching process, identify students' difficulties, and illustrate the teaching process through adapted research articles to teachers that have had no previous experience in teaching through this genre. At a later stage, the episodes were edited and included in the curriculum guide.

4. Some of the difficulties met by students who learnt through adapted research articles were mapped and remedial measures were designed in order to overcome the problems that had surfaced.

5. The last stage in the development of the guide was used as the basis for a teachers' workshop (56 hours). A group of five teachers participated in this workshop, and in parallel implemented the curriculum in their classrooms.

2.2- The implementation process

In order to characterize the extent in which the teachers succeeded in implementing the pedagogical aims of the curriculum and the curriculum guide impact on this process, we interviewed four teachers that implemented the curriculum in their classes. The four high school teachers we interviewed - Hanna, Noa, Sigal (female) and Gil (male) (not their real names) are experienced teachers (more than five years of teaching experience) and had MSc degrees (three teachers) or a PhD degree (one teacher) in Biology before they began their teaching career. Noa's and Gil's research involved topics in developmental biology. Even though several years have passed since they finished their biological research, all four teachers still enjoy recollecting episodes from their previous research experience.

These teachers volunteered to teach the curriculum based on adapted primary literature following previous acquaintances with the developers (Gil), or following a training workshop of 56 hours. During the training workshop the developers taught the articles of the curriculum by implementing the conversational model and other teaching strategies. The teachers began to teach the unit in 12th grade (Hanna, Noa and Gil) and in 11th grade (Sigal) during the 2003-2004 academic year. From the start of teaching the curriculum we provided the teachers with the "Pool of questions and tasks" and with the section "Why and how to teach through research articles?" from the curriculum guide.

During the interviews the teachers were also exposed to a teaching episode from the curriculum guide and were asked to comment on it. The 60-90 minutes semi-structured interviews were conducted at the teachers' homes or schools, recorded using a Sony mini-disk recorder device and transcribed by one of the authors. The interviews were analyzed using the ethnographic-qualitative approach (Guba & Lincoln, 1998).

3. Description of the curriculum guide

The CD-ROM format was chosen for the curriculum guide because it enabled us to present the teachers with:

1. Authentic teaching episodes;
2. Visual models of molecular topics;

3. A gallery of all the pictures in the student's book in a format that allows their use for presentations in the classroom;
4. Web-quest assignment in bioethics;
5. A pool of questions and activities to the introductory section of the curriculum and to the research articles.

In addition, the guide contained the following textual information:
1. An introductory section entitled: "Why and how to teach through research articles". This section presents the developers' opinion about the need to expose the students to research articles and their recommendations about possible means to teach through adapted primary literature;
2. Remedial measures for the difficulties encountered by the students;
3. Activities aimed at enhancing the understanding of different forms of scientific communication;
4. A list of the main biological principles of the articles;
5. Assessment questions from matriculation examinations.

Here we shall further describe and discuss those sections of the guide that we consider to be most relevant to the process of studying through primary literature and which were purposely developed in order to provide support to this novel mode of teaching biology in high-schools in Israel.

3.1- Teaching strategies

The teaching strategies presented to the teachers in the section "Why and how to teach through research articles?" were previously described in detail (Yarden et al., 2001). The main strategy we developed was the "conversational model" based upon an iterative process of constructivist discourse between the students and the article, according to the following stages:
1. The article is read in class, section by section. The students raise questions on each section of the article.
2. Some of the questions are answered by the students by reading the following section.
3. The students make predictions about key elements of the research (research questions, results, suitable methods, conclusions) before reading about them in further sections of the article.
4. This study process can be repeated for each section of the article.

Other teaching strategies proposed were peer-group cooperative reading, and answering questions and jigsaw-groups presentation of different methods or experiments from the article. The teachers were told to choose the strategy that suits them best or to use any strategy they felt would suit their pedagogical aims. Only two main recommendations were given: (a) to proceed gradually, using more guided strategies at the beginning of the teaching process and moving toward strategies that offer the student more independence, and (b) to vary the teaching strategies as much as possible.

3.2- Authentic teaching episodes

The video taped teaching episodes, lasting from 3 to 10 minutes were subtitled and accompanied by the following texts:

1. Description of the background of the recorded episode: school, class grade, previous articles studied by the students, the aim of the study session and the teaching sequence of the session including the recorded episode;
2. Description of the episode: stage-by-stage description of the events occurring during the episode, without any comments (e.g. "The teacher waits for a long time before the first student answers");
3. Pedagogical comments on some of the main didactic and cognitive processes which occurred in the episode. The teachers are explicitly told that these comments solely reflect the authors' view and they are prompted to elaborate upon their own interpretation of the events whenever they feel it necessary.
4. Open questions, asking the teachers to compare the interventions in two or more episodes, or to elaborate on alternative teaching strategies.

The episodes can be watched without viewing the accompanying texts or concomitantly with the scrolling of one of the texts.

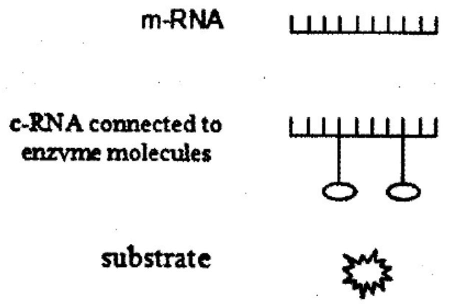
We expected that watching the teaching episodes and analyzing them would lead the teachers to:

- Realistic expectations which may enhance the self-confidence needed for successfully coping with the novel teaching environment of using adapted primary literature
- Context-sensitive modeling stemming from a "virtual" apprenticeship of the novice teachers with the "role models"
- Critical analysis which would include an inherent comparison between the novice teacher's personal teaching style and the "role model" teacher performing in the episode

3.3- Pool of questions and activities

A copious number of questions and activities were developed for each section of the introductory unit and research articles. The teachers were presented with the questions and their answers and in some cases pedagogical comments were added. In the introduction to this section of the curriculum guide, the teachers were presented with a categorization of the questions and were encouraged to use the examples provided (similar to the ones presented in Table 1) as a template in order to formulate their own questions.

By integrating a variety of questions into the teaching process through primary literature, we hoped to facilitate the creation of a dialogue between the student and the content of the article. The logically structured order of the article sections sometimes conveys, to the novice reader, a false feeling of comprehension. The questions on the article are supposed to unravel this false feeling and to compel the student to look for a deeper understanding and for new connections between the ideas presented in the article and the students' previous knowledge (Brill et al., 2004). The teachers were encouraged to use only those questions and activities they feel are best suited for their aims and their students' cognitive level and to modify them using the standard Word tools. It was thought that the fact that teachers can choose from a collection of questions and modify them according to their

Understanding the methods rationale	Which of the following methods could be used in order to establish when and where are the myogenic genes expressed during embryonic development? a.extraction and analysis of DNA from different embryo tissues b.extraction and analysis of m-RNA from different embryo tissues c.in situ hybridization of embryo tissues with c-DNA of a myogenic gene d.protein extraction and analysis e.in-situ reaction of embryo tissue with antibodies against myogenic proteins f.detection of muscle cells in different tissues. (for the article "Lack of skeletal muscles in new born mice bearing a utated myogenin gene). Draw the molecular complex that is formed in embryos when using the c-RNA detection method. (for the article "Genetic regulation of the developing Drosophila embryo head") 
Highlight the main developmental biology ideas of the article	Three groups of genes influence the embryonic development according to the following hierarchy: - genes that regulate the expression of the *bicoid* gene - the *bicoid* gene that encodes for the morphogene of the head formation - genes involved in the head tissue formation and controlled by the product of *bicoid* gene Which group would you expect to be expressed earlier during the development? If a mutation occurs in a gene belonging to one of the three groups, in which group is it expected to have a more critical influence? (for the same article).

needs, may enhance the appropriation of the questions and their usage.

We categorized the questions provided according to the cognitive skills required from the student and the content field sampled by the question, as shown in Table 1. We found this categorization to be suitable for addressing the main aims of teaching through adapted primary literature (Yarden et al., 2001): acquaintance of the students with the nature of scientific research, understanding of the rationale behind the research plan and methods and critically asserting the goals and conclusions of the scientific research. Some of the activities are in accordance with the stages of the "conversational model"- formulating questions, making predictions and finding answers in the subsequent sections of the article. Several questions and activities were added as remedial measures after mapping students' difficulties in studying the adapted primary literature (data not shown).

Table 1. Sample questions or activities from the teacher's guide

Category	Sample question or activity from the teachers' guide
Knowledge organization	Write down the differences between maternal and zygotic genes that determine the embryonic development, considering: the cells in which these genes are transcribed, the transcription time since the fertilization and the stage in which the protein products of these genes are active in the cell. (for the article "Genetic regulation of the developing Drosophila embryo head").
Inquiry skills:	Design an experiment in order to investigate the hypothesis that during two and a half hours after fertilization, the embryo's genes are not transcribed. (for the article "Genetic regulation of the developing Drosophila embryo head").
Critical assessment of the article conclusions	"1From this evidence it is possible to conclude that *myogenin* is not essential when cells begin to differentiate to muscle cells, but... [2]without *myogenin* expression the differentiation will not occur." Write down evidence for each part of this statement from the Discussion section. (for the article "Lack of skeletal muscles in new born mice bearing a mutated myogenin gene).
Application of the main ideas of the article in other contexts	The biotechnology company "Moneygen" reported a sensational success: the production of myogenin containing pills for athletes interested to improve their performances without sweating. The competing company "Musclegen" is also advertising a natural product intended for athletes: their product is a natural plant extract that was shown to increase the myogenin production in mice embryos. As a gym fan, would you use these products? Justify for each of the applications. (for the article "Lack of skeletal muscles in new born mice bearing a mutated myogenin gene).

4. Evaluating the use of the curriculum guide through teachers' interviews

To expose the reactions and comments elicited by the teaching episodes included in the guide and to recognize their possible benefits, we watched, together with each teacher, one videotaped episode from the curriculum guide. We were interested in the extent to which the teachers would be aware of the complex classroom situation presented by the movie and how they would react considering their experience in implementing the curriculum. Hence, an additional focus of this analysis was the variation in the teacher's comments, expected to implicitly and explicitly reflect their previous experience with teaching through adapted primary literature. After watching the episode, we asked the teacher some of the questions provided in the section "Questions to think about" that accompany the movie, without the teacher is being aware that the questions were included in the guide.

In the episode presented to the teachers, a class studying the Methods section of the article "The Hedgehog gene mediates the activity of the polarizing zone of the limbs" is shown. The students are attempting to understand how it is possible for a virus, which they previously encountered only as a pathogen, to be used as a vector in order to introduce a gene into tissue-cultured cells. The impression of the authors was that in order to deal with students' difficulties, the teacher merely repeats her explanations several times, and does not implement any focused strategy while waiting for the students to understand the concept of the virus as a vector. The four teachers had not seen this episode previously and were not acquainted with the teacher involved.

4.1- The reasons for volunteering to teach the curriculum

To further analyze the outcomes of the teaching process, we investigated the reasons the teachers had chosen to teach the curriculum. We found that the teachers' choice stemmed from three main reasons:

1. The content of the curriculum - Noa's and Hanna's enthusiasm to teach a molecular subject in general, or developmental biology in particular.

"I said to myself, this is almost the only subject you teach that is based on 20th century research instead of 17th or 18th century" (Hanna).

2. The genre of the curriculum - the belief that high-school students need to learn a subject through research articles.

"To show the students the real world. They study, but they don't know what happens beyond. The one that studies biology doesn't know what the expert is doing. Is he a biologist? What is he doing? So I teach them and they begin to know. ...because in the school laboratories they are doing everything in the opposite way. A real researcher never comes and the technician hands him a tray with all the materials and the protocol. He first of all asks questions" (Gil).

3. Practical reasons to become acquainted with the curriculum before it becomes compulsory in the high-school syllabus (Sigal).

4.2- The teaching process

Two main aspects surfaced when teachers elaborated on the way they teach the developmental biology curriculum. They found that the main difference between using

research articles versus textbooks for teaching was being able to raise inquiry questions and answer them. In addition, all the teachers noted the relatively large number of inquiry questions which were raised by the students when learning through research articles.
"*Now I remember, they had questions I didn't know how to answer. For instance, they told me, look, you use a complementary probe, right, c-RNA, you have to know the right sequence in order to prepare it, right? So how will you know? It didn't bother me that I didn't know how to answer, it shows that they understand, that they begin to ask nice questions*" (Hanna).

The second aspect emphasized by the teachers was the research methods. The methods are the main characteristic of research articles that are usually absent from textbooks. The teachers reported feeling that they had to focus on the methods because of their importance and because understanding them was one of the main difficulties met by students.

The "conversational model" was implemented by all the teachers, to different extents. The teachers expressed satisfaction from the model and reported that the strategy suited teaching through research articles.
"*The dynamics that is created with all these questions and this deliberation, you almost don't study contents, you learn to deal with an article. So the discourse is at a completely different level. There is a discourse. It's not one-way traffic of information, as when the teacher teaches and the students answer or ask. That's what I like*" (Noa).

Sigal reported that she also enjoyed "the conversational model", for different reasons.
"*As they work in the class it becomes easier than when I give them home assignments. They all participate and they don't drag out some unprepared assignments. So there is an advantage, kind of a dialogue, class work*" (Sigal).

Noa reported applying the "conversational model" for all the three articles included in the unit, while other teachers reported only being able to apply it to the first article studied as the students got bored with its slow pace and were interested in applying other, more independent strategies.
"*I also had the feeling that after they get it [the conversational model] students internalize it and they apply it already by themselves*" (Hanna).

Gil mentioned that the common denominator of all the teaching strategies he used was their student-centered nature, in which the students play an active role in the teaching process. His choice of teaching strategies was dictated by the students themselves since "*if I would have begun to use frontal teaching I would have found myself alone at the end of the session*"(Gil).

4.3- The pool of questions and activities

We were aware that teachers might feel compelled to use all the questions provided in the guide, thus making the teaching process unreasonably slow and tedious. When presenting the rationale underlying the pool of questions and activities, we urged the teachers to use only those that they thought might be useful for their students. We hoped that the fact that they were able to easily edit their own worksheets, would encourage a discerning approach.

In spite of this, Noa reported to have used all the questions, with no difficulty for her or her students. She was video taped in a sequence of three episodes which were subsequently used for the teachers' guide, leading a whole session around two questions from the guide. Gil used mainly activities requiring the students to use molecular concepts in explaining cellular processes, or activities requiring the mapping of molecular concepts. His preference was congruous with the fact that his students had difficulties dealing with molecular concepts. Sigal reported using only questions referring to the introductory unit of the curriculum, arguing that in her opinion in the introductory unit she had to focus on teaching content whereas while studying the articles, the focus was on understanding the rationale of the research.

All four teachers elaborated on the importance of the pool of questions and activities, in contrast to possible superficial reading of the article which may occur without the usage of the questions.
"*Sometimes the better students feel it's too easy... again the same old story of thinking science. They [the scientists] take from here, move there. It seems trivial to the good students. These questions, it's the same experiment they know, but suddenly a small twist [by a question from the teachers' guide]... these things are very important*" (Gil).
A somehow unintended outcome was the fact that the teachers used the questions and the answers to the questions as an ad-hoc guide to content knowledge.
"*Some of the questions opened my eyes to see the things, pointing to a difficulty that I didn't pay attention to when I read the article*" (Hanna).

4.4- The videotapes of teaching episodes

A variety of comments surfaced in response to the videotaped teacher's attempts to help her students understand the rationale behind using a virus as a vector. Hanna considered this to be a process of focusing on the important points of the method, by distinguishing between the main rationale and the less important details. Gil also agreed with the teacher's strategy and defined it as "guided inquiry" – he considered the slow pace that the teacher deployed as an advantage, as it provides the students with the required "time on task" to reach understanding by themselves. Noa interpreted the teacher's behavior as "flowing" with the students: first of all she allows them to try and understand by themselves and her intervention is no more than a "translation" of the students' own words into a better formulated style.

The only one critical of the teacher's reaction was Sigal: "*It will only take longer time, the way she wants to make them understand by themselves, it will take a long time*". As the interview progeressed, Sigal exposed her beliefs about teaching, further clarifying her attitude towards teaching through research articles: "*The way I see teaching, I think that today we exaggerate; we want the students to reach everything by themselves. I feel that they didn't acquire more knowledge or comprehension...you can't manage all the teaching like this, as comprehension should be based on knowledge*".

Her view that content knowledge should be explained explicitly by the teacher and constructivistic approaches should be used only to acquire inquiry skills is further detailed in the following: "*First of all, I would say, that the student should arrive to the article only after he already knows 70% of its contents. The methods and everything. Because the article should elicit thinking but it can't be that it will all be new to the student. I want to teach inquiry skills through the article, but in my opinion the article should come later, after the student has acquired the knowledge*". Sigal's comment was important to us as it illustrates a perspective which is different from ours, but probably prevalent among high-school teachers: that the acquisition of knowledge and skills should be separated.

The role of the teaching episodes presented in the guide were viewed by the teachers on several levels:

1. Presentation of the teaching environment unique to this curriculum and its characteristics such as students' questions, situations that reflect the students' lack of essential prior knowledge. This simulation of the classroom situation challenges the teachers to perform adequately: "*To figure out to what point you should drift with them [the students] and ask yourself should I join them, shouldn't I, should I take them into another direction?*" (Hanna).
2. Watching and appropriating different teaching strategies: "*Here, she [the teacher] is using it nicely, here she is focusing on how to conclude from the experiment. That I buy*" (Sigal).
3. Planning of teaching using research articles: "*You learn what to emphasize*" (Noa).
4. Allowing the experienced teachers to compare the performing students to the students in their own class: "*This is a question that my students raised as well, this virus matter, will the virus harm the cells or not*" (Gil).
6. Enhancing the self confidence of the novice teacher, before he starts teaching using research articles: "*Yes, I think he will see that he is capable of doing it, he might think that it will be difficult, a subject at the leading edge of science, 'maybe I will not make it',* [but] *you see it's possible* (Gil).

5. Comments and conclusions

The use of adapted primary literature with high-school students to study a biological subject may enable the achievement of many scientific literacy goals, including understanding the nature of science and developing inquiry skills. Adequate teaching strategies are required to harness the benefits of the adapted primary literature genre toward the fulfillment of these goals. The purpose of the multimedia curriculum guide was to convey our view on the PCK of study through adapted primary literature, without impeding the teacher's requirement for autonomy.

Since the beginning of the implementation of the curriculum based on adapted primary literature in high-schools, two studies have been performed to characterize the learning process using this genre. The first was a laboratory study (Brill et al., 2004), in which the learning processes of two students reading an article and answering questions from the pool were characterized. The other study reported on an increase in the number of higher-level thinking questions formulated by students during the study of an article from the curriculum (Brill et al., 2003). The present study was a first attempt at characterizing the teaching process through adapted primary literature using reports from teachers who had implemented this teaching in their classrooms. As several parts of the curriculum guide were offered to the interviewed teachers from the beginning of the implementation process, the teachers' opinions about the guide were very strongly connected to their opinions of the teaching process.

While investigating the process of teaching using research articles with the aid of the guide, we found that the videotaped class episodes that are included in the guide facilitate the simulation of teaching situations that occur while studying through adapted primary literature. We found the teachers' stimulated reactions to be consistent with their teaching experience and values, and to a certain extent with their short experience in teaching our curriculum. We assumed that the comments that the teaching episodes elicited were influenced by the reductive bias known to manifest itself when interpreting recorded events (Spiro et al., 1988; Eilam & Poyas, 2004). We harnessed this bias in order to tap into important information on the teaching philosophy and strategies of the interviewed teachers.

By analyzing the teachers comments on the pool of questions and activities, we understood that it not only provided them with an easily adaptable teaching tool, but that through this tool we had also conveyed our PCK perspective. However, since we prompted the teachers to edit and thus appropriate only those questions they felt were suitable for their students, the usage of the questions also reflected the teaching values of the individual teachers. For example, in the belief that the article should not be used in order to teach contents, but only inquiry skills, one of the teachers used only the questions provided for the introductory unit. Considering the molecular concepts and transfers between macro-micro levels to be a main difficulties for the students, one of the teachers used mainly tasks addressing this topic. The teachers even adapted the questions and activities to pedagogic usages which we had not intended. For example, one of the teachers used questions from the pool as a central axis for a teaching session. We encountered this approach while videotaping one of the teaching episodes and, due to the design research approach that we had adopted, in the final version of the guide, this opportunity is mentioned to the teachers. Moreover, the pool of questions and their answers were used by the teachers to gain self-confidence with the content knowledge of the curriculum. These various usages strengthen the opinion that curriculum materials are far richer in their potential than is envisaged by their developers (Ben-Peretz, 1990).

The teachers reported that by providing them with an ample and flexible pool of questions and activities, we influenced the learning discourse in class, leading to a question-rich culture eliciting students' questions. "*They had questions I didn't know how to answer*" (Hanna); "*The dynamics that is created with all these questions and this deliberation, you almost don't study contents, you learn to deal with an article*" (Noa). The importance of teachers' questions to the enculturation of students in asking their own questions has been previously reported (Morgan, et al. 1991; Durham, 1997). The question rich environment created during studying through adapted primary literature is also in accordance with previous reports about the usage of research articles (Brill & Yarden, 2003) and case studies (Dori et al., 1999) as catalysts for students questions. In this study, we cannot separate between the effect of the adapted primary literature and that of the conversational teaching strategy applied during the study sessions in eliciting students' questions, since all the interviewed teachers implemented the unit by applying the "conversational model". Sadly, it seems that this beneficial effect is not of long duration and that both students and teachers associate it only with the adapted primary literature curriculum. When one of the teachers (Sigal) was asked if the "different discourse" continued when the students started to learn a new subject, she said that it completely stopped and that she herself considers it to belong only to study through primary literature.

The conversational model (Yarden et al., 2001), the aim of which is to lead the students to actively build their own knowledge structure while reading an article, uses elements of text-based learning (Pearson & Gallagher, 1983; Epstein, 1970). The fact that this model was used by the teachers when teaching through the research articles indicates that they were prone to adopt the main teaching strategy offered by the guide, negating our former concerns that it is difficult to promote change in teachers' strategies. Our interpretation of this finding is that when dealing with a subject based on new content (developmental biology) and presented in a novel way (research articles), teachers adopt new teaching strategies more easily. However, further analysis of the teachers interviews indicated that although most of them (Noa, Gil, Hanna) reported to have used teaching strategies conveyed by the developers, they mainly adapted previously held beliefs and teaching strategies. The advice in the guide merely rendered these strategies legitimate and their usage more conscious. Furthermore, with respect to this outcome, we cannot at this stage separate between the contribution of the guide and the contribution of the workshop in which the teachers participated (Shkedi, 1998). In other words, we can interpret the changes that occurred in the teaching strategies used by the teachers as belonging to their professional development within their zone of proximal development (ZPD) (Vygotsky, 1962).

The application of the ZPD concept in relation to teachers' development through curriculum materials (Eisner, 1990; Pontecorvo, 1993; Wells, 1999) implies "bringing to life those functions [of teachers] which are embryonic and require conscious control" (Pontecorvo, 1993). Our results indicate that the implementing teachers that we monitored by us were acting within their ZPD, on the growing edge of their competence and the guide provided them with the scaffolding necessary for growth. This is the reason why, in analogy to Smith, di Sessa and Roschelle's recommendation to gradually recraft existing novice knowledge instead of attempting to create a cognitive conflict when teaching new concepts (Smith et al., 1993), we feel that such an attitude can also be fruitful when dealing with teachers' development and when designing curriculum guides.

The different ways in which the teachers chose to implement the unit demonstrate the flexibility of our materials, allowing the teachers to express their individual approaches to teaching and to their classes (Ben-Peretz, 1990). As good curriculum materials should provide resources that amplify the teachers' ability given the circumstances (Eisner, 1990), it seems, according to the idiosyncratic interpretation of the tools provided in the guide by the interviewed teachers, that the curriculum guide we designed both educated and emancipated the implementing teachers.

However, it should be borne in mind that the teachers that volunteered to implement the curriculum are in no way representative of the average biology high-school teacher. Not only are their education level and research experience higher than required for teaching biology in high schools in Israel, but their educational values, as expressed when referring to the reasons for teaching the unit were very similar to the values of the developers. Gudmundsdottir (1990) stated that teachers' values, "passion combined with a sense of mission", can influence the restructuring of curricula. These values permeated the narratives of three of the interviewed teachers, whereas one of them (Sigal) held values which are different from the developers'; she remarked that one cannot teach contents through primary literature, only inquiry skills and she found the implementation process more frustrating. We feel that it may be common to evaluate curricular material by monitoring the teachers whose values induce them to be among the first to volunteer to implement that curriculum. Therefore, when studying through adapted primary literature becomes a compulsory requirement of the syllabus in Israel, we plan to evaluate how teachers who hold other values and have no previous research experience are able to implement it and how helpful the curriculum guide is in assisting them in their endeavor. Analyzing a larger sample of teachers, supplied with the complete curriculum guide, will also enable us to evaluate what sections of the guide are most useful to the teaching process. In addition, we shall attempt to determine whether observing the teaching episodes will also model the teaching strategies to be used by teachers who teach another primary-literature-based curriculum in biotechnology (Falk et al., 2003), for which no teacher's guide is yet available.

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PAPER 4

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"Here the Scientists Explain What I Said." Coordination Practices Elicited During the Enactment of the Results and Discussion Sections of Adapted Primary Literature

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Abstract Adapted primary literature (APL) is a novel text genre that retains the authentic characteristics of primary literature. Learning through APL represents an educational intervention with an authentic scientific context. In this case study, we analyzed the 80-min discourse developed during the enactment of an article from an APL-based curriculum in biotechnology in one class, and examined epistemic practices used by students during their meaning-making of the Results and Discussion sections of the article. Specifically, we examined coordination practices, by which students connected elements belonging to different epistemic status or context (theory, data, experimental stages, biotechnological applications and text). The application of coordination practices was identified more than 70 times during the lesson. In the context of the Results section, the students displayed research-oriented coordination practices, which were frequently associated with claims of comprehension difficulty. In the context of the Discussion section, students displayed text-oriented coordination practices, associated with analysis of the text characteristics. We are suggesting that the research-oriented coordination practices and some of the text-oriented ones enabled the emergence of authentic scientific practices and learning by inquiry. Another type of text-oriented coordination practice enabled reflection on scientists' experimental processes, enabling learning science as inquiry. The enactment model of APL used here allowed for both the emergence of the two dimensions of inquiry learning and the promotion of scientific literacy in the fundamental and derived senses.

Keywords Adapted primary literature (APL) · Biology education · Biotechnology education · Coordination practices · Discourse analysis · Epistemic practices · High school · Inquiry · Scientific literacy

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Introduction

Research articles (primary literature) are an authentic genre of science communication, written by scientists in order to communicate their research findings to the scientific community. For educational purposes, we developed a novel text genre that retains the authentic characteristics of primary literature, while adapting the contents to the comprehension level of high-school biology students, and termed it adapted primary literature (APL; Yarden et al. 2001). Since reading, writing and analyzing primary literature are authentic scientific practices, learning through APL provides an authentic scientific context. In addition, since APL presents students with data obtained through others' research, it can also be termed second-hand inquiry (following Palinscar and Magnusson 2001).

A previous study on the enactment of a biotechnology curriculum based on APL (Falk et al. 2008) showed that engagement, inquiry thinking, active learning and integration of knowledge are among the benefits incurred by students during the enactment. Difficulties were manifested mainly during meaning-making of the molecular methods, probably due to the abstract nature of biotechnological methods and the need to apply prior knowledge for their comprehension. The Discussion section of the APL was also found to elicit difficulties, as it raises new research questions, hampering the self-confidence acquired by the students in the context of the previous sections (Falk et al. 2008). Thus, different sections of an APL article were found to elicit different difficulties among the students.

Within primary literature, the Results section belongs, together with the Methods, to those sections of an article that deal with the particulars of the study (Swales 2001). This part of the article is written in an expository genre and exhibits empirical data in a graphic manner. The empirical data are sometimes ambiguous or anomalous, and can contradict each other or the investigators' hypothesis, unlike the 'clean' data that students are usually exposed to in other learning materials (Chinn and Malhotra 2002). In contrast, the Discussion section displays an argumentative genre, and focuses on coordinating the specific findings with the relevant theory, other research components, and relevant investigations. We hypothesized that the different genres and roles of the Results and Discussion sections in the context of the APL article may call for the application of different epistemic practices by the students. Here we focus on students' coordination practices and claims of difficulty, during the enactment of the same biotechnology curriculum based on APL.

Our research stems from three interrelated theoretical dimensions. The first refers to scientific literacy, in its suggested fundamental and derived senses (Norris and Phillips 2003). Since the APL article presents students with text-based second-hand inquiry, it offers an opportunity to promote both meanings of scientific literacy. The second dimension refers to the two aspects of inquiry learning, learning science as inquiry and by inquiry (Tamir 1985), and the different ways of unifying these aspects by using APL for learning (Falk et al. 2008). The third theoretical dimension refers to the role of authentic inquiry interventions in closing the gap between real-world science and school inquiry, and to the extent to which such inquiry can yield scientifically authentic epistemic practices. Specifically, to what extent can enactment of the APL-based curriculum promote the emergence of scientifically authentic coordination practices? Overall, we wanted to explore the manner and extent of epistemic practice application during the enactment in general, and when tackling difficulties in particular, while referring to aspects of scientific authenticity, inquiry learning and scientific literacy. How are these three distinct but interconnected dimensions confronted by the epistemic practices applied in the context of the Results and Discussion sections?

Theoretical Background

Divergent Meanings of Scientific Literacy and Inquiry Learning

Scientific literacy is one of the main goals of the contemporary effort to educate the citizens of tomorrow towards decision-making (Norris and Phillips 2003). Understanding the tenets of scientific inquiry and the nature of science (NOS) is at the core of scientific literacy (American Association for the Advancement of Science [AAAS] 1993; National Research Council [NRC] 1996; Schwartz et al. 2004). Norris and Phillips (2003) suggested two distinct meanings of scientific literacy: the fundamental sense, which is the ability to read, interpret and write a scientific text, and the derived sense, which is the knowledge of scientific ideas and the ability to use them in a scientific manner. These two meanings of scientific literacy are not concurrent but dialectic, as they support and complement each other (Norris and Phillips 2003).

The emerging idea is that the fundamental sense is critical in supporting the derived sense. The opposite is also true: "How, for instance, can we imagine interpreting a science text by making interconnections throughout the text (an activity we have associated with the fundamental sense) without being knowledgeable of the substantive content of science (literate in the derived sense)?" (Norris and Phillips 2003, p. 236). One of the aspects of the derived meaning of scientific literacy is the ability to think scientifically (DeBoer 2000). Since, from an epistemological perspective, inquiry is simply the process of doing science (cf., Schwab 1962), we regard inquiry thinking as one aspect of the derived sense of scientific literacy.

Inquiry learning has been classified as learning science as inquiry and by inquiry (Tamir 1985). Learning science as inquiry includes learning about the way in which the scientific endeavor progresses, and analyzing the inquiry process performed by others, sometimes using historical perspectives (Bybee 2000; Schwab 1962). This characterization converges with the understanding of the NOS, which refers to the values, influences and limitations intrinsic to scientific knowledge and to science as a human endeavor (Schwartz et al. 2004). Aspects of the NOS that are considered important objectives of science education include: understanding the nature, production, and validation of scientific knowledge, the internal and external sociology of science, and the processes of science (Aikenhead and Ryan 1992). Learning by inquiry, or learning "the abilities necessary to do scientific inquiry" (Bybee 2000), involves the learner in raising research questions, generating a hypothesis, designing experiments to verify them, constructing and analyzing evidence-based arguments, recognizing alternative explanations, and communicating scientific arguments.

Schwab suggested 'enquiry into enquiry' as an optimal approach to promoting inquiry learning, claiming that: "The complete enquiring classroom would have two aspects. On the one hand it would exhibit science as enquiry. On the other hand, the student would be led to enquire into these materials" (Schwab 1962, p. 65). Schwab also claimed that translated and excerpted primary literature can be an optimal intervention for promoting 'enquiry into enquiry'. Since APL provides students with a context that promotes both dimensions of inquiry learning (Falk et al. 2008), an important theoretical question is whether it can also provide a context for promoting both senses of scientific literacy. The claim that text and inquiry require and promote similar cognitive processes (Gaskins et al. 1994) might support this theoretical framework. If suitable scientific texts can promote both inquiry and literacy, a further question would be: in what way do these texts relate to the existing gap between school science and real-world science?

The Gap Between School Science and Real-world Science

While inquiry learning has been established as one of the main goals of school science (National Research Council [NRC] 1996), a gap between real-world science and school science, and between scientific research and school inquiry learning, has been noted (Chinn and Malhotra 2002). Since scientific inquiry tasks given to students in school usually reflect science as "simple, certain, algorithmic and focused at a surface level of observation" (Chinn and Malhotra 2002, p. 190), the cognitive processes needed to succeed in many school tasks are often qualitatively different or even antithetical to the cognitive processes and epistemology needed to engage in real scientific research. At the level of classroom practice, the students' classroom responsibilities, roles and routines differ from scientific practices (Ford and Wargo 2007).

Since authentic scientific research is conducted by scientists in their everyday practice, mapping its characteristics can inform efforts to engage students in authentic scientific tasks and by that promote students' authentic scientific practices and a sound understanding of the NOS (Chinn and Malhotra 2002). The analysis of scientific practices and their investigative endeavor indicates several interconnected attributes:

1. Complexity: Authentic scientific research is a complex activity employing complex theories, highly specialized knowledge, and elaborate and expensive procedures. This complexity calls for reasoning processes that are qualitatively different from those required by simple school tasks, and is reflected by practices that include, among others: transformation of observations, coordination of theoretical models with multiple sets of contradictory data, and rationally and regularly discounting anomalous data (Chinn and Malhotra 2002).
2. Coordination practices: In the process of allowing new knowledge claims into the scientific canon, conclusions should cohere with the range of evidence, even when data are conflicting, demanding high scientific standards to form consistency between theoretical models and observations of phenomena (Chinn and Malhotra 2002; Hogan and Maglienti 2001; Perkins and Simmons 1988).
3. Argumentative rhetoric: Scientific practice is characterized by attitudes of uncertainty as both the techniques and results of scientific inquiry are subject to continual re-examination. Within the processes of coordination and re-examination, an important role is played by rhetoric and argumentation. The discursive processes employed by scientists to construct concepts and theories from empirical data include argumentation as a means of presenting and weighing evidence, assessing alternatives, interpreting texts and evaluating a concept's potential (Latour and Woolgar 1986). Argumentation also plays an essential role in the processes of writing, reading and making sense of the findings of others (Bazerman 1988; Yore et al. 2002).
4. Writing and reading: These scientific practices are considered constitutive parts of science (Dunbar 1995; Norris and Phillips 2003, 2008). Professional research articles are the main tool by which scientists communicate. The canonical structure of the primary literature genre (Abstract, Introduction, Methods, Results, Discussion) drives science writing toward the discipline's norms, values and ideology (Yore et al. 2002). Such reports are meant to serve as arguments for the scientists' claims (Bazerman 1988; Yore et al. 2002). A central communicative feature of primary literature is the use of multiple representations, including graphical ones (Lemke 1998b), to display the experimental results (Myers 1992).

Bridging the Gap Using Authentic Contexts

Authentic activities are described as the practices of a community's culture. By engaging in authentic practices, learners gain access to the practitioners' meaning and purposes (Brown et al. 1989). The implementation of authentic activities promotes the adoption of scientific practices by helping students learn scientists' attitudes, tools, techniques, and social interactions (Edelson et al. 1999). The possibility of recruiting real scientific practices for educational interventions has been previously suggested (Dewey 1964), but its implementation has been scarce.

Although designing authenticity requires mapping the nature of scientific practices and implementing them, it is important to remember that school science differs from real-world science. The differences lie in the questions addressed and the methodology used to address them, and in the students' discipline content knowledge, their motivational goals, commitment, resources and social organization (Chinn and Malhotra 2002; Edelson et al. 1999; Lee and Songer 2003). Therefore, it is important to understand which of the practices attributed to real-world science are presently being used in educational interventions and how to design further authentic contexts to be used in the nonauthentic school setting.

Past calls for promoting the acquisition of inquiry skills using hands-on activities are now being replaced by calls to promote the rhetoric of science based on criticism and argumentation when seeking evidence and reasons for the ideas or knowledge claims (i.e., Jimenez-Aleixandre et al. 2000). Instead of viewing practical experimental work as the basis of students' scientific procedural practices, it is suggested that it be valued for the role it plays in providing evidence for knowledge claims (Millar and Osborne 1998).

Two types of educational intervention that can present an authentic context, namely first-hand and second-hand investigations, have been suggested (Palinscar and Magnusson 2000). First-hand investigations allow students to solve problems themselves, via hands-on projects (Zion et al. 2004), laboratory work (Kanari and Millar 2004), or computerized simulations (Lee and Songer 2003). Second-hand investigations present students with results that have been obtained by scientists (Hug and McNeill 2008): most of these interventions are presented through software resources and only a few make use of texts (Hapgood et al. 2004). The authenticity of these investigations is enforced by the concept that much of what scientists know has been acquired through the thoughts and experiences of others—that is, through learning in a second-hand way (Palinscar and Magnusson 2000). Possible drawbacks raised by text-based second-hand investigations stem from the fact that there is strong apprehension about the use of texts in school science, particularly in the inquiry science tradition (Cervetti et al. 2006); therefore, text has not typically been situated in the context of science curriculum and pedagogy (Palinscar and Magnusson 2000).

Students' Authentic Epistemic Practices

Considering the various types of authentic interventions and curricula, an important question is the extent to which those materials support students' scientifically authentic epistemic practices. Epistemic practices are cognitive and discursive practices that are central to the processes of constructing, analyzing, communicating and appropriating knowledge (Sandoval and Reiser 2004). In the context of the present work, we use the term 'coordination practices' as a type of epistemic practice.

Coordination practices are the connections made by students between elements with different epistemic status (data, theory, experimental stages, biotechnological applications, text) or between the same elements situated in different contexts. Although the term coordination (Chinn and Malhotra 2002; Sandoval and Millwood 2005) is used extensively in the science education literature, several other terms are also used when referring to similar cognitive processes: e.g., interconnection (Norris and Phillips 2003), relation building (Myers 1991), integration of knowledge (Falk et al. 2008), and 'linking' between theory and data (Havdala and Ashkenazi 2007). Coordinating between data and theory is a key epistemic practice associated with authentic scientific inquiry (Chinn and Malhotra 2002; Perkins and Salomon 1989). The application of coordination practices is a challenging requirement of reading scientific articles, since much of the difficulty in interpreting scientific text may lie in a failure to grasp the implied connections between one statement and the next (Myers 1991).

Some of the challenges affecting the use of epistemic practices deal with the complexity of the intervention in relation to students' disciplinary content knowledge (Sandoval 2003; Songer et al. 2003). If students' knowledge level affects the authenticity of the enactment outcomes, and if this level is inherently low relative to that of scientists, the intervention has to establish a fine balance between the complexity of science (Chinn and Malhotra 2002) and the simplicity required for authentic outcomes (Songer et al. 2003). Such a balance seems difficult to achieve, and the teacher therefore plays an important role in promoting the authentic outcomes when enacting interventions with authentic context (Hapgood et al. 2004; Wu and Krajcik 2006).

APL as a Second-Hand Inquiry Intervention

To promote the development of cutting-edge scientific knowledge together with inquiry thinking and a better understanding of the NOS, we developed a biotechnology curriculum for biology majors based on APL (Falk et al. 2008). The authentic attributes of this genre were designed at several levels:

1. The adaptation process retained the canonical structure of the research articles and some of the original results, while adapting their contents to the high-school biology students' comprehension abilities (Yarden et al. 2001). This process preserved the authenticity of primary literature while adjusting to the comprehension level of high-school biology students.
2. An inquiry-associated problem-solving approach (Edelson et al. 1999; Lee and Songer 2003) was addressed by both the problem-solving orientation of the APL genre and the biotechnology content (Falk et al. 2008).
3. Teachers were suggested to enact the curriculum using the 'conversational model' (Yarden et al. 2001) or group assignments followed by whole-class discussions (Falk et al. 2008), thereby mediating a constructivist dialogue between the students and the articles and sharing their knowledge authority with that of the article.

In the present study, we analyze students' epistemic practices during the enactment of an APL article from this curriculum. Specifically, we map and compare the coordination practices deployed by students during meaning-making of the Results and Discussion sections of an APL-based article.

The following research questions are addressed:

- What coordination practices are applied by students in the context of the Results and Discussion sections and what is their role in the class discourse?
- How are the coordination practices associated with students' claims of difficulty in meaning-making?
- What is the extent of scientific authenticity in the applied coordination practices?

Methodology

Research Design

The methodology of the present work brings together ethnography and discourse analysis. It focuses on analyzing the enactment that occurred during two consecutive lessons, in one class, in the context of the Results and Discussion sections of one APL article from the biotechnology curriculum. The teacher's professional development and experience, and her views of the students' cognitive level were explored during two semi-structured interviews: a short one (30 min), performed immediately following the enactment, and a longer one (90 min), performed 1 month after completion of the curriculum enactment.

Research Population

We analyzed the discourse exhibited in one class, in an urban, girls-only religious high school. The students, 17 to 18 years of age (n=8, 12th grade), were considered by their teacher to exhibit a medium-high cognitive level; they had chosen biology as a major subject and had previously studied three compulsory topics (Systems in the human body, The living cell and Ecology) and one elective topic (Microbiology).

The teacher, female, around 55 years of age, had extensive teaching experience, a MSc degree in biochemistry and a good content knowledge of both theoretical and laboratory practices in microbiology and biotechnology. She was teaching the APL-based curriculum for the first time, concomitantly participating in two professional development workshops. This teacher's proficiency with the relevant content knowledge, her engagement as expressed in the interview, and her willingness to participate in two workshops led us to consider her an exemplary teacher.

The small number of students belonging to this study group, the fact that this was the second year they were studying biology with the same teacher and had built a trusting relationship with her, and the fact that their discourse seemed to be unaffected by the presence of the investigator and her video camera, led us to consider the setting as representative of best enactment conditions.

The Content of the Article

This study is based on the enactment of the first article from the APL-based biotechnology curriculum (Falk et al. 2003). This curriculum, which includes an Introductory Unit and three APL articles on different aspects of molecular biotechnology, is an elective topic in the high-school biology majors' syllabus in Israel (Israeli Ministry of Education 2003). Between 30 and 35 h are dedicated to the study of the curriculum in the 11th or 12th grade. Approximately 6 to 8 h are dedicated to the study of each article from the curriculum. The APL article entitled "The development of a biosensor for the detection of genotoxic materials" was adapted from an article published by an Israeli research group (Davidov et al. 2000).

The Results section of this APL article (3.5 pages) includes four graphs; two of them were discussed during the course of the enactment analyzed here, Graph 3 and Graph 4 (Figs. 1 and 2 in the Appendix, respectively). Graph 3 focuses on the performance of the biosensor following storage at 4°C. Its independent variable is storage time (up to 100 days) and the two dependent variables are the biosensors' relative luminescence and reaction time. Graph 4 presents the relative luminescence emitted by the biosensor in the presence of treated and untreated industrial wastewater. The text accompanying Graph 3 introduces the process of embedding the biosensor into a gel matrix in order to monitor water quality in real time, and the need to have a biosensor with a long shelf life for marketing purposes. The text accompanying Graph 4 introduces the need for a biosensor that is sensitive to genotoxic materials (materials that damage DNA) found in a natural mixture, as occurs in wastewater.

The "Discussion" section of this APL article (two pages) discusses the advantages of the genetically engineered biosensor over other monitoring tools, the meaning and implications of the results, an improved measurement method based on dilutions that can be used to avoid ambiguity in the interpretation of the results, as well as other biotechnological applications of the biosensor.

Lesson Context

The two consecutive lessons observed were chosen as a convenience sample, following the teacher's invitation. For these lessons, the students obtained a group task that required each student group to analyze one of the graphs appearing in the Results section. The students were asked to determine the research question and hypothesis, the independent variables and the methodology used for their alteration, the dependent variables and the methodology used for their measurement, to describe the results and draw conclusions. One student (S4), who analyzed Graph 3 together with two other students during the group task, was the only one present in the documented lesson from her group. Therefore, the teacher addressed mainly this student during the first part of the lesson and asked her to present her group's findings.

The two consecutive lessons observed during the course of this study included a whole-class analysis of graphs 3 and 4 from the Results section and an analysis of the entire Discussion section. Out of a total 80 min, 56 min were dedicated to the enactment of the last part of the Results section and 24 min to the enactment of the Discussion section.

Data Collection and Analysis

The enactment was audio- and videotaped during the whole session with a hand-held camera that in most cases could focus on the student who was speaking. The recordings were fully transcribed by a neutral transcriber based on the audio- and videotapes. The interviews with the teacher were processed in a similar manner.

Students' and teacher's discursive turns were numbered consecutively, resulting in a total of 1,158 turns: 869 turns for the Results section and 287 turns for the Discussion section. A turn included the interlocutor's words, until another interlocutor began to speak, or, in the case of two interlocutors speaking at once, until the first interlocutor stopped. Therefore, a turn could include several sentences, fulfilling several discursive roles. The allocated numbers further served as a reference when addressing a specific turn. In cases in which only part of the utterances belonging to a turn were quoted, the number allocated to the turn was followed by a lettered suffix. The turns were attributed to different students according to voice and video identification. The students were each given an annotation (S1, S2…) which remained constant throughout the lesson. Whenever the speaker could not be identified, her utterance was attributed the general annotation 'S'.

The transcribed text was segmented into action/topic episodes according to transitions in the main discussed topic or enacted activity (e.g., a change in episode such as an event or specific activity, or a shift in focus to a different discussion question, (following Jimenez-

Aleixandre and Reigosa 2006). This stage can be problematic, as boundaries across texts are not definite and units of meaning can have fuzzy boundaries (Lemke 1998a). The fragmentation resulted in a total of 36 episodes: 23 for the Results section and 13 for the Discussion section. The role of the determined episodes was auxiliary to the discourse analysis: they were used mainly to facilitate the description of the activities performed in the context of the lesson and to locate the analyzed examples within its framework. The initiator of a new episode was established by determining whose utterance (student's or teacher's) caused the shift in the pursued activity/topic.

Following extensive reading of the enactment discourse, categories of epistemic practices were constructed by moving back and forth (Lincoln and Guba 1985) between the class discourse and various epistemic theories (Chinn and Malhotra 2002; Hofer 2004; Sandoval 2005; Sandoval and Millwood 2005). Subsequently, we focused on epistemic practices with a pronounced cognitive dimension, namely on coordination practices and on claims of difficulty.

Coordination practices were defined as connections made between elements possessing different epistemic status: data, the biological theory explaining the data, experimental stages, practical applications of biotechnology and the text of the article, or connections between the same elements found in different contexts. By scanning the discourse, turn by turn, coordination practices were identified. The emerging coordination practices were studied closely to determine whether certain patterns of such practices repeated themselves and stood out. The detected patterns were analyzed from the perspective of the theory referring to the coordination practices (Chinn and Malhotra 2002; Hofer 2004; Sandoval 2005; Sandoval and Millwood 2005) until a category and type of categorization was crystallized.

In some cases, a single student could complete the coordination practice by herself, by presenting two elements and the connection between them in a single discursive turn. In many cases however, the coordination practice was completed in a collaborative manner, with the help of other students and the teacher's guidance, in several discursive turns. Every such connection was considered a single practice, irrespective of the time spent for its deliberation or the number of interlocutors participating in the meaning-making process.

Claims of difficulty were defined as students' declarations of meaning-making difficulties or uncertainties, expressed as questions, exclamations or affirmative utterances. They were mapped by scanning the class discourse turn by turn.

Overview of the Enactment Session

The enactment session focused on the analysis of graphs 3 and 4 of the Results section and of the whole Discussion section. In the class discourse that took place in the context of the Results section (episodes 1–23, Table 1), there is almost no apparent leading organization of the activities enacted, as most of them stem from student–teacher interactions. This section was organized around the group task, while students' claims of difficulty and the teacher's reflective replies contributed to the open enactment structure. The apparent lack of organization reflected the teacher's didactic goals as stated during the post-enactment interview: "I wanted to see what they understand…what they can reach by themselves, what ideas they can yield." As seen in Table 1, some of the activity/topic episodes (e.g. 2, 3, 9, 10, 12, 16, 18, 22) are directly oriented to meaning-making of the article data, while others are associated with scaffolding of the meaning-making process.

Table 1 Episodes enacted during the study of the Results and Discussion sections of the article 'The development of a biosensor for the detection of genotoxic materials' from the APL-based biotechnology curriculum, by criteria of enacted topic and activity

Episode	Activity/topic episode description	Initiator	Start time	Start turn
Results section				
1	Overview of the last session assignment (students discussing the results of the article in groups) in order to begin the presentation of the student's answers	T	0:00	1
2	The nominated student raises a question about the two dependent variables of Graph 3 which was analyzed by her group	S	1:26	21
3	The students and the teacher raise critical comments on Graph 3	T	3:40	58
4	The teacher asks for an overview of the biotechnological aim of the experiment	T	7:25	113
5	A student is refining the biological and technological meaning of a 'biosensor'	S	10:39	151
6	Students and teacher summarize the differences between the experimental aim and the biotechnological aim and discuss the potential buyers of the biosensor	S	11:22	163
7	The class is refining the aim of developing the biosensor (to detect a variety of genotoxic materials) and discussing how to calibrate the system for a new genotoxic material	S	12:43	183
8	The nominated student begins describing Graph 3 and redefines the term 'relative bioluminescence'	T	17:34	230
9	A discussion on the meaning of an anomalous result in the graph	S	19:03	253
10	Refining the methodology of the experiment in order to understand the meaning of the anomalous data	T	23:00	317
11	Students establish how long it is possible to store the biosensor, in order to still be able to use it	T	26:20	358
12	Elaboration on the presence of mitomycin during storage of the biosensor	T	28:11	389
13	Students are discussing storage at low temperature	S	30:30	441
14	Suggestions about the time of storage to a potential user of the biosensor	S	31:30	463
15	Students suggest how to improve the biosensor	T	32:14	477b
16	Drawing conclusions from the results of Graph 3	T	32:56	486
17	Students are refining the concept of 'reaction time' and its practical implications	S	33:24	494
18	Students again discuss the practical implications of the increase in biosensor reaction time when stored in the cold	S	34:51	527
19	Negotiation on the nomination of another student as a main speaker announcing the results	S	36:00	543
20	Concluding the results presented in Graph 3 of the article. Two parallel discussions: while the teacher and some students are summarizing the graph, one of the students continues to ask about the difference between the storage and experimental conditions	T	36:20	552
21	Re-clarifying the difference between the storage and experimental conditions. The teacher acknowledges the student's question and the deliberation is focused on it	S	38:09	593

Table 1 (continued)

Episode	Activity/topic episode description	Initiator	Start time	Start turn
22	Students analyze Graph 4 of the article	T	49:51	779
23	Refining the analysis of Graph 4 by analyzing the implications of the biosensor's applicability	T	54:15	849
Discussion section				
24	Beginning of the Discussion section analysis. The teacher and the students are presenting their expectations	T	55:40	870
25	Reading aloud and analysis of the first paragraph, recognizing the presentation of the research aims	T	57:00	875b
26	Reading aloud and analysis of the next paragraph, recognizing a summary of the findings	T	58:11	892
27	Reading aloud and analyzing the next paragraph, focusing on the novelty of the information presented	T	59:44	909
28	Comparing the information in the paragraph with the findings of Graph 3	T	1:01:25	930
29	Reading aloud and analyzing the next paragraph, focusing on the novelty of the information presented	T	1:02:28	942b
30	Comparing the scientists' claims with the findings of Graph 1	T	1:03:20	953
31	Reading aloud and analyzing the next paragraph, focusing on clarification of terms	T	1:04:04	977
32	Comparing the scientists' claims in the paragraph with the findings of Graph 4	T	1:05:09	990
33	Reading aloud and analyzing the next paragraph, focusing on the description of an improved measurement method	T	1:06:05	1009
34	Reading aloud and analyzing the next paragraph by comparing the scientists' claims with Graph 2	T	1:08:20	1040b
35	Reading aloud and analyzing the next paragraph, focusing on suggested applications of the biosensor	T	1:11:25	1076b
36	Further deliberations on the application of the biosensor	T	1:15:20-1:17:20	1130b

The initiator of the episode (teacher/student) the start time and start turn are provided for each episode

T teacher, *S* student

In some cases, students needed to understand the differences between the experimental goals and the biotechnological applications of the research presented in the article (for example, in episodes 4, 5, 6, 7, 14, 18, 23, Table 1) in order to make meaning of the research methods and the resultant data. In other cases, students recruited their prior knowledge in order to apply it in the context of the meaning-making process, as in episodes 5, 8, 17 (Table 1). Some of the episodes were iterative and focused on problematic aspects of the Results section of the article. For instance, the fact that the biosensor bacteria were stored for different time periods at 4°C, but were assayed at 26°C was challenging for students (episodes 13 and 21).

In contrast, the enactment of the Discussion section was more structured, and a recurrent pattern emerged: the students would read a paragraph aloud, as suggested by the teacher, who also asked several iterative questions referring to the novelty of the information provided in the paragraph and the scientific research stages reflected by it. After a brief discussion and a summarizing comment by the teacher, a student would begin to read the next paragraph. In several cases (episodes 28, 30, 32, 34), the teacher directed the students to review the data in the graphs in order to establish the validity of the scientists' conclusions as outlined in the "Discussion".

Results

The students' discourse in the context of the Results and Discussion sections of the APL article was characterized by a copious number of coordination practices. We focused on these coordination practices, some of which were elicited spontaneously, others by the teacher. Most student claims of comprehension difficulty, as well as their efforts to address those difficulties, were accompanied by a coordination practice. We distinguished the different types of coordination practices, and investigated their role within the context of the lesson and their scientific authenticity.

Characterizing Students' Coordination Practices

Some of the coordination practices applied by the students were based on causal connections presented in the Introduction and Methods sections of the article, between biological explanations and research stages. Other were developed by students using resources found within the article or by recruiting previous knowledge acquired during previous biology lessons or everyday knowledge. Many of the coordination practices were developed gradually. They were initially built step-by-step, in an implicit and collaborative manner, sometimes involving the teacher's guidance; only later were they expressed explicitly by the students.

Different types of coordination practices were identified and classified into two main categories, research-oriented and text-oriented, according to the focus of their application and the epistemic status of their elements. Meaning-making of the research, the findings and their implications was the main focus of the research-oriented coordination practices, as described further on. Although most of the information used for this category of coordination practices was textually provided in the article, research-oriented coordination practices focused on the analysis of the research itself and not on the way it was described in the article.

Research-oriented coordination practices include connections between any two of the following four elements: (1) the different stages of the experimental research, as described by the 'scientific method' (the research questions and hypotheses advanced, the research methods used, the conclusions drawn); (2) the obtained data, as displayed by the graphic representations; (3) the biological explanations that served as a-priori theory and assumptions for the research; (4) the practical aspects of biotechnology associated with the specific research. Among the most frequent types of research-oriented coordination practices we identified:

a. *Data-theory coordination*, causally connecting the data presented in the graphs with the biological explanations of these data, namely the theory. The theory is based on students' prior school knowledge of the physiology of bacteria, and on the knowledge provided in the Introduction section of the article on the influence of genotoxic materials on bacterial DNA. The following example demonstrates this type of coordination:

246. T: So, why do they have **background luminescence**?

250. S4: Because there is always some <u>damage to the DNA</u>. It's always affecting the <u>regulatory mechanism</u>.

251. S8: But <u>not severe damage</u>.

(In this example, the 'data presented in the graphs' appears in bold, while the 'biological explanation of these data [the theory]' is underlined.)

b. *Data-experimental stage coordination*, involving connections between the data and the experimental stages of the research, i.e., asking research questions, raising hypotheses, designing suitable research methods, performing the experiment and reaching the conclusions. This coordination type is actually a collection of several subtypes of coordination practices (data-hypotheses, data-methods, data-conclusions), not all of them emerging during the discourse.

For this type of coordination practice, students relied on the data presented in the graphic representations in the Results section, on the textual information provided in the Introduction and Methods sections and on additional information provided by the teacher. The following example demonstrates this type of coordination:

231. S4: …and the **relative luminescence**, it's not written here how they measured it, but I guess they did it with this device, the spectrophotometer.

(In this example, the 'data presented in the graphs' appears in bold, while the 'the experimental stage' is underlined.)

c. *Data-application coordination*, including connections between the data and elements of practical biotechnology, e.g., environmental problems and their possible solutions, practical aims of the research, industrial aspects of the product, merchandizing the product.

The following example demonstrates this type of coordination:

820. S3: Now, about **the luminescence**, there is no general trend in industrial wastewater, it's going up and down, up and down, so our conclusion was that **it depends on the day itself**. Like, the companies spilled more wastewater into the sea, one can never know. Because there is nothing special on February 25th, they can't really predict it, every day depends on its environmental conditions, the environmental conditions affect the water pollution.

(In this example, the 'data presented in the graphs' appears in bold, while the 'application' is underlined.)

d. *Experimental stage-application coordination* involves connecting the experimental stages with the aspects belonging to practical biotechnology. The following example demonstrates this type of coordination:

183. S4: So, what I think is, that, OK, after they did **the experiment**, let's say there is a chance that mitomycin and peroxide harm the DNA, so that's it, they place a warning with a list of the harming substances, so they don't need to sell the bacteria, because they just bring it (the list) to the industrial company.

(In this example, the 'experimental stage' appears in bold, while the 'application' is underlined.)

e. *Theory-experimental stage coordination* involves connecting the aforementioned elements of theory with experimental stage, without immediate involvement of the data, as in the following example:

739. T: Some of them died during **storage**, or, what else could have happened in storage?

740. S4: Maybe this gene was affected.

(In this example, the 'experimental stage' appears in bold, while the 'theory' is underlined.)

Text-oriented coordination practices are focused on the text of the article itself, its function, organization, genre and the manner in which it reflects the research process. They connect the text that is being discussed with textual information provided in other sections of the article, or the discussed text with the experimental stage. Two types of text-oriented coordination practices were identified:

a. *Text-text coordination* connects the knowledge presented in a specific section or paragraph of the article with knowledge provided in another section. The students used the text that was previously read aloud by one of the students, as well as prior sections of the article discussed in previous lessons. Since we consider each section of the article as providing a different context, we included this type of coordination within the discussed coordination practices, as a practice that connects between different contexts. The following example demonstrates this type of coordination:

917. T: Is there any new information **here**?

919. S: Yes, **it's faster** [the biosensor].

920. S: They spoke [in the Introduction] about **multicellular organisms [serving as biosensors]**…

926. We just knew that **they preferred the biosensor**.

b. *Text-research coordination* connects the experimental stages with the way in which they are presented in a specific paragraph of the article. The following example demonstrates this type of coordination:

1031b. T: Now, what else is interesting **here**? When [you are] speaking about explanations, what do they [the scientists] bring?

1039. S: They are <u>raising hypotheses</u> and afterwards they are <u>contradicting them</u>.

(In these examples, the 'text' appears in bold, while the 'research' is underlined.)

The Role of Coordination Practices in the Context of the Results Section

In real-world science, data are obtained by complex methods which often consist of multiple stages and are indirect. Empirical findings are often ambiguous, contradictory or anomalous (Chinn and Malhotra 2002). In contrast to textbooks and popular scientific articles, APL retains the characteristics of scientific data within the Results section of the article. Thus, students encounter difficulties during meaning-making of the data and the methods used to obtain them. Since the enactment session analyzed here involved a group task dedicated to meaning-making of the data, the findings presented in the article are more familiar to the students that analyzed them than to the other students. Although the entire article was available to the students, from the class discourse we understood that the students did not use the Discussion section when attempting to make meaning of the data presented in the graphs. The different roles of the coordination practices as applied in the context of the Results section are illustrated in the following examples.

Meaning-making of Data Obtained Using Indirect Methods

The excerpt below illustrates the way in which a student (S4) addresses the complexity of Graph 3, with its two dependent variables. The question she poses is based on coordination between the experimental stage and the data. By 'experimental stage', we are referring to her prior knowledge about the method used to measure the reaction of the biosensor, obtained from the Methods section of the article. By 'data', we are referring to the data presented in Graph 3, in which the luminescence of the biosensor and its reaction time appear as two dependent variables. The coordination between the experimental stage and the data supports the meaning-making process.

> 27. S4: We were not sure if they measured the reaction [time] by the luminescence or if it's two different things, because how could they measure only the reaction? So we thought they measured the reaction by measuring the luminescence. It's like only one single question. Do you understand?
>
> 34. T: Look for a moment, look, you've got the legend of the graph, right?
>
> 41. S4: I think it's like they just wanted to **measure how long it takes them to react and they measured it according to the luminescence** because otherwise they cannot know how long it takes them to react.
>
> 44. T: Anyone, can anyone tell us how it is possible to measure reaction time?
>
> 54. S2: Maybe **from the moment you put in the material until it starts emitting light**?
>
> 55. T: From the moment you begin, you introduce the material, until it starts emitting light.
>
> 56. S4: Right, so they used the luminescence, that's what we said, because **according to the luminescence they knew when the bacteria reacted, at that moment, they knew how long it takes them to start emitting light**. How long it takes them to react. Right?
>
> 57. T: Yes, I get it. Right, you understood it all right. You did.
>
> (In this example the 'data' is underlined, while the 'experimental stage' appears in bold.)

As a first reply to the student S4's question, the teacher uses the legend of the graph to point out the title of one of the curves (turn 34, above), and the student immediately exhibits the same graph-reading practice for the second curve (turn 39, not shown). By using this strategy, the teacher has probably ascertained that the student's problem does not stem from erroneous reading of the graph. Then, she mobilizes a definition of the 'reaction time' concept, which the students previously encountered in the Methods section of the article. Since this term was encountered in a previous teaching session, it is now less accessible to the students, without explicit elicitation. The correct answer is provided by another student (S2, turn 54, above), enforced by the teacher and agreed upon by S4, who can now construct a correct coordination that includes the method of measuring the reaction time. The data-experimental stage coordination practice applied in this excerpt, which was initiated by the student's question and further supported by the teacher and other students until the correct conclusion was reached, served as a meaning-making tool for the complex data presented in Graph 3. The conclusion from this coordination allowed S4 to understand that the curve of the reaction time is measured when the biosensor luminesces, and is therefore different from the curve representing the luminescence of the biosensor.

Meaning-making of Anomalous Data

The example presented below illustrates the coordination practices applied to make meaning of an anomalous point in Graph 3 (see Fig. 1 in the Appendix). One of the curves in this figure represents the dependency of the relative luminescence on storage time. It shows a decreasing trend, except for one anomalous point that is lower than the proximal points on either side of it (the second point from the left). A student (S4) remarks that this is 'unusual' and that her group did not understand the meaning of this anomalous point. Although the teacher intervenes authoritatively (turn 301, below) by claiming that one does not need to explain every point on the graph, the students keep looking for mechanistic explanations for this anomalous point. The complexity of the data that the students have to find a meaning for is illustrated by their attempt to coordinate the ambiguous point with both the possible damage to the bacteria during storage in the cold and the bacterial uptake mechanism of genotoxic materials that may be harmful to them. Both of these theoretical explanations had been presented in previous sections of the article (Methods and Graph 2 in the "Results" section) and the students are attempting to apply these theoretical explanations to explain the anomalous point.

Because of the difficulty in deciding which of the coordinative explanations offered by the students is true, the teacher is exposing the rationale of disregarding an anomalous point. Only then is she able to help her students accommodate both their need to coordinate data with theory and their difficulty in doing so, due to the many possible mechanisms that could be involved.

257. S4: But isn't it a little bit strange?

301. T: You can't look at the value of each point like it's perfect.

302. S8: Yes, it is possible that **the bacteria died** <u>at that point</u>.

303. T: Right.

304. S4: No, **they died here**, <u>in the lower part [of the curve]</u>.

305. S8: But, it could be that they also died <u>here</u>.

306. S3: <u>In the middle</u> [of the curve]? Then, how come <u>they increased again</u>?

314. S8: So, what I'm saying is that it could be that **some of the bacteria died** <u>here</u>.

315. S4: But **they don't die** <u>here</u>, **they die** <u>here</u> [pointing at the graph].

334. S4: <u>Their luminescence went down already</u>.

336. S4: Maybe, **maybe they needed a longer time to get used**…

350. S8: …or **their mechanism was damaged**.

352. S2: On the contrary, **their mechanism functioned better**.

353. S3: No.

354. S: No, no, no!

355. S3: **They were damaged and then more died, relatively**, and that affected…

356. T: Maybe, maybe also, maybe it also affected their background luminescence, maybe they were less affected, maybe there were some other conditions that they [the scientists] didn't pay attention to when they assayed that sample.

(In this example the 'data' is underlined, while the 'theory' appears in bold.)

In this excerpt, the resources used by the students for their theoretical explanations are recruited from previous sections of the article (turns 350, 352, 355 above) and from their prior knowledge about bacterial physiology (turn 336 above). Their attempts to find mechanistic explanations for an anomalous point may be typical of science novices. In contrast, the teacher is modeling the epistemic practices of the domain-specific community of practice (turn 356 above), using resources that she has probably acquired as a participant in this community. By accepting the plausible mechanistic alternatives that may explain the phenomenon, and pointing out the difficulty of deciding between them (turn 356 above), she enables the students to transform their scientific epistemic practices into authentic epistemic practices of scientists, who rationally disregard anomalous data. Commenting on the importance of the debate on the anomalous point, the teacher says:

344. T: But our main question is, look girls, the reason that I am so insistent about this point is because in many of your exams, when you are requested to analyze a graph and you observe some deviation from the general trend, you are immediately alarmed and think that you need to explain it.

From the teacher's comment, it can be understood that although the students displayed a similar difficulty in the past, they did not have the opportunity to explicitly experience the difference between their epistemic practice and the one applied by scientists, and therefore, this was a recurring challenge for them. The present discourse appears to have provided a convenient opportunity to externalize and debate this epistemic aspect.

Meaning-making of Unfamiliar Experimental Methods

Storing bacteria in the cold is a routine practice in laboratories that employ these microorganisms. The low temperatures slow the bacteria's metabolism and rate of division, and in this way they preserve bacterial viability. Because students are not familiar with this practice, it represents a meaning-making challenge for them. An additional challenge is superimposed by the fact that Graph 3 indicates that the stored bacteria do not retain their characteristics as biosensors in storage. A plausible reason could be that the bacteria are dying during storage, in contrast to expectations. Since biotechnological research is mainly driven by practical problem-solving, in many cases the biological aspects are not fully investigated. Although Graph 3 shows that the storage time in the cold affects the luminescence intensity and the reaction time of the biosensor, the Results and Discussion sections of the article do not supply any biological reason for this phenomenon, but focus instead on the practical implications of the findings. This additional complexity represents a challenge for the students who have not previously met the disciplinary practice and rationale of practical biotechnology.

During the collective meaning-making process, the students are applying their prior knowledge in order to explain why the bacteria are stored in the cold. By applying theory-experimental stage coordination, they are trying to coordinate a well-known microbiological process—the slowing of bacterial metabolism at cold temperatures—with the experimental method they have to make meaning of, i.e., why the investigators chose to store the bacteria in the cold. The students suggest two opposite expected outcomes of the storage at low temperatures: that slowing down the metabolism inhibits bacterial division (the right answer) or is killing them.

441. S4: Ah, but why **to store in the cold**?

442. T: Why in the cold? Somebody?

443. S6: The metabolism…

444. T: Wait a moment, why in the cold?

445. S6: Their metabolism…

446. T: What about it?

447. S6: When the temperature is higher, it is faster, when it's colder then it is less [fast]. Their metabolism is slower.

448. T: Slower metabolism and…

449. S7: They could die.

450. S8: They don't divide.

451. T: So they can't divide and then, what becomes possible?

452. S5: **To store them**.

(In this example the 'theory' is underlined, while the 'experimental stage' appears in bold.)

The complexity of this apparently simple experimental method is enhanced by the contradiction between the data presented in Graph 3 and students' prior knowledge of the influence of cold conditions on bacterial metabolism. Although the curve seems to indicate that the bacteria are dying during storage in the cold (the luminescence of the bacterial population is decreasing and its response time is increasing), students' prior knowledge can only explain why the bacteria survive under these conditions.

Students' consideration of both theoretical answers (bacteria do not divide/bacteria die in the cold) may indicate the fragility of their prior knowledge and the problematic application of prior theoretical knowledge in the context of the complex experiments presented in the article, as previously described (Falk et al. 2008). In the present example, coordination of the theoretical knowledge with the method described in the article, with the help of the teacher who acknowledges only the correct answer, is both enforcing the theoretical knowledge and providing an understanding of the method's rationale. Nevertheless, this theoretical knowledge cannot provide the students with an explanation for why the bacteria died during cold storage, and it therefore necessitates the application of further coordination practices.

Criticizing the Graphic Representations

This example illustrates the use of coordination practices to support critical claims about the graphic representations. The critical claims are first presented by S4 as a claim of difficulty, which emerges because the two dependent variables presented in Graph 3, although plotted on the same Y axis, have different measurement units. Under the teacher's guidance, the student's difficulty turns into an explicit critical remark accompanied by a suggestion of improvement (turns 98 and 102, below): such data should be plotted on two different graphs.

92. S4: But it's strange, because one cannot understand something here.

93. T: What can one not understand?

96. S4: I don't know, they got the reaction time, measured in minutes, great, how long it takes [for the bacteria to emit the luminescence] and then the luminescence, in general [the intensity of luminescence] like, it's not the same, completely different, units.

97. T: What you've got here, like, so, what's your claim about this graph, that you actually have?

98. S4: That one needs another graph for it.

99. T: There is a common axis for the two variables that are?

100. S4: Different, they measure different things.

101. T: Completely different, one is measuring the relative luminescence, and the other is measuring the reaction time in minutes. You would expect that…

102. S4: That it should be in different units, like, it's completely different. That they should have an additional graph.

105. T: Did you ever see such a graph? [the teacher is drawing a graph with two Y axes on the board]

106. S6: Ah, yes, **for bacterial division. With logarithms**.

107. S5: Right.

108. T: OK, so we got…

109. S4: **Here we got the bacterial weight and their number**.

110a. T: Right, so we have two Y axes for the same independent variable and each one is measuring something different and has its own measurement units…

(In this example the 'text' in the context of the Results section is underlined, while the 'text' in the context of prior studies appears in bold.)

The teacher is asking S4 to mobilize prior procedural knowledge on the way such data can be presented and is drawing a graph on the board that displays two Y axes. By applying a text-text coordination practice, S4 is first connecting the graph drawn on the board to a similar graph previously encountered during her microbiology studies, which presented parameters of bacterial growth as two dependent variables. This explicit coordination with a scaffolding resource supplied by the teacher (the graph on the board) further facilitates the coordination between the graph that appears in the article and the graph describing the bacterial growth that seems to better fit the representation of this type of data. Critical assessment of the data and the way in which they are represented are important elements of scientific research. In this case, the student, guided by her teacher, is performing a coordination that allows her to develop a critical claim into an implicit suggestion of a better alternative for a graphic representation.

Meaning-Making of the Practical Aspects of Biotechnology

In their meaning-making of the implications stemming from the graphic representation of the data, the students need to understand both the experimental and practical goals of the experiments. For instance, the practical purpose of the experiment presented in Graph 3 is to find the best conditions to increase the shelf life of the bacterial biosensor. The experimental purpose is to find how storage in the cold affects the sensing abilities of the biosensor. The discrepancy between the investigative and practical purposes is an additional source of challenge for the students. Although the practical purpose of the research as a whole is stated in the Introduction section of the article, the practical purpose of the specific experiment is not explicitly stated, either in the original article or in the APL version of it. Its inference from the information included in the Introduction and Results sections is possible, but depends to a great extent on the familiarity of the discussant with the biotechnological rationale.

In the following excerpt, the teacher states the significance of the short shelf life of the biosensor for its developer. She then uses an analogy between the biosensor's shelf life and the importance of the shelf life of milk products for their manufacturer. Although the concept of shelf life is unfamiliar to the students in the context of biotechnology, their familiarity with it in the context of everyday life and the analogy drawn by the teacher enable them to deliberate within the biotechnological context. Following the analogy, they apply two coordination practices. The first coordinates between two applications: the shelf life of the biosensor and the economic implications for its producer. The second coordinates between the shelf life of milk products and the shelf life of the biosensor that is the subject of the investigation presented in Graph 3. The application of these coordination practices allows students to understand the importance of determining the shelf life of the biosensor before supplying it to consumers, and therefore, meaning-making of the practical purpose of the experiment has been achieved.

137. T: Why isn't it applicable?

138. S2: Because, if they are going to **store it [the biosensor] for many years, they [the bacteria] are going to die*** and then all the money they've invested*…

139. T: OK, now, just a moment, if they are going to store them for many years, then it's OK. I, as a developer could be really satisfied. I got a product with a shelf life of several years. What's the problem? Not several years.

140. S3: **Here it's a matter of days**.*

141. T: Of days, do you understand? That I have developed a product whose shelf life…

142. S: **Is short**.*

143. T: Is short and then?

144. S: It is not worth producing it.*

145. S4: It's a waste of money.*

146. T: It's almost like…yogurt and cheese.**

147. S4: But **here [for the biosensor] they do not know for how long [it can be stored]**.**

(In both examples the 'application' referring to the shelf life of the biosensor appears in bold, while in the first example [marked with *] the 'application' referring to the economical implications is underlined and in the second example [marked with **] the 'application' referring to the shelf life of the biosensor appears in bold.)

In this example, coordination of an application element with everyday life that is familiar to both the teacher and the students has supported the understanding of the practical aspects of biotechnology which are not explicitly presented by the article.

Improving the Experimental Design

In several cases, coordination practices were performed in the context of future experiments that were suggested by the students as an alternative to the experiments and applications presented by the scientists. For instance, using experimental stage-theory coordination, the students suggested increasing the shelf life of the biosensor by storing spores, as an alternative to storing bacteria in the cold.

477a. T: If you were the developers of the biosensor, what would you have done [in order to increase its shelf life]? Do you have any idea?

478. S2: **Look for a more resistant bacterium**.

479. S4: **Use these bacteria**…

480. S2: **For a longer time, so that it will be possible to keep them longer in the cold**.

481. S4: Ah, **it's possible to use their spores**.

482. S: What?

483. S4: Yes, and then it will be possible to keep them for long periods of time and germinate them when required.

484a. T: Yes, maybe, maybe it's not such a bad idea.

(In this example the 'experimental stage' appears in bold, while the 'theory' is underlined.)

In this case, prior school knowledge about bacterial physiology supplied the resource for the theory of the performed coordination, while the experimental-stage element, using spores during storage, is based on an attempt to improve the research method used by the scientists.

Association of Coordination Practices with Claims of Meaning-Making Difficulty

The analysis of the discourse in the context of the Results section showed that many of the coordination practices are associated with claims of difficulty or uncertainty in the process of meaning-making of the data and of the experimental and practical elements related to the data. The difficulty was expressed both as questions and affirmative utterances, as described in the Methods section (under "Data Collection and Analysis", above). Since students' claims of difficulty are intended activities that are used by them in the process of acquiring and evaluating knowledge, we considered them to be a type of epistemic practice. This type of authentic practice stems from the students' motivation towards meaning-making of the Results (in contrast to some traditional school situations in which the teacher is the one probing for or even admonishing meaning-making difficulties). In most instances, the claims of difficulty seemed to be based on metacognitive processes, as they emerged from attempts to regulate previously acquired knowledge within the context of the Results.

For Graph 3, the meaning-making difficulty was associated mainly with the data (i.e. anomalous data), the data representation (i.e. two dependent variables plotted on the same graph), the complexity of the research methods by which the data were obtained (the absence of mitomycin during storage in contrast to its presence when assaying the stored bacteria), and the superposition of practical biotechnological goals on the investigators' biological research goals. An additional difficulty stems from students' epistemological commitment, which is explicitly expressed by an exclamatory utterance during an argumentative challenge, when attempting to answer a question posed by the teacher based on Graph 3:

> 358 T: If you would have sold this product [the biosensor] what would you have suggested to the buyer?
>
> 360–378 [Students are suggesting different storage times without warranting their claims]
>
> 379 S3: But how did you establish this? You cannot say it just like that.

No one challenges S3's statement, and during the entire discourse, her explicitly expressed epistemology seems to be an established presumption within this class community, even if it is not always implemented. We consider this epistemological stance a difficulty because it motivates the students' need for coherence between theory, data and research.

Coordination practices were expressed in 13 (65%) of the 20 claims of difficulty referring to Graph 3. The total number of coordination practices associated with this graph is relatively high (39), representing 80% of the total coordination practices applied in the context of the Results section. The claims of difficulty referring to Graph 4 were mainly associated with questions asked by the teacher, requiring coordination between the data in the graph and the aim of the experiment and its conclusion. The difficulty was apparent in the students' ambiguous or contradictory answers but it was not explicitly claimed. The total number of coordination practices associated with Graph 4 was relatively low, only 20% of the total coordination practices applied in the context of the Results section.

Although the task assigned for the two graphs was identical, several possible reasons might explain why students found Graph 4 to be less problematic. Only one dependent variable is displayed in this graph, in contrast to the two dependent variables in Graph 3, leading to less ambiguity. In contrast to Graph 3, Graph 4 is based on observations and not on an experimental manipulation, and therefore the students did not spend time searching for the specific mechanistic explanation of the findings, as they did in Graph 3. Additional reasons might be that the students in charge of the analysis and presentation of Graph 4 were less metacognitive, or that they had internalized some practices from the meaning-making process of Graph 3, such as the fact that one does not always need to find the exact mechanism explaining anomalous or fluctuating data (as discussed above).

Since the teacher allowed the debate over each graph to exhaust itself before moving to another topic or activity, the time dedicated to each graph was different: 50 min for Graph 3 and 6 min for Graph 4.

The Role of Coordination Practices in the Context of the Discussion Section

The argumentative genre of the Discussion section was unfamiliar to the students of this class, as this was their first article from the curriculum that they were learning. In the course of their study of biology towards the matriculation examinations, these students will need to write a discussion for a required ecological inquiry project. Thus, their teacher aimed the analysis of the Discussion section to the text and to the information that it should include, in order to model the scientific writing of a discussion. The following example of the teacher's instructions demonstrates this aspect:

870. T: Now we are going to read the Discussion section, and I want you to pay attention to two interesting things. What is the structure of the Discussion? How do they construct it? Do they use a certain method that maybe you can copy? Because you've got a discussion to write, right, for your ecology projects, so pay attention to the structure of the Discussion, what they include and what they don't. I also want you to pay attention to whether any new information appears here that we didn't already know…

The students read the Discussion section aloud, in class. They read the successive paragraphs of the Discussion section according to the segmentation suggested by the teacher and created meaning of each paragraph by coordination with the information provided in other sections of the article or with the inquiry process performed by the scientists, as outlined by their teacher. The different roles of the coordination practices applied in the context of the Discussion section are presented below.

Assessing the Novelty of the Information Provided in the Discussion Section

Students view the Discussion section as representing a summary of the data presented in the Results, without being aware of its argumentative role. After the students read one paragraph of the Discussion that referred to the importance of the biosensor relative to other tools for monitoring pollution levels, they coordinated the information in the paragraph to the knowledge they had acquired previously in other sections of the article. They distinguished between the detailed information provided in the Discussion section and the more concise information provided in the Introduction section of the article. The biosensor 'reaction time' that is referred to in the Discussion section was not mentioned in the Introduction, but was measured in the experiment presented in Graph 3 and was analyzed in the first part of the enactment session. One of the teacher's questions (turn 917, below) promoted students' coordination of the information provided in the Introduction section with information provided in the Results section (text-text coordination). Since the information about the reaction time without storage is included in the data in Graph 3, the teacher directs them to this graph, where they are able to detect it:

917. T: Is there any new information here?

918. S4: **They are comparing this method to other methods**.

919. S: Yes, it's faster.

920. S: <u>They spoke [in the Introduction] about multicellular organisms.</u>

921. T: OK, they compare it [the bacterial biosensor] with multicellular organisms, what else?

922. S3: **The ratio of the reaction rate**.

923. S: **The reaction rate**.

924. T: Did you know about it until now?

925. S: No.

926. S3: We knew they preferred the method of the biosensor…

927. T: …that they are investigating, and they want to know if the biosensor has a shorter reaction time, but did you know, from the experiments, that one can measure the light emission only two hours later?

928. S: No.

929. S: No.

930. T: …from the moment they exposed the biosensor to genotoxic materials? Now, is this what is presented in Graph 3?

(In this example the 'text' in the context of the Introduction and the Results is underlined, while the 'text' in the context of the Discussion appears in bold.)

In this case, we consider that a coordination practice has been performed, even though the student negates the appearance of the same information in previous sections of the article, correctly for the Introduction, and erroneously for the Results.

Additional similar examples occurred while discussing other paragraphs of the Discussion, and the teacher's question "Is there any new information?" is iteratively repeated for each new paragraph. The coordination practices applied in this context are consistent with the teacher's recommendation that the students should detect any new information that is provided in the Discussion section.

Meaning-making of the Scientific Inquiry Process

Two excerpts illustrate the characterization of the scientific inquiry process. The first one, referring to a simple paragraph, presents a correct coordination. The second one, referring to a more complex paragraph, presents a wrong coordination and elaborates upon the meaning of the mistake displayed by the students.

Immediately after reading the first paragraph of the Discussion, the students are required to recognize what stage of the research it is reflecting:

885. T: What do we have here?

886. S6: A kind of **an introduction to the experiments** that they are going to perform.

887. T: OK.

888. S7: That's like **their purpose**.

889. S: **What they performed in the experiment**.

890. T: Right, actually they are presenting here the experimental aim, right? Or how they raised the research question.

891. S2: **The reasons to perform the experiment**.

(In this example the 'text' is underlined, while the 'experimental stage' appears in bold.)

By collaborative meaning-making, the four students advance from a coordination that includes a general literacy element—"kind of an introduction"—to a coordination including a scientific literacy element—the experimental goals—which refers to the experimental stages, which is further reinforced by the teacher. In the context of the Discussion section, students further recognize the stages of the biosensor's technological design and the research questions involved.

In the 33rd episode, following the reading-aloud of a paragraph, the students are coordinating between the text and the stage of the research reflected by it. The discussed paragraph refers to the different possible conclusions to be drawn from Graph 1 which presents the dependence of the biosensor's luminescence on the concentration of genotoxic material. The luminescence is reduced at both low concentrations, because the bacterial DNA is not affected, and very high concentrations, because the bacteria are dying. A method based on the dilution of industrial wastewater aliquots can explain this ambiguity and is suggested in the same paragraph.

In the context of the analysis, the students applied a text-experimental stage coordination practice, claiming that the scientists provided alternative explanations for the data being discussed. This coordination, although correct in the context of the graph, does not consider the rhetorical role of these alternative explanations within the macro-level of the Discussion section, where they argue for the need for a measurement based on dilutions. We witness here the students' difficulty in grasping the role of the alternative explanations provided in the Discussion. This may stem from an erroneous text-research coordination, referring to the alternative explanations as hypotheses.

1031b. T: Now, what else is interesting <u>here?</u> <u>When speaking about explanations, what do they bring?</u>

1032. S: **Different possibilities**.

1033. S: **Hypotheses**.

1034. T: They present different explanations, different hypotheses.

1035. S3: But **they are contradictory**.

1036. T: Or alternatives, they present the alternatives and then they…

1037. S2: …are **suggesting an experiment in order to explore them**.

1038. T: They are suggesting an experiment, no, they already did the experiment.

1039. S: **They are raising hypotheses and afterwards they are contradicting them**.

1040a. T: "That's what we did, that's why we did it." They are saying why they used several dilutions. It means that they are presenting different alternatives and are contradicting them. They say why this is not possible. They are not satisfied with only one explanation, "that's how it is," so they raise several other alternatives.

(In this example the 'text' is underlined, while the 'experimental stage' appears in bold.)

Students' difficulty in distinguishing between past experiments, reviewed in the Introduction of the APL article, and the experiment that is the focus of the article, has been previously reported (Brill et al. 2004). Here, we can see the same difficulty arise during the enactment of the Discussion section. This difficulty further influences the manner in which the students recognize the actual stage of the research.

The teacher's summarizing comment focuses on the scientific process, emphasizing the scientists' suggestion of alternative explanations and their rhetoric when presenting them.

Although she previously remarked that the experiment had already been done (turn 1038, above), she does not explicitly refer to the students' mistake when regarding these explanations as hypotheses.

In the above example, the students are using their prior knowledge of science as inquiry in order to recognize the scientists' hypothesis. Knowing about the 'scientific method' and its stages is part of the high-school biology curriculum, referred to, for example, during research laboratory sessions and when analyzing 'unseen' texts. Since their prior knowledge is based on external factors (a hypothesis is the claim that precedes the description of a procedure) and because of the complexity of the text, in the present case they cannot apply the coordination correctly.

Analyzing the Validity of the Scientists' Conclusions

In the context of episodes 28, 30, 32, 34 (Table 1), as guided by the teacher, the students return to the graphic representations of the Results section, and coordinate the scientists' conclusions in the Discussion section with the data upon which these conclusions are based. When the students are again confronted with the data presented in the graphs, the types of coordination practices performed are identical to the ones applied during the analysis of the Results section. In most instances, the students apply research-oriented coordination practices in order to reach their own conclusions from the data, usually overlooking the required coordination with the scientists' conclusions as exposed in the Discussion section.

953. T: What they are suggesting, I mean, let's go back for a moment to Graph 1, what do they say?

954. S3: That the fact that the luminescence is different…

955. S: That **[with] mitomycin**…

956. T: That [with] mitomycin…

957. S5: It **[the biosensor] is reacting stronger**.

958. T: It is reacting stronger or it is more toxic than with peroxide?

959. S8: But it doesn't make sense, it doesn't make sense to me!

960. S6: That's why **its light emission reaction is faster**.

961. S8: Because **they are dying faster**.

(In this example the 'data' is underlined, while the 'theory' appears in bold.)

The above example shows that although at the beginning of this sequence, the students refer to the scientists' conclusions (turns 954–957, above) as directed by the teacher, following an apparent contradiction, they try to find a meaning for Graph 1 using data-theory coordination. When confronted with the data in Graph 1, a student claims meaning-making difficulty, but following the collaboration with her colleague, she is able to complete the coordination correctly and to understand the meaning of the data.

Characterizing Similarities Between Scientists' and Students' Inquiry

The analysis of the discourse in the context of the Discussion section reveals two instances in which students coordinated between practices exhibited by them and by the scientists that wrote the article. In one, the students are performing a text-experimental stage coordination in which the experimental stage component refers to the coordination practice underlying the scientists' own argumentation on the meaning of their results:

1027. T: What they [the scientists] do here, they begin [to discuss] each graph, one by one.

1028. S: They also **connect one to the other**.

1029. T: They begin to explain the results, not only to describe them.

1030. S: They are also **connecting between the graphs**.

1031a. T: Right, they are also connecting between the graphs and with the results of parallel experiments.

(In this example the 'text' is underlined, while the 'experimental stage' appears in bold.)

In this sequence, although the students recognize the coordination performed by the scientists between the data presented in different graphs, neither they nor their teacher is explicitly noticing the similarity to their own coordination processes.

In contrast, in the next sequence, the student is aware of the similarity between her explanations and those of the scientists, and is emphasizing it, in order to gain legitimization for her own views.

1051. T: What do they say at the end [of the paragraph]?

1052. S8: Here* **the scientists explain*** *what I said.** Why, the sensitivity, ***why the same reaction occurs***,* because we expect that [with] mitomycin…**

1058. S8: We expect a more, a stronger reaction, like it will increase more, the luminescence reaction** because we know **that it is not removing [genotoxic] materials**.**

(In the first example [marked with *], the 'text' is underlined, the 'scientists' experimental stage' appears in bold, 'the students' experimental stage appears in italics, while the 'scientists' and the students' common experimental stage' appears in bold and italics. In the second example [marked with **], 'data' is underlined, while 'theory' appears in bold.)

Two different adjacent coordination practices are apparent here. The first is a combined text-experimental stage coordination performed between the text "here", the student's previous explanation "I said" and the scientists' explanations "they explain". This type of research-oriented coordination is unique in this lesson. It emerged in the context of the enactment sequence used, which promoted students' inquiry and meaning-making of data in the context of the Results section, before reading the scientists' conclusions in the Discussion section. We can understand from this student's comment "Here the scientists explain what I said" not only the cognitive process of coordination between her view and the scientists' view, but also a dimension of symmetric partnership between them. The second coordination, between the data presented in the graph (increased luminescence of the mutant bacteria) and the biological explanation of this phenomenon (the mutant bacteria cannot pump out the genotoxic material), is a data-theory coordination, similar to the coordination practices illustrated in the paragraph referring to the analysis of the validity of the scientists' conclusions.

Mapping Students' Coordination Practices and Discourse Characteristics in the Context of the Results and Discussion Sections

A difference in the profile of coordination practices that emerged in the context of the Results and Discussion sections was identified. The Results section prompted a relatively high percentage (96%) of research-oriented coordination practices fitting many of the characteristics of real-world science coordination practices. In only two cases (4%) were text-oriented practices applied in the context of the Results section. In contrast, in the Discussion section, 65% of the coordination practices belonged to the text-oriented category, fitting the characteristics of reading as an inquiry process. The other coordination practices applied in the Discussion section (35%) were classified as belonging to the research-oriented category. They occurred when the students and their teacher re-explored the graphs from the Results section, in order to make meaning of the investigators' conclusions as presented in the Discussion.

Discussion

Our study of the coordination practices applied in the context of the Results and Discussion sections of an APL-based curriculum is based on the analysis of a discourse that took place in a naturalistic whole-class setting. We found that the students applied various types of coordination practices that we classified into research-oriented or text-oriented categories. The text-oriented coordination practices were applied almost exclusively in the context of the Discussion section, while the research-oriented coordination practices were applied in both sections. In the Results section, the students used the research-oriented coordination practices to make meaning of the graphically presented data, the research methods employed by the scientists and the practical aims of the biotechnological applications of the data. These practices were also used when students criticized the data representations, when they suggested an improved experimental design or biotechnological application, or while interpreting the scientists' conclusions. The research-oriented coordination practices were found to be associated with students' claims of comprehension difficulty, either as congruent with the claims themselves or as part of the collaborative meaning-making process while overcoming the claimed difficulties. In the context of the Discussion section, the research-oriented coordination practices were used to assess the validity of the scientists' conclusions. As already noted, the text-oriented coordination practices were applied almost exclusively in the context of the Discussion section. Their role was to characterize the genre of this section and the scientists' research as reflected in the various paragraphs.

These findings enforce several conclusions made in our previous analysis (Falk et al. 2008), where students' integration of knowledge, originating from both the genre and content of the curriculum, was a prominent characteristic noted by teachers (Falk et al. 2008). However, the need for integration of knowledge was also considered a challenge, attesting to the complexity of the genre. This manifestation seems to indicate that the application of coordination practices is promoted in the course of APL-based learning. On the other hand, in other classes we did not detect such a high number of coordination practices (unpublished observation). Therefore, the generalization of our findings awaits additional studies.

The enactment sequence implemented in this lesson allowed active learning in the context of the Results section, preceding a more guided learning in the context of the

Discussion section. Thus, students were allowed to first make meaning of the findings on their own and then read about the scientists' interpretation of those same findings. This enactment sequence allowed for further coordination between the students' and scientists' conclusions.

Class enactment involves a complex integration of numerous interrelated and independent factors (Shuell 1996; Wu and Krajcik 2006). In our case, the main interacting factors were APL-dependent ones (Falk et al. 2008), including the genre and content of the article, and the teacher's APL-related Pedagogical Content Knowledge (PCK). APL-independent factors, such as students' prior knowledge, the class culture and the teacher's communicative approach, were important as well. We attempted to focus our study on the association of coordination practices with the genre and content of the article. This was achieved by comparing the discourses referring to the Results and Discussion sections during the same lesson. Nevertheless, it is important to bear in mind that our findings are influenced by the teacher's educational goals for the two sections (following Schoenfeld 1998) and by her instructional strategies, emanating from her APL-related PCK. The group task assigned by the teacher and her willingness to allow for argumentation and collaborative meaning-making in the context of the Results section made use of the genre characteristics of this section (i.e., the graphic representations), students' prior knowledge in microbiology and their prior skills in graph analysis. The teacher's structured approach in the context of the Discussion section suited the students' nonfamiliarity with reading scientific texts and their need for a model of scientific writing for another school assignment. As previously noted by several investigators, the enactment of second-hand inquiry seems to be sensitive to teachers' strategies, making it difficult to distinguish between the influence of the genre and that of teacher (Hapgood et al. 2004; Hug and McNeill 2008; Tabak and Baumgartner 2004). Therefore, we believe that the teacher's exemplary enactment in this study illustrates the emergence, under suitable conditions, of a satisfactory APL-enactment model.

Students' prior knowledge, inquiry skills, and scientific epistemological beliefs are additional factors that may affect the discourse and coordination practices. Since at the time that this study was carried out, the students had just completed the study of Microbiology, they were able to coordinate their disciplinary knowledge with the data and with the research stages outlined in the paper that they read. Since the students had previously analyzed graphic representations in the context of inquiry laboratories and 'unseen' texts (Tamir 2004) and were also starting to perform a project in ecology (Zion et al. 2004), their standards of inquiry thinking were high. The teacher considered these students to be good learners. This is compatible with the suggestion that competent learners are better equipped to cope with ambiguities (Alexander and Jetton 2000), allowing them to cope with the raw, somewhat ambiguous data presented in the Results section of a research article. The coordination practices applied by the students implicitly reveal their epistemological commitment, which seems to be sophisticated enough to consider the compelling need for coherence between theory, data and research. The students' epistemological level is also apparent when creating meaning for an anomalous point by attempting to find a mechanistic explanation for its occurrence. This status can be categorized as characteristic of average high-school students who believe that absolute knowledge is obtainable with enough diligence and effort (following Carey and Smith 1993). In the next level (Carey and Smith 1993), towards which the students are moving during the meaning-making process, they understand that although scientific theories provide rigorous standards for knowing, biological reality is fundamentally elusive and uncertain, and therefore, one cannot always find the exact mechanistic explanation for the anomalous point.

Authentic Practices

The context within which the students are acting is scientifically authentic: they make sense of the results obtained by the scientists through the communication tool of the practicing scientific community—the scientific article. The authenticity of students' coordination practices emerges at several levels: in the Results section, the complexity of the presented research and its findings promotes a variety of research-oriented coordination practices. Students use these practices to tackle the characteristics of the Results section: complexity, ambiguity, anomalous data, and practical aspects of biotechnology. Most of the applied coordination practices are similar to those used by scientists in the course of their research, and stand in contrast to school inquiry tasks, in the context of which students have only to seek a local consistency between a conclusion and the findings of a study (following Chinn and Malhotra 2002). Where students' epistemic practices differ from those of the disciplinary community (i.e., the initial difficulties in analyzing anomalous data or in making sense of practical biotechnological aspects), it is possible to follow up during the lesson the enculturation process they are experiencing toward elicitation of authentic practices. The text-text coordination practices applied to coordinate between different sections, and the research-oriented coordination practices used to assess scientists' conclusions while studying the Discussion section, can also be considered scientifically authentic, since connections between statements are made by scientists when reading scientific articles (Myers 1991).

We consider the text-experimental stage type of coordination practice to be of a different nature. When performing this type of coordination, instead of acting like scientists, the students are reflecting on the scientists' work (Schwartz et al. 2004). While an authentic scientist's perspective maintains a cognitive focus on the research itself, reflection on the research appears to require cognitive disengagement from the authenticity of scientific activity in order to develop one's conceptions of the NOS (Schwartz et al. 2004). Following Schwartz, we suggest that by reflecting on the scientists, the students are more likely to consider the nature of the enterprise in which they have become a part and learn about science as inquiry.

The relationships that develop between the scientists' community of practice and that of the students are dynamic. At the beginning, their relative positions are not symmetrical: the scientists are presenting their findings and describing the research via which they were obtained, and the students are attempting to make sense of them. But as this process progresses, using research-oriented coordination practices, students begin to act like scientists: they deliberate over the meaning of the findings, criticize the scientists' work and even suggest how to improve the biosensor. The two communities begin to have a closer and more symmetrical relationship, because the students become active participants in the construction of scientific knowledge. In the context of the Discussion section, the students further examine the scientists' rationale and writing genre, knowing that they will have to use it as a model for the discussion they need to write for their personal project. When assessing the scientists' conclusions, the students compare their own claims to the scientists' claims, until the explicit coordination "Here the scientists explain what I said" may indicate the formation of a new, virtual community, encompassing both the scientists that wrote the article and the students that are reading it. By analyzing the same data and applying similar epistemic practices, after criticizing the scientists' graphic representations and suggesting ways in which the scientists can improve their biosensor, the students feel confident enough to share, virtually, the same community of practice.

Texts can be used as a tool to mediate collective knowledge building (Klein 2006). We suggest that the democracy in meaning-making provided by the text, for students and teacher alike, enabled the students to share the authority of knowledge together with their teacher. This authority empowered them, in their view, with the legitimate right to join the scientists' community of practice.

Comparison with Other Second-hand Inquiry Interventions

Among the types of simulated research tasks reviewed by Chinn and Malhotra (2002) as providing students with elements of authentic inquiry, two types possess properties that are partially similar to those of APL—databases and evidence-evaluation tasks. Databases (e.g., BGULe), in which students examine evidence that has been gathered by others, elicit processes that are similar to the cognitive and discursive processes described here in the context of the Results section. Students try to make meaning of the data, and during this process they integrate data from several sources. Evidence-evaluation tasks (e.g., WISE), present students with written reports of evidence, including data and the scientists' explanations for them, similar to the Results and Discussion sections of APL articles. Here, students need to evaluate the interpretation of the data, suggest alternative explanations and coordinate conflicting evidence. Chinn and Malhotra suggest that a good way to develop school tasks that capture most features of authentic science would be to combine two or more task types. Our claim is that APL articles, due to their genre characteristics of presenting data in the Results section and the scientists' perspectives on these data in the Discussion section, indeed present such an authentic type of intervention.

Contextualization of prior and everyday knowledge when analyzing the findings of second-hand data has been previously reported (Palinscar and Magnusson 2001), similar to the data-theory coordination practices performed by the students that participated in this study. The complexity of second-hand data has been reported to elicit the identification of patterns, drawing of conclusions, and consideration of content knowledge in order to make meaning of the data (Hug and McNeill 2008). In contrast to our students, students of the other second-hand inquiry interventions were reported to not be critical of the presented data (Palinscar and Magnusson 2001). It is remarkable that despite the differences between the age groups studied—primary school (Palinscar and Magnusson 2001), junior-high school (Hug and McNeill 2008) and senior high-school (in the present study), similar epistemic practices emerge when using second-hand inquiry, suggesting possible common characteristics of these interventions. Nevertheless, it appears that scientific authenticity, at the level of both context and practices, is at its highest level with the APL enactment.

Educational Implications

In the context of the Results and Discussion sections of APL, the students that participated in this study performed both dimensions of inquiry learning: learning by inquiry when meaning-making of the data, and learning about science as inquiry when meaning-making of the scientists' experimental stages and written rhetoric.

Sandoval claims that as future citizens, most students will not actually engage in science in practice, but will rather need to reflect upon scientific knowledge claims as they relate to personal or policy decisions (Sandoval 2005). Opposing Kelly's view (Kelly et al. 1998), Sandoval further claims that simply engaging in practices of authentic science will not lead to such reflective ability. The complementation of the 'authentic epistemic practices' form of enculturation by the explicit analysis of the scientific rhetoric and epistemology, as provided by the presented APL-based enactment model, could supply a meaningful solution to this educational dilemma.

The two suggested meanings of scientific literacy (Norris and Phillips 2003) are strongly interrelated in the enactment model of the two sections of the article analyzed here. The text-text coordination practices, as performed in the context of the Discussion section, are typical of 'reading as inquiry', characteristic of scientific literacy in its fundamental sense. The research-oriented coordination practices, enabling learning by inquiry, can be considered as supporting the derived sense of scientific literacy. A transitional stage between the two suggested senses of scientific literacy is provided by the text-experimental stage coordination practices which both support the characteristics of reading as inquiry and promote a better understanding of the NOS. The reciprocal support of the two suggested senses of scientific literacy (Norris and Phillips 2003) is apparent in several of the analyzed examples. For instance, in the Results section, reading the legend of the graph or scrutinizing the Methods for the presence of key words (both mapped as text-experimental stage coordination practices), facilitate students' understanding of the research. On the other hand, students' difficulty in distinguishing between the performed experiment and a suggested method (the derived sense of scientific literacy) impedes the 'reading as inquiry' process.

The convergence of science and reading, which emerges in the context of APL, should not be surprising in the framework of theories describing the isomorphism of these two activities (Cervetti et al. 2006). Since coordination is described as a major practice in both science research and reading, our report of the emergence of a rich variety of coordination practices during the enactment of the APL article could reflect a synergistic effect promoted by students' exposure to both science and text, in the context of APL.

Our findings also indicate that future developers of additional APL-based curricula should not regard the complexity and the inherent difficulty associated with this genre as negative factors, and should not strive to overcome them through the adaptation process. The complexity can be considered, to a certain extent, an elicitor of authenticity at the level of the context and of the applied epistemic practices, provided that the difficulties are claimed and can be answered by teachers and peers in a suitable manner. This rationale could also impact the choice of articles to be adapted. If the results presented by the original article are clear and unequivocal, we believe that less coordination practices will be elicited during the meaning-making process.

We consider the enactment model applied during this lesson suitable for the implementation of the Results and Discussion sections of an APL article, since it allows the emergence of scientifically authentic epistemic practices as well as the two dimensions of inquiry learning. This enactment model could be suggested to additional teachers. At the same time, we believe that additional enactment models used in the context of these sections should be identified and compared for their impact on students' epistemic practices in general and coordination practices in particular.

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Appendix

The graphs discussed in the "Results" section

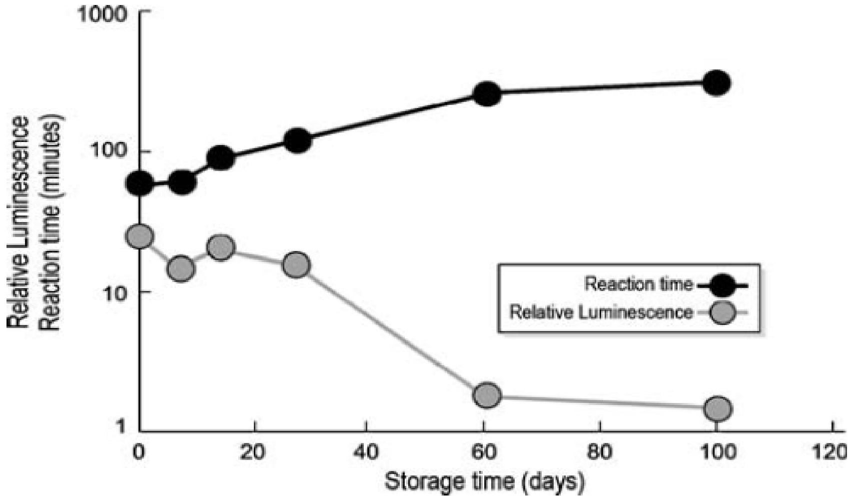

Fig. 1 The influence of storage time at 4°C on the relative luminescence and reaction time of the biosensor. This is a copy of Graph 3 of the article 'The development of a biosensor for the detection of genotoxic materials' from the APL-based biotechnology curriculum

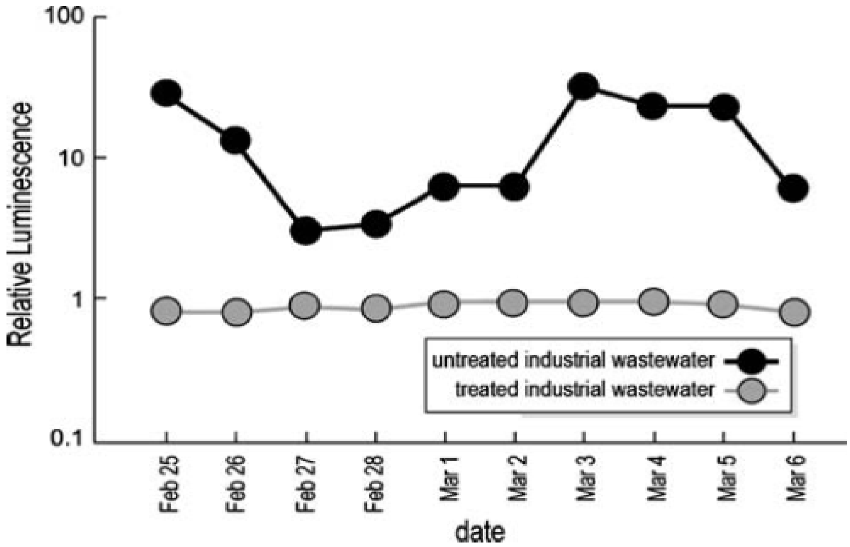

Fig. 2 Relative luminescence of the biosensor following exposure to treated and untreated industrial wastewater. This is a copy of Graph 4 of the article 'The development of a biosensor for the detection of genotoxic materials' from the APL-based biotechnology curriculum

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PAPER 5

Falk, H., & Yarden, A., (2009b) Inquiry aspects in the context of adapted-primary-literature (APL) enactment discourse. (Paper presented at the European Science Education Research Association – ESERA conference, Istambul**.)**

Inquiry aspects in the context of adapted-primary-literature (APL) enactment discourse

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Abstract

Adapted primary literature (APL) is an educational text genre that retains characteristics of inquiry articles while adapting their contents to the comprehension level of high-school students. The enactment discourse of a biotechnology article based on APL was explored. In the context of this case study, we explored the inquiry aspects performed by students, the coordination practices they applied, and teacher's discursive approach and instructional strategies. Our findings indicate the students performed a wide array of inquiry aspects like exploring the theoretical basis of experimental elements, their role within the experimental design and practical implications. They suggested alternative methods, designed experiments and predicted their results. The coordination practices applied included connections between data and theory, data and experimental stages, theory and experimental stages, different experimental stages, and between experimental stages and biotechnological applications. The teacher alternated between dialogic and authoritative approach, sharing her authority with that of the APL article. She supported coordination and inquiry by first asking text comprehension questions and only at a later stage inquiry questions, and by frequently recruiting students' prior knowledge. Educational implications of our findings are further explored.

Background and Framework

Research articles written by scientists (primary literature) are the main genre of science communication. We designed a genre that retains the characteristics of primary literature, while adapting its contents to the comprehension level of high-school biology students, and termed it adapted primary literature (APL) (Yarden et al., 2001). We developed an APL-based biotechnology curriculum that includes three articles reporting on up-to-date molecular biotechnology research (Falk et al., 2008). Inquiry learning, a declared goal of APL (Falk et al., 2008), refers both to learning about science as inquiry and to learning by inquiry (following (Tamir, 1985). Learning by inquiry, involves the learner in performing similar cognitive processes to scientists in their research (National Research Council, 1996). We have shown that in the context of a specific enactment model of an APL article, students extensively applied data-theory coordination (Falk & Yarden, In press), considered a scientifically authentic inquiry practice (Chinn & Malhotra, 2002). Nevertheless, the extent by which students perform learning by inquiry when using APL texts for learning was questioned (Osborne, In press). Inquiry curricula, designed to promote inquiry-thinking skills, have been shown to be challenging for teachers, as they require a relatively high level of pedagogical content knowledge (PCK) (Crawford, 2000). The teaching practices used by the teachers enacting APL were diverse and changed according to the components of the curriculum, the sections of the article, teachers' PCK, and students' constraints. Our results point out that suitable APL enactment models could promote learning by inquiry (Falk et al., 2008).

Purpose and Rationale

Here, we analyse the different aspects of inquiry learning and teaching that emerged during a class enactment of the APL sections that deal with the particulars of the scientific study - the Methods and the Results, (following (Swales, 2001), and the research questions (as part of the Introduction) - by exploring the following research questions:

1. What inquiry aspects are performed by the students in the context of the Introduction, Methods and Results sections of APL? 2. What coordination practices do the students apply and in what manner are they associated with the different aspects of inquiry? 3. What teacher's strategies are associated with the inquiry aspects and the coordination practices observed?

Methods

We analyzed the discourse exhibited in one class, in an urban high school. The students, 17 to 18 years of age (n = 10, 12th grade, all females), had chosen biology as a major subject. The teacher, a female, around 35 years of age, have extensive teaching experience and an MSc degree in molecular biology. The enacted article, entitled "The development of a biosensor for the detection of genotoxic materials" from the APL-based biotechnology curriculum (Falk et al., 2008), presents the research performed in order to develop a genetically engineered bacterial biosensor.

During the two consecutive lessons observed (76 minutes), the class enacted the last paragraph of the Introduction referring to the research questions, the Methods and part of the Results section. The enactment was audio- and video-taped and the recordings were fully transcribed. The transcribed text was segmented into 11 episodes, each beginning by one student loudly reading a paragraph and ending when the analysis of that paragraph was completed. The 11 episodes focused on discussing the research questions (1 episode), the Methods section (7 episodes) and the Results section (3 episodes). By moving back and forth between the transcribed text and theories of inquiry learning (Grandy & Duschl, 2007) we compiled a list of inquiry aspects that was further applied in order to map their occurrence. Coordination practices were defined as connections made between any two elements possessing different epistemic status: data, theory, experimental stages (e.g. the research questions, hypotheses, methods, conclusion), practical applications of biotechnology, the text of the article, or connections between the same elements found in different contexts and were mapped by scanning the discourse. The teacher's discourse and interventions were analysed (following Mortimer & Scott 2003) while focusing on specific learning aspects of APL.

Results

The inquiry aspects performed by the students (Table1, middle column) correspond to those performed by scientists both before running an experiment and when analyzing the experimental results. Inquiry aspects previously remarked in hands-on inquiry (e.g. making observations, collecting data, recording and representing data) are missing here, due to the APL context.

Table 1: Inquiry aspects and coordination practices deployed in each article section

SECTION	INQUIRY ASPECTS*	COORDINATION PRACTICES
Inquiry questions	- design the experiment - predict the experimental results - discuss the practical aspects of the predicted results	- theory-experimental stage - experimental stages
Methods	- explore the role of the presented methods - suggest alternative methods - explore the theoretical basis of the methods - criticize the graphical representation of a model - predict the experimental results - explore practical aspects of the predicted results	- text-experimental stage - experimental stage-predicted data - theory-predicted data - theory-application - theory-experimental stage - theories - applications
Results	- define variables - describe graphs - explore the theoretical basis of the data - interpret and compare graphs - draw conclusions by graphs comparison - explore practical aspects of results	- experimental stage-application - theory-experimental stage - theory-application - data-theory - data - experimental stages

*Social aspects of inquiry, like debating with peers, were an integral part of the class enactment.

The most ubiquitous inquiry aspects that emerged in the majority of the episodes were explanations of the theoretical aspects of experimental elements (in 7/11 episodes) followed by the analysis of their role in the experimental design and the analysis of their practical implications (in 5/11 episodes each). Part of the inquiry aspects performed focused on the experimental stages or elements presented in the text of the immediately read paragraph. However, in many cases, the inquiry referred to experimental stages and elements presented in later paragraphs of the article (still unread by the students). At instance, when reading and analyzing the Methods section, the students predicted the results to be obtained when using the methods presented and alternative methods suggested by them and discussed the practical affordances and limitations of using these methods in the context of the research.

Although some inquiry aspects could be performed without the application of coordination practices (i.e. reading a graph), most other inquiry aspects were only made possible using coordination (table 1, right column) between research elements mentioned in the respective paragraph and elements from other resources like other sections of APL, prior school knowledge and everyday life. At instance, when making meaning of the research methods presented, the students explored their role in the framework of the research by coordinating between elements of the methods presented in the article and the same elements used by them in school laboratories. By applying coordination between experimental stages (the goal and the methods) when reading about the research questions, the students predicted the data to be obtained.

The teacher regulated the class discourse and activity, by designating the text to be read aloud and the extent of time spent on meaning-making of it. Her discourse alternated between a dialogic approach when reacting to students' questions and comments to an authoritative approach when presenting information unavailable to students, like the epistemic practices of scientific communities. The teacher repeatedly recruited and consolidated students' prior knowledge, resulting in the promotion of coordination practices. She both required the students to perform specific inquiry aspects (graph interpretation and comparison) and discussed inquiry aspects initiated by the students (predicting practical aspects of the results). In the context of many episodes, she first raised text-comprehension questions (allowing for a more superficial meaning-making) and only at a later staged she addressed coordination and inquiry (allowing for a deeper one).

Conclusions and Implications

The association between scientists' research practices and different types of coordination practices was previously noted for authentic scientists' inquiry (Chinn & Malhotra, 2002). We would like to claim that the complexity of the research presented by the APL text (as it retains authentic features of science) required the students to apply a variety of coordination practices in order to make meaning of the text. These coordination practices supported inquiry, much in accordance with the authentic research performed by scientists and differing from the simple inquiry usually performed in school science (Chinn & Malhotra, 2002). The inquiry aspects and coordination practices were both explicitly promoted by the teacher and spontaneously emerged during the enactment. Nevertheless, not all the present students applied coordination practices and performed inquiry. Designing tasks explicitly requiring the application of coordination practices may tilt the balance toward a more general students' participation. Raising teachers' awareness to the association between coordination practices and inquiry learning explored here, may promote their better support of learning by inquiry in the context of APL and the enactment of other scientific texts.

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PART 3 - DISCUSSION

3-1 Overview of the main findings

My work is the first comprehensive study of the APL enactment in the naturalistic whole-class setting, focusing on both students and teachers. The importance of my research on APL enactment was recognized by the two leading scientific journals, Nature (Moore, 2008) and Science (McCartney, 2009).

I have characterized several aspects associated with the enactment of APL-based curricula: students' benefits and challenges, teachers' PCK components and the class dialogue emerging during the enactment. This multidimensional characterization was critical because of the novelty of APL as a second-hand inquiry intervention. Besides its analytical importance, it provided the theoretical base necessary for developing scaffolding materials for students and teachers enacting the APL curricula.

I showed that both aspects of inquiry learning can take place in the enactment context of different sections of APL articles. Therefore, Schwab's tenet about learning 'enquiry by enquiry' (Schwab, 1962) can indeed be fulfilled by APL, as he has predicted for 'translated' scientific articles. Class discourse analysis has enabled me to establish a theoretical framework characterizing students' coordination practices and I further pinpointed the extensive application of these epistemic practices in the context of APL enactment and their association with inquiry learning.

The analysis of teachers' strategies has revealed that teachers deployed different enactment models for different sections of the articles. The Conversational model suggested by us was widely used and found adequate for the enactment of APL and promoting learning by inquiry.

Scaffolding the teachers in their endeavor to enact this novel educational genre was a critical task without which the implementation of the APL-based curricula would have probably failed. The multimedia curriculum guide I designed, including video-recorded class episodes accompanied by pedagogical comments and a variety of tasks and assignments, has been found to support the enactment of APL (Falk, Brill & Yarden, 2004).

3-2 Learning aspects of APL enactment

Engagement, inquiry learning, active learning and integration of knowledge are among the benefits incurred by students during the enactment of the APL-based biotechnology curriculum (Falk et al., 2008). Inquiry learning which is considered a declared target benefit of APL (Israeli Ministry of Education, 2003), was the focus of three of my papers (Falk et al., 2008; Falk & Yarden, 2009a; Falk & Yarden, 2009b). The association of APL enactment with inquiry learning was remarked both by teachers enacting the Biotechnology curriculum and those enacting the Developmental biology one, indicating a strong association of this characteristic with the APL genre characteristics. The feeling of inquiry prevailing during the enactment and the ability of making transfer of inquiry aspects from the APL context to the school-lab were remarked by teachers and students (Falk et al., 2008). Analysis of the enactment discourse emerging in one class, revealed that various inquiry aspects were performed by students studying the Methods and Results sections, including: exploration of the theoretical basis of the methods and data, interpretation, comparison and conclusion drawing of graphical representations of data, suggestion of alternative methods, design of experiments, prediction of the experimental results and exploration of their practical implications (Falk & Yarden, 2009b). An additional case study (Falk & Yarden, 2009a) revealed that the two aspects of inquiry learning were performed in the context of APL enactment: learning by inquiry in the context of the Results section and learning science as inquiry in the context of the Discussion section.

Further analysis of these two case studies, impressed that inquiry aspects were strongly associated with the application of different types of coordination practices. Although coordinating between data and theory, a key epistemic practice associated with complex scientific inquiry, is usually not applied for simple school inquiry (Chinn & Malhotra, 2002), in the context of two different enactment models of an APL article, students extensively applied coordination practices (Falk & Yarden, 2009a; Falk & Yarden, 2009b). Learning by inquiry was mainly associated with research oriented and text-text coordination practices while learning science as inquiry was associated with the application of text-experimental elements coordination practices (Falk & Yarden, 2009a). Since coordination practices are considered authentic scientific epistemic practices (Chinn & Malhotra, 2002), their copious application in the context of APL enactment indicates that this second-hand inquiry intervention can provide not only a scientifically authentic context, but can also promote scientifically authentic practices.

We can also conclude that since the enactment of the APL genre is promoting both forms of inquiry learning, it can be beneficial to the derived sense of scientific literacy (following Norris and Phillips 2003). Although the fundamental aspect of scientific literacy has not been explicitly addressed in this work, we think it likely that students that experience the complexity of scientific inquiry, the eventual ambiguity and anomalism of data, who participate in the argumentation process and criticize the research while suggesting improvements to it might be better equipped to critically read media reports primary literature (Norris et al., 2009).

Students' difficulties were manifested mainly during meaning-making of the molecular processes, due to the abstract nature of the biotechnological methods, their complexity, the need to apply prior knowledge for their comprehension and the fact that the characteristics of the APL genre require a more extensive elaboration of processes and methods than other scientific genres (Falk et al., 2008; Falk & Yarden, 2009a). Many of the difficulties reported for the enactment of the two APL-based curricula were of similar nature (Falk et al., 2005; Falk et al., 2008), which is not surprising considering the molecular biology contents of both. Students' comprehension difficulties when reading APL compared to popular communications have been previously reported (Baram-Tsabari & Yarden, 2005), again in the context of a molecular biology content.

The association of coordination practices with students' claims of difficulty was both displayed in the context of the enactment discourse and expressed by the teachers (Falk et al., 2008; Falk & Yarden, 2009a). By discourse analysis coordination practices were found to be applied both in the context of utterances exposing students' difficulties and in the context of discussions that attempted to cope with these difficulties (Falk & Yarden, 2009a).

This expressed duality was further enforced by teachers' remarks: teachers complained about the complexity incurred by the coordination practices that students had to perform in order to make meaning of the text; nevertheless, they remarked the performance of coordination practices as a desirable characteristic of APL (Falk et al., 2008).

The association between students' difficulties and their application of beneficial coordination practices is similar in some respects to the lack of coherence impact on the process of deep-comprehension of texts (McNamara, Kintsch, Songer & Kintsch, 1996). These authors have found that readers benefit from a minimally coherent text by inferring "unstated relations", in a compensatory process. Inferring these "unstated relations" is similar to students' application of coordination practices in order to make meaning of the article, as observed by us. It seems that complex texts like APL, in the context of which difficulties interfere with immediate comprehension, increase the active involvement of readers. Active readers, applying coordination practices in order to make meaning of the text, exhibit scientifically authentic epistemic practices and are using second-hand inquiry in order to perform inquiry learning.

In order for the coordination practices to be beneficial, students' disciplinary content knowledge has to be adequate. This is compatible with the suggestions that competent learners are better equipped to cope with ambiguities (Alexander & Jetton, 2000) and that some of the challenges affecting the use of epistemic practices in authentic contexts interventions stem from the complexity of the intervention in relation to students' disciplinary content knowledge (Sandoval, 2003; Songer et al., 2003). If students' knowledge level affects the authenticity of the enactment outcomes, and if this level is inherently low relative to that of scientists, the intervention and its enactment has to establish a fine balance between the authentic complexity of science (Chinn and Malhotra, 2002) and the simplicity required for authentic outcomes (Songer et al., 2003). Such a balance seems difficult to achieve, and the teacher therefore plays an important role in promoting the authentic outcomes when enacting interventions with authentic context (Hapgood et al., 2004; Wu & Krajcik, 2006).

3-3 Teaching aspects of APL enactment

Our research focused the enactment of APL-based curricula by two groups of teachers and their students. The first group included "non-expert" teachers that didn't specialize in fields related to molecular biology or biotechnology during their graduate studies. Nevertheless, they felt motivated to choose the biotechnology curriculum that is linked to modern molecular biology and based on inquiry (Falk et al., 2008). Their narratives allowed us to conclude that they cannot be considered mavericks in the classical sense; that is, exhibiting extraordinary behavior that is seldom found among other teachers (Squire et al., 2003). The analysis of this group was especially relevant at the beginning of our studies, when we expected the APL curricula to become a general requirement for biology majors (which eventually turned out to appear among the other elective topics), as it enabled us to infer not only from the ‘boutique’ enactment of APL-based curricula, but from a plausible scenario fitting numerous classes, in order to anticipate the potential usefulness of such curricula.

The second group included "expert" teachers with previous molecular biology education (Falk et al., 2005; Falk & Yarden, 2009a; Falk & Yarden,2009b; Falk & Yarden, submitted). Two of the teachers enacting the biotechnology curriculum were considered by us "exemplary teachers" because of their high-level PCK, previous experience in scientific research, disciplinary knowledge and high motivation; the discourse taking place in their classes was analyzed at a high resolution, in order to serve as best scenario enactment models, to be eventually used in order to further scaffold the enactment of other teachers. No direct comparison between the two teachers groups was possible due to the different resolution analysis performed for the "non-expert" and "exemplary" teachers.

My findings showed that teachers have applied various instructional strategies, depending, among the others, on the part of the curriculum and on the section of the article enacted. The different enactment of the Introductory unit and the APL articles allows to distinguish between the effect of these teachers' PCK on the enactment and the influence of the APL genre. While the Introductory Unit was enacted by traditional instructional strategies, the articles were enacted by strategies promoting active learning and inquiry learning (Falk et al, 2008): use of the Conversational model, analysis of graphs by group assignments, guided discussion, complex questions addressing inquiry. The widespread use of the Conversational model presented to teachers in the Developmental Biology curriculum guide (Falk et al., 2005) and during professional development workshops is attesting to the suitability of the model for the enactment of APL. I suggest that the suitability of the Conversational model reflects the fact that it provides the student with two types of scaffolding (following Reiser, 2004):

1. Structuring, as the cognitive load is reduced by reading separate paragraphs of the article, and the paragraphs are further sampled by students exploring questions.

2. Problematization, as the students are required to formulate the exploring questions,

find the answers by themselves and make predictions on different stages of the research, instead of passively reading the article.

Although the Conversational model was found to be widely used for the opening sections, teachers used alternative instructional strategies, for the same article sections, therefore supporting the benefits and minimizing the respective limitations of each (Falk & Yarden, submitted). For example, one teacher used popular reports in order to complement the content knowledge of the Introduction section of a Biotechnology curriculum article. She used the comparison between the different scientific genres for discussing with her students aspects related to scientific communication, in the wider framework of NOS (Falk & Yarden, submitted). Another teacher guided his students to theoretically solve by themselves the practical problem presented by the article, before beginning to read and analyze it (Falk & Yarden, submitted). By using these instructional strategies, the teachers are actually reinventing the curriculum. They are doing so according to the rationale of the developers (following Fishman & Krajcik, 2003) , who have stressed the importance of promoting students' different aspects of inquiry learning.

All over the enactment of the articles, the inquiry-eliciting instructional strategies used by the teachers were complemented by engagement-eliciting and strategies promoting the comprehension of complex scientific contents, aimed to spur students' efforts and to support them. Overall, the instructional practices applied during enactment greatly conform to the PCK that has already been found to improve students' inquiry thinking: teaching 'enquiry into enquiry' (Schwab, 1962), active learning (Fisher, 2000), suitable discourse (Minstrell, 2000), or adding to task demands (Mannes & Kintsch, 1987).

A main characteristic of primary literature (Swales, 2001) and of APL (Falk et al., 2008) is the different scope and rhetoric style of the different article sections. It was possible to see that the teachers have been able to draw on this characteristic and use its educational potential by varying their strategies according to the enacted section: while the conversational model was often applied for the opening sections (Falk et al., 2008; Falk & Yarden, submitted), group assignments (Falk et al., 2008; Falk & Yarden, 2009a), complex questions (Falk et al., 2008) and guided discussion (Falk & Yarden, 2009b) were used for the Results and Discussion sections. Moreover, an exemplary teacher had explicitly expressed her different pedagogical goals to be achieved from the Results and the Discussion (Falk & Yarden, 2009a). Another exemplary teacher used the Scientific Literacy model for the Introduction of an article (Falk & Yarden, submitted) and guided discussion for the analysis of Methods and Results (Falk & Yarden, 2009b), focusing the characteristics of scientific communication for the first section and learning by inquiry aspects for the following ones.

This PCK characteristic is enhancing the genre characteristics of the article. Thus, resulting in students' exposure to a synergistic distributed scaffolding (following Tabak, 2004) between the teachers and the text genre of APL articles. These results conform to those of several investigators, concluding that the enactment of second-hand inquiry seems to be extremely sensitive to teachers' strategies, making it difficult to distinguish between the influence of the genre and that of teacher (Hapgood et al., 2004; Tabak & Baumgartner, 2004; Hug & McNeill, 2008).

Since I used partially different analytical tools for the enactment characterization of the two APL-based curricula, no direct comparison between them is possible. Nevertheless, on the basis of the conclusions reached for each of them, no major differences existed between the instructional strategies used by the teachers enacting the two curricula. Therefore, I can claim with a relatively high level of confidence that the instructional strategies reported are associated with the APL genre and not with the contents of a specific curriculum. The validity of this claim is limited by the fact that both curricula are based on molecular biology contents. Only the analysis of the enactment of an APL-based curriculum based on a completely different domain of biological content (i.e. physiology) could indicate in a clearer manner the relative contribution of genre versus biology contents on the instructional strategies deployed by teachers.

For both APL-based curricula, the curricular transformations performed by teachers in the context of the enactment have not always been faithful to our perspective of inquiry learning. One teacher enacting the Developmental Biology curriculum, dissociated between learning by inquiry in the context of the article and learning new contents (Falk et al., 2005). Another teacher enacting the Biotechnology curriculum admitted that she had to settle for teacher-centered enactment of the article because her students did not cooperate with more inquiry oriented models. My class observations have revealed several similar cases, where students were not active learners and only a few coordination practices were applied by them. A more detailed investigation, focused on the differences between the teachers performing faithful curricular transformations and those that failed to do so, might help our understanding of factors associated with this problem. At the same time, developing and disseminating additional scaffolding tools for teachers and students, might promote a more general faithful transformation of the curriculum.

3-4 Scaffolding the teachers enacting APL

The guide for the Developmental Biology curriculum was effective at providing the teachers with environment-effective advice while enhancing their feeling of autonomy (Falk et al., 2005). Teachers have remarked that the various questions and the commented enactment episodes enabled them both to understand the rationale of the developers and transform the curriculum materials according to this rationale. The assessment of the curricular guides can be based on two seemingly contradictory aspects: their ability to educate the enacting teacher in order to be faithful to the pedagogical ideas of the curriculum developer and the ability to provide him autonomy in order to transform the content in the context of practice (Eisner, 1990; Shkedi, 1998). Our results have shown that both these aspects have been promoted, allowing teachers to "faithfully reinvent" the curriculum, thereby improving their ability to enact inquiry-based curricula.

Nevertheless, the usability of these scaffolding tools has been analyzed only for volunteering teachers that participated in PD workshops as well. Thus, we cannot know at this stage to what extent the general teachers' population and teachers using these materials with no mediation of PD workshops could benefit from them.

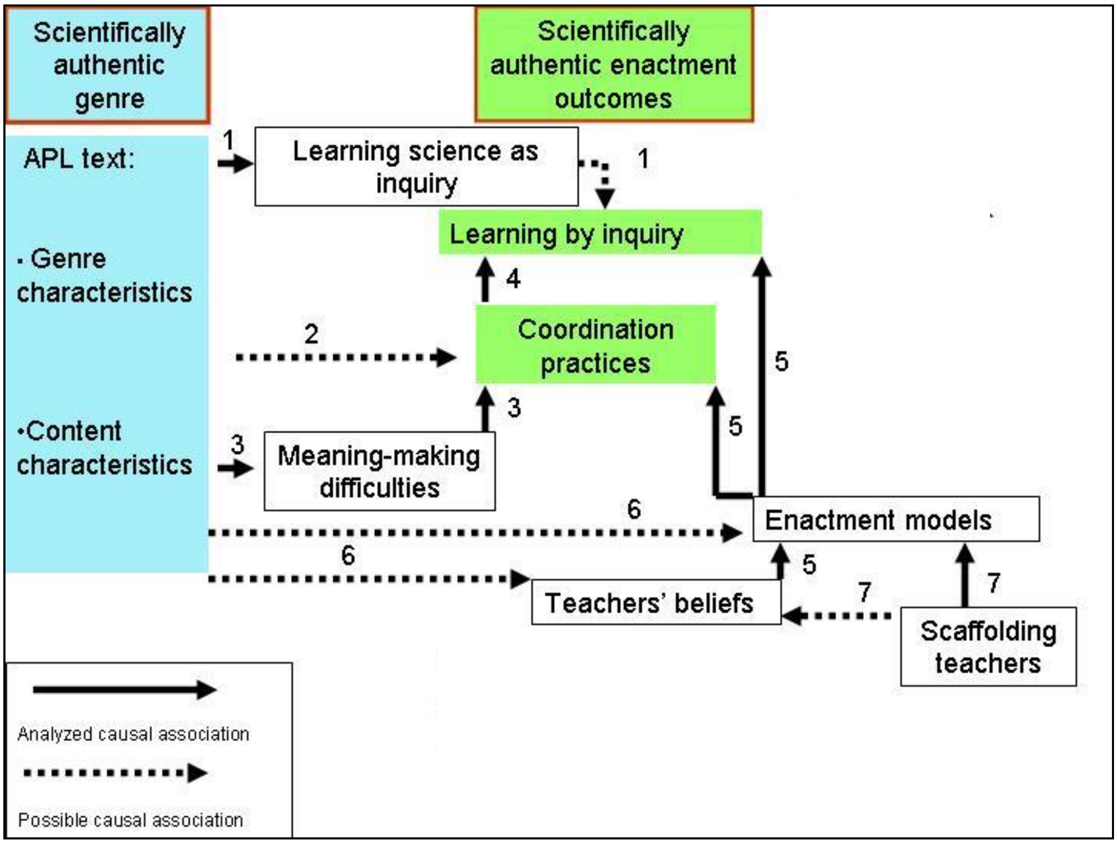
The impact of the curriculum guide for the Biotechnology curriculum has not been investigated as part of this work. It was presented to teachers on a Web site (Falk et al., 2005) and in a printed book that included many of the elements present in the Development Biology curriculum guide: a section presenting the developers rationale, a pool of questions and activities, answers to the questions in the student's book, animation of molecular processes presented in the curriculum. Printed case studies were suggested to replace the video-recorded enactment episodes of the Development Biology curriculum in the Biotechnology curriculum guide. Several such episodes were prepared and used in two professional development workshops, but since they were found to be less effective for scaffolding than the video-recorded episodes, they were not included in the curriculum guide.

3- 5 An enactment model for APL

A model integrating the student-oriented and teacher-oriented enactment aspects of APL-based curricula (Figure 2) is emerging from my study. This model is focusing the elements enabling the scientifically authentic genre of APL to yield scientifically authentic enactment outcomes. It is based both on causal associations that have analyzed in my in the papers included in my study and on additional associations that have been noticed, but have not been analyzed.

Figure 2: Schematic model of APL enactment

The characteristics of APL as a scientifically authentic genre have been colored in blue, the scientifically authentic enactment outcomes have been colored in green. The numbers point the casual association between the different factors and are further referred in the textual description.



The scientific authenticity of the APL genre (in blue) is based on several genre's and content's characteristics, which are faithfully reproducing the characteristics of research articles: the canonical structure of the article, the rhetoric roles of the different article sections, the ambiguity and anomalism of the results, the complexity of the research methods presented. Altogether, these characteristics present a faithful picture of science as an inquiry process. The enactment taking place in the context of this scientifically authentic genre yields two main scientifically authentic outcomes at the learning level (in green): the emergence of learning by inquiry and the application of coordination practices. The association of the authentic genre characteristics with these scientifically authentic learning outcomes is complex, multi-factorial and dependent to a large extent on the instructional strategies applied by the teacher, as further illustrated by the graphic model:

1. Presenting science as inquiry by the APL text promotes students' better understanding of this topic. This inherent outcome of APL curricula enactment might influence also students learning by inquiry.
2. The research articles present bring different scientific ideas in close proximity and reveals new content in the context of the investigations by which it was obtained. Solving biotechnological problems involve the integration of knowledge from different biological domains, most of it previously studied by the students. These characteristics may promote the application of coordination practices.
3. The complexity of contents is sometimes leading to meaning-making difficulties. With suitable scaffolding, students cope with these difficulties by the application of coordination practices which further lead to the emergence of inquiry aspects.
4. The emergence of inquiry aspects is strongly associated with the application of coordination practices: i.e. in order to interpret the results the students have to coordinate between data and theory and between different experimental elements.
5. Inquiry-oriented enactment models (like the Conversational model) and the distributed scaffolding between the teacher's interventions and the text promote students' learning by inquiry: they pose questions, design experiments, refine and interpret experiments, analyze data and criticize the scientists. The elicitation of prior knowledge (part of it from previous sections of the article, promotes the application of coordination practices.
6. The two main aspects of teachers' PCK, teachers' beliefs and their instructional

strategies could be affected by the text characteristics.

7. Teachers' distributed scaffolding with the text and their suitable instructional characteristics are promoted by the scaffolding of teachers through the case studies and materials presented by the teachers' guide and by additional teachers' development levels.

It is relevant to ask to what extent it is legitimate to generalize our case-studies findings to the level of an APL enacting model. The agreement between the declarations of most non-expert teachers and their students and between our findings on the enactment of the exemplary teachers might indicate the possibility to generalize our case-studies conclusions to a larger teachers' and students' population. Nevertheless, the fact that we didn't notice a similar richness of inquiry aspects and coordination practices in other classes (unpublished results), is indicative of the need for further research in order to better establish the conditions leading to what we consider to be a suitable APL-based enactment. Moreover, the model presented does not refer to student dependent factors: the number of students in the class, their knowledge level and cognitive abilities. These factors can deeply affect the enactment and only further research focusing them will be able to elucidate their impact on APL –based curricula enactment.

3-6 Overview of the main research limitations

I would like to discuss several research limitations, some of them inherent to the qualitative methodology used and some to the complexity of the whole-class setting of my study that could reduce the validity and generalization strength of the conclusions reached. I have attempted to circumvent some of these limitations, as described below. Further research will hopefully answer the other ones.

Choosing the teacher samples to be studied out of the teacher population that has volunteered to teach the curriculum is limiting my study to only those teachers who have a deep appreciation of modern biology aspects and are confident that their students' level is good enough in order to obtain high evaluation scores at the Matriculation examination questions about the APL-based curricula. According to our data and to additional unpublished data from focus groups with non-enacting teachers, it is questionable whether these two characteristics prevail among the majority of high-school biology teachers in Israel. In addition, one cannot know at his stage if the class discourse observed for the two exemplary teachers and its outcomes at the students' level characterizes the enactment of APL-based curricula in additional classes, or if teachers possessing a less suitable content knowledge or PCK could model it.

The videotaped lessons have been a convenience sample, following the teacher's invitation. They could represent the best enactment of the respective teacher or what she thinks should be her best enactment and not her most often used enactment model. The concern about the "observer effect" has been previously discussed about class videotaping (Stigler et al., 1999). These authors remark that many different investigational tools could suffer from the same bias, but that teachers who try to alter their behavior for the videotaping will likely show some evidence that this is the case. Students, for example, may look puzzled or may not be able to follow routines that are clearly new to them. In no case did this occur in the studied classes. At the same time, it is notoriously difficult to change one's way of teaching, but we could indeed get an idealized form of that teacher's enactment (Stigler et al., 1999).

Since most of the teachers were interested to have my feedback at the beginning of their APL-based enactment process, most lessons observed were about the first article of the curriculum "The development of a biosensor for the detection of genotoxic materials". The extent to which the data obtained in the context of this article represent the enactment of other articles of the curriculum can be questioned. The enactment observed in a small sample of recorded lessons about other articles did not differ significantly, and since these lessons were enacted by other teachers and students, no direct comparison could be performed.

An additional limitation stems from the novelty of the APL-based study curricula and of biotechnology curricula for biology students. Since no other biotechnology curriculum, based on different instructional materials, is available today for biology majors, we could only infer the relative contribution of the genre and content on the enactment outcomes.

Some of these limitations have been addressed during the study: triangulating data of teachers' interviews, students' group interviews and observations of class enactment have been used in order to consolidate the conclusions reached by each of these research tools. Investigating both APL-based curricula, provided similar results, attesting to the effect of the genre compared to content as curriculum factor. The comparison between the enactments of different article sections, in the context of the same lesson, by analyzing the same teacher and students, allowed us to focus on the association between the enacted section, the instructional strategies and the learning outcomes. Evidently, as for many qualitative studies, in order to reach more reliable conclusions, additional cases have to be investigated using the same and different methodologies. Eventually, when the characterization stage of APL-based curricula enactment will advance, quantitative studies, addressing the previously diagnosed curriculum factors and enacting outcomes, will be able to indicate more clearly causative relationships between them.

3-7 Educational implications

Closing the gap between real science and school science is considered one of the main goals of scientific education. I have shown that, within the limitations discussed, APL-based curricula enactment can help fulfill this aim and can serve as a suitable bridge between scientific inquiry and school inquiry. The exhibited complementation of authentic epistemic practices characterizing learning by inquiry by the explicit analysis of the scientific rhetoric and epistemology, characterizing learning science as inquiry could supply a meaningful solution to the educational dilemma of whether students should mainly engage in the practices of authentic science (Kelly, Druker & Chen, 1998) or reflect upon scientific knowledge claims as they refer to personal and political decisions (Sandoval, 2005). Therefore, APL can be considered to be a beneficial addition to the long time tradition of biology high-school inquiry learning in Israel (Tamir, 1985b) and a faithful sequel of Schwab's recommendations (Schwab, 1962).

Today, in Israel, the APL-based curricula are "competing" with other less demanding elective curricula which are not oriented towards cutting edge topics, do not demand molecular knowledge and are based on more traditional and established instructional materials and instructional strategies. Nevertheless, about 10% of the biology majors in Israel are exposed to the benefits of this novel genre.

The main obstacle to the implementation of APL curricula as a general requirement for biology majors seems to be the alleged difficulty of the genre for many students and teachers. I believe that this claim should be balanced with the promise of long-term cognitive and epistemic gains incurred by these complexity associated challenges.

I have shown that many students' difficulties during APL enactment were associated with the comprehension of molecular-based contents. Therefore, I would like to suggest that general, non-elective implementation of APL-based curricula could be better promoted by developing additional APL–based curricula, maintaining the genre characteristics, but based on less challenging, non-molecular contents. By the enactment of these curricula, students could still benefit from the outcomes of APL, while being less challenged by abstract and problematic contents. Nevertheless, when developing these future, non-molecular APL-based curricula, it will be important to maintain the complexity of the APL genre alongside with the simplicity of contents, in order not to hamper the associated authentic practices expected to emerge.

The development of additional APL-based curricula should be viewed in association with teachers' ability to enact APL by inquiry-based teaching. It was shown that teachers can better enact inquiry-based teaching when they posses a sound knowledge of relevant scientific contents and of teaching theory (Crawford, 2007; Blanchard et al., 2008). Therefore, professional education programs which provide teachers with both these aspects will probably enhance teachers' ability to enact APL-based curricula by inquiry-based teaching.

These two complementary trends, one at the level of further curriculum development and the other at the level of teachers' professional development, endorsed by suitable political decisions could promote and facilitate the enactment of APL-based curricula by students and teachers of diverse abilities, in order to generalize the beneficial outcomes of this genre. If such a curriculum will become a general requirement, it will be possible to establish whether the conclusions of the present research are true for the general population of teachers and students or only for the volunteering ones.

At the international level, APL based-curricula in additional science domains have been developed by groups that have been influenced by our work (Norris, Macnab, Wonham & de Vries, 2009). In the future, when the enactment of these APL-based curricula will be investigated, it will be possible to compare the findings and reach further conclusions on the relative contribution of different curricular factors in different contexts.

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PART 4 - APPENDIXES

1. McCartney, M. (2009). Highlights of the recent literature: From journal to classroom. *Science*, *325*, 518.

2. Phillips, L. M., Yarden, A., Falk, H., Norris, S. P., Jimenez-Aleixandre, M. P., & Ford, D. J. (2008). Reading scientific texts: Adapting primary literature for promoting scientific literacy. (Paper presented at the NARST Annual International Conference: Impact of Science Education Research on Public Policy, Baltimore, MD).

3. Yarden, A., Falk, H., Federico-Agraso, M., Jimenez-Aleixandre, M. P., Norris, S. P., & Phillips, L. M. (2009). Supporting teaching and learning using authentic scientific texts: A rejoinder to Danielle J. Ford. *Research in Science Education*, 39 (3), 391-395.

4. Norris, S. P., Falk, H., Federico-Agraso, M., Jimenez-Aleixandre, M. P., Phillips, L. M., & Yarden, A.(2009). Reading science texts—Epistemology, inquiry, authenticity—A rejoinder to Jonathan Osborne. *Research in Science Education*, 39 (3), 405-410.

Appendix 1

McCartney, M. (2009). Highlights of the recent literature: From journal to classroom. *Science*, *325*, 518.

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EDITORS' CHOICE: HIGHLIGHTS OF THE RECENT LITERATURE

EDUCATION:

From Journal to Classroom

Melissa McCartney[*]

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Can cutting-edge science be taught in the classroom? Adapted primary literature (APL) retains the structure and results of original research papers while adjusting the content to fit high-school students. The use of APL in the classroom via conversation or group discussion introduces students to the idea that the written text serves both to construct arguments and to present them for evaluation by others.

In a case study at a girls-only religious high school, Falk and Yarden observed the coordination practices—which integrate elements from theory, methods, data, and applications—of eight 12th-grade biology students during an APL-based lesson. In text-oriented practices, the student connects different sections of the text, whereas in research-oriented practices, the student connects the scientific methods used to the data that were generated. The findings reveal not only that coordination practices enhanced APL-based learning but also that students are able to engage with this type of curriculum—learning science by inquiry and learning about science as a means of inquiry. Furthermore, developers of APL-based curricula need not avoid the complexity of the primary scientific literature because coping with ambiguous data through coordination practices expands the students' appreciation of scientific authenticity.

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Appendix 2

Phillips, L. M., Yarden, A., Falk, H., Norris, S. P., Jimenez-Aleixandre, M. P., & Ford, D. J. (2008). Reading scientific texts: Adapting primary literature for promoting scientific literacy. (Paper presented at the NARST Annual International Conference: Impact of Science Education Research on Public Policy, Baltimore, MD).

Reading Scientific Texts: Adapting Primary Literature for Promoting Scientific Literacy

A Symposium Presented at the National Association of Research in Science Teaching 2008 Annual Meeting, Baltimore, USA

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Rationale

While science textbooks concentrate on presenting the conclusions of scientific research, science journals define problems, as well as describe and justify methods, and present and defend results and interpretations (Norris & Phillips, 1994). Schwab (1962) previously suggested that "Papers by scientists reporting scientific research have two major advantages as materials for the teaching of science as enquiry. One advantage is obvious. They afford the most authentic, unretouched specimens of enquiry that we can obtain…The second advantage of original papers consists in the richness and relevance of the problems they pose for enquiry into enquiry. The papers which pose an excessive problem of reading can be edited, excerpted and 'translated'." Despite this unequivocal recommendation, there is scant evidence of curricula that use the primary literature genre for high-school science learning (Yarden, Brill, & Falk, 2001).

The use of primary literature for science learning may not only help in closing the gap between public knowledge and the frontiers of scientific inquiry, it can help in developing scientific literacy among learners (Baram-Tsabari & Yarden, 2005; Yarden et al., 2001). Primary literature may instruct students on the nature of scientific reasoning (Muench, 2000) and help to teach complementary aspects of scientific investigation and writing (Kuldell, 2003). In addition, students may find reading research articles a novelty and a challenge (Epstein, 1970), and may also identify with the researchers' quests.

Learning through research articles is both a challenge and a difficult task for novices, requiring adequate adaptation in order to be employed as a basis for high-school curricula. This symposium brings together researchers who have begun to examine the use of the primary literature genre for high-school science learning in various settings and formats. Together with the discussant, the participants of this symposium hope they will be able to draw connections between the various means to use primary literature for promoting scientific literacy among high-school students.

Overview of each of the projects

Using adapted-primary-literature to bridge the gap between the language of science and the language of school science

Linda M. Phillips & Stephen P. Norris, University of Alberta, Canada

We shall argue that reading scientific text is an inquiry activity and that reading as inquiry could become a part of school science instruction through the use of adapted primary literature. Looking at the results of a series of studies, we shall contrast the language of science and the language of school science. We shall offer an alternative to the simple view of reading that is found in science education. The alternative view is far more attuned to the promotion of scientific literacy and citizen engagement with science.

The research we describe shows that scientists use a variety of speech acts when they write and read scientific text. The research also shows that these speech acts are marshalled into an overall argumentative structure that defines the nature of the text. For example, the range of speech acts includes: motivating their studies, reporting relevant past results, reporting limitations of past research, describing what was done, arguing for the suitability of techniques, explaining observations, conjecturing what might be happening, and challenging interpretations. Arguments found in papers include ones such as in the motivation of a study, whose aim was to provide evidence for the amorphization of nanocrystalline zirconia by ion irradiation, where the authors provided a full-paragraph case for the proposition that zirconia is one of the most radiation resistant ceramics known (Meldrum, Boatner, & Ewing, 2002). The point of the argument was to signal that the results of this study were not to be expected, that previous conclusions would have to be modified, and that therefore this study was significant.

Thus, the language of science at the macrolevel is argumentative, in the sense that it is structured so as to support conclusions on the basis of reasons. At the microlevel, scientific language is usefully characterized as performing a variety of speech acts, which, when taken in combination, create the argumentative structure seen at the larger scale. Scientific language is understood at the macrolevel by one who grasps the connections that are made and implied among its microlevel parts.

The language of science teaching is manifested paradigmatically in the language of science textbooks. Whereas science is fundamentally concerned with using language to demonstrate conclusions, in the sense of providing evidence and argument for them, science textbooks are concerned with illustrating, in the sense of showing, summarizing, and defining (Myers, 1997). In the research we report, we compared textbooks to media reports of science. If the comparison had been to scientific research articles, the contrasts would have been starker. We found that between 90% and 99% of the statements in the textbooks sampled presented science as truths. By comparison, between 57% and 92% of the statements in the media reports sampled presented science as truths, with on average 24% of statements presented as uncertain of truth status. The media reports were therefore considerably more hedged than the textbooks and more closely resembled science journal articles in this respect. The type of text most frequently found was expository in both the textbooks (75% to 100%, averaging 92%) and media reports (57% to 100%, averaging 83%). What was not expository in the textbooks was narrative, marking a difference from the media reports where the non-expository text was argumentative. Between 51% and 77% of the statements in textbooks provided facts or conclusions. Given that only 2% of statements provided reasons, most of the facts and conclusions were presented without providing either insight into their origin or into how they were related to other statements. Striking differences were noted between these findings and the media reports. Media reports devoted 13% of their space to what prompted the research to be done and another 13% to how the research was done, both proportions being four to six times those found in textbooks. The media reports also devoted between 2% to 43% (13% on average) of their space to providing reasons, over six times the proportion devoted to reasons in the textbooks. Again, as in findings by others, textbooks expose and do not argue (Newton & Newton, 2000; Peacock & Weedon, 2002; Rowell & Ebbers, 2004).

We conclude that the language of school science revealed in textbooks stands in marked contrast to the language of science itself. The former is characterized by attention to word meanings, facts, illustrations, and belief formation. The latter, although attentive to all of the elements of the former, is more concerned with relationships that create holistic meanings, logical argument and probabilistic demonstrations, and the avoidance of credulity. Science teachers, we believe, must come to see themselves also as literacy teachers. One way to make this role acceptable to science teachers, who believe that the teaching of reading falls to others, is to use adapted primary literature. Science teachers will recognize such text as genuinely scientific, and are thus less likely to resist teaching it to students.

Learning biotechnology using adapted-primary-literature: benefits and challenges

Anat Yarden & Hedda Falk, Weizmann Institute of Science, Israel

Primary literature is a genuine genre of science communication, having been written by the scientists who conducted the research in order to communicate their findings to the scientific community (Beall & Trimbur, 1999; Mallow, 1991). Reading and analyzing primary literature is an authentic scientific cognitive activity, as scientists' conclusions are grounded in the theoretical and empirical work of other scientists (Chinn & Malhotra, 2002; Dunbar, 1995). Therefore, reading primary literature may be beneficial to students as it represents an authentic inquiry activity, similarly to the one carried out by scientists.

Adapted-primary-literature (APL) refers to an educational genre specifically designed to enable the use of research articles for learning science in high-school. The adaptation process maintains the canonical structure of the research article and some of the original results, while adapting its contents to the high-school students' comprehension abilities, as previously described (Yarden et al., 2001). Following the requirements of a newly published syllabus for biology majors in our country, we recently designed an APL-based curriculum in biotechnology (Falk, Piontkevitz, Brill, Baram, & Yarden, 2003).

Previous studies show that high-school biology students who read an APL text better understood the nature of scientific inquiry and raised more scientific criticism of the researchers' work compared to students who read a popular scientific text (Baram-Tsabari & Yarden, 2005). High-school students were also shown to pose questions that reveal a higher level of inquiry thinking and uniqueness during and following learning through APL (Brill & Yarden, 2003). In the present investigation, we focus on the benefits and challenges for students from four different classes in which the APL-based curriculum in biotechnology was enacted. While our initial studies mainly used questionnaire-based means, here we attempted to conduct our analysis in the complex setting of the classrooms, allowing the information to originate from the class discourse that developed during the enactment as well as from teachers' and students' interviews. Two successive teaching sessions (45 minutes each, 12^{th} grade biology major classes) of the four teachers were video-recorded, at least one of them during the enactment of an APL article. The theoretical analyses of the interviews and the enactment episodes were performed according to the narrative-constructivist procedure recommended for multiple-case analysis (Shkedi, 2005).

We examined the benefits and challenges to students while learning through the APL curriculum, as expressed by both the students and their teachers and as reflected in video-recorded class episodes. We found that the APL-based curriculum promotes engagement, inquiry thinking, integration of knowledge, nature of science (NOS) understanding, and comprehension of the subject matter among the high-school students. Despite the positive student and teacher responses, learning through APL is not a trivial task. The main challenge reported was linked to the comprehension of biotechnology processes and methods, which required the use of prior knowledge in new contexts and often led to a cognitive load. Understanding the biotechnology processes and methods required: i) integration of knowledge and application at two levels—prior school biology knowledge integrated and applied in the context of a method and suitable methods to be further integrated into a coherent entity and applied in order to solve a problem; ii) inquiry thinking—understanding the complex inter-dependency of the research question and the method selected to investigate it, and between the selected method and the results obtained and their interpretation.

A complex interaction between the APL genre and the biotechnology contents, shaped students' learning outcomes. The expository sections of the APL article, the Methods and the Results, possess the strongest genre-specific characteristics. Although in the process of adapting the Methods section most of the technical details were omitted and the theoretical fundamentals of the methods applied were emphasized, the methods were presented in more detail than previously met by students in other curricula (Yarden et al., 2001). Thus, they conveyed a dimension of reality and a glimpse of real-world science and may have contributed to the concretization of previously learned abstract biological processes. The Methods section also provides examples of the different ways in which biological knowledge can be applied toward practical problem-solving. Therefore, the Methods section may create engagement and better comprehension of prior biological contents.

The Results section exhibits raw, empirical data, sometimes contradicting the investigators' hypothesis or each other (Chinn & Malhotra, 2002). Since raw data have a strong element of ambiguity, their critical reading and analysis is an additional source of knowledge-integration requirements. In addition to the aforementioned outcomes, the genre characteristics posed several challenges. The complexity of the Methods section was the most challenging for this cognitive process and it is plausible to assume that students' prior knowledge and cognitive abilities were constraints that influenced the enactment outcomes. The Discussion section was found to be challenging for students who felt that the new inquiry questions and investigators' self-criticism were interfering with the comprehension they felt they had acquired in the previous parts of the article. Based on the trends outlined in this study, additional investigations should be designed to elucidate the specific discourse that occurs in classes during APL enactment.

Inquiry learning in the context of the Results and Discussion sections of adapted-primary-literature

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One of the important goals of science education is to engage students in the reasoning and discursive epistemic practices of scientists (Sandoval, 2003), and thereby promote scientifically authentic epistemologies and inquiry learning (Chinn & Malhotra, 2002). Inquiry learning has been classified as learning on inquiry and learning by inquiry. While, learning on inquiry has been suggested as learning about the way in which the scientific endeavor progresses, and analyzing the inquiry process performed by others, learning by inquiry involves the learner in acquiring 'the abilities necessary to do scientific inquiry' (Bybee, 2000; Tamir, 1985). Schwab suggested 'inquiry on inquiry' as an optimal approach to inquiry learning, and claimed that learning through adapted scientific papers have several benefits in promoting inquiry learning (Schwab, 1962).

Our recent work has shown that the enactment of an adapted-primary-literature (APL)-based curriculum in biotechnology (Falk, Brill, & Yarden, 2008) is indeed associated with inquiry learning. We were able to show that while learning on inquiry is inherently linked to the APL genre, learning by inquiry depends on teachers' pedagogical content knowledge (PCK). But are these two types of inquiry learning used uniformly throughout the enactment of the APL articles, or are they each predominantly used within the enactment of specific sections of the article? In order to answer this broad research question, we specifically examined whether students exhibited similar epistemic practices, and in particular those considered to be "scientifically authentic", while learning different sections of the article and whether the teacher's discourse shifted according to the enacted section. In order to answer these questions, we investigated students' epistemic practices and teacher's discursive approaches and interventions during the enactment of the Results and the Discussion sections of an article from the APL-based curriculum in biotechnology (Falk et al., 2003). We hypothesized that a different discourse will take place while learning the Results and the Discussion sections due to the different genres. The Results section of research articles is written in an expository manner and contains raw data, usually presented in a graphical manner. Data are often ambiguous, contradictory and anomalous, unlike the "clean" data that students are used to see in other learning materials (Chinn & Malhotra, 2002). In contrast, the Discussion section displays mainly an argumentative genre (S. P. Norris, personal communication), and focuses on the coordination of the data with the relevant theory and with other research components. The process of adaptation of the research articles judiciously maintains these canonical genre characteristics of the primary literature in the APL articles (Yarden et al., 2001).

In the present investigation, we analyzed the 80 minutes discourse developed during the enactment of an article dealing with the detection of genotoxic materials in water by bacterial biosensors in one class from an urban, religious high-school for girls (n=8, biology majors, 17-18 years old). Their teacher has an MSc degree in genetics and relatively extensive teaching experience. The lesson was video-recorded and fully transcribed. It was the fourth lesson dedicated to this article in which an analysis of the graphical representations in the Results section of the article was carried out via a group task. Categories of epistemic practices were constructed by moving back-and-forth between the discourse transcripts and various epistemic theories (Chinn & Malhotra, 2002; Hofer, 2004; Sandoval, 2005; Sandoval, Bell, Coleman, Enyedy, & Suthers, 2000). We analyzed teacher's discursive approach, i.e. reflective (Van Zee & Minstrell, 1997), and authoritative/dialogic (Scott, Mortimer, & Aguiar, 2006), as well as the types of her interventions (i.e. questions, elicitations).

While analyzing the data in the Results section, the students displayed a large number of epistemic practices, mostly considered as scientifically authentic. Students coordinated between the data, the theory that explained it mechanistically, and different elements of the research and biotechnological applications. The coordination practices were associated with metacognitive practices, usually claiming un-understanding, with contextualization of prior knowledge, usage of the article resources and collaborative meaning-making that often exhibited an argumentative stance.

Considerably fewer epistemic practices belonging to these categories were found during the enactment of the Discussion section. Instead, students analyzed the characteristics of the scientific writing resources, coordinating between the research elements and the scientific text. Within the Results section, the lesson advanced mainly by questions posed by the students and was not structured by the teacher. Fifty-six minutes (871 turns) were spent on making meaning of the two (out of four) presented research results (2 pages that include 2 graphs). However, not more than 24 minutes (300 turns) were dedicated to the study of the whole Discussion section (2.5 pages). Its sequence pattern was more uniform as it stemmed mainly from the teacher's authoritative discourse that focused on the role of the Discussion section. Thus, in the teacher's approach, discourse and interventions differed between the two sections. In the Results the teacher approach was mainly dialogic and reflective, while during the Discussion the teacher displayed a more authoritative approach. Three times during the enactment of the Discussion section, the teacher called for a re-examination of the graphical representations in the Results section, and in these cases students' epistemic practices and teacher's discourse reversed to what was previously observed for the enactment of the Results section. These reversions are enforcing our belief that the process of meaning-making of raw results promoted the scientifically authentic epistemic practices observed while in the Results section.

Within the enactment model presented, the APL genre and its enactment promote both inquiry learning modes: learning by inquiry when making meaning of raw data in the Results section and learning on inquiry when reading about the research and about the data analyzed in the Discussion section. The analysis of raw data is associated with a variety of scientifically authentic epistemic practices. Nevertheless, familiarizing the students with the rationale of the scientific communication is not less important, because besides promoting scientific literacy, it may further facilitate learning by inquiry in the framework of students' own scientific projects and when reading scientific texts.

West Nile Virus: Using adapted-primary-literature in mathematical biology to teach scientific and mathematical reasoning in high school

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This presentation will describe a means of addressing two perennial problems in the high school science curriculum: (i) the failure to treat in a systematic and comprehensive way the nature of scientific reasoning and argument and how they are connected to scientific conclusions; and (ii) the persistent failure to introduce students to some of the most interesting and important ideas of modern science, particularly of interdisciplinary research. One of the greatest problems facing the teacher of science is that it is quite possible to learn a great deal of scientific content without learning the meaning of it. We attempt to deal with this issue by introducing students to the interdisciplinary work of a team of biologists and mathematicians trying to solve a contemporary public health problem – how best to control the spread of the West Nile Virus.

Science curricula typically are built upon a foundational model. They attempt to structure a subject according to a logical or psychological model of what knowledge is prior to what. Thus, it might be assumed that understanding Newtonian mechanics is a prerequisite to understanding Einsteinian relativity, or that solutions must be taught before electrochemistry. The assumptions underlying these models are by-and-large untested. However, even more troublesome than their lack of verification, reliance on the models locks students into a structure that never allows them to study what is most recent, and often most exciting to them, in science.

We are attempting to counter this situation by developing and testing curriculum protocols that have two characteristics: first, they introduce a topic from modern science that is not currently covered in the high school curriculum and does not fit its hierarchical structure; and, second, they take as a major aim instruction in the nature of scientific reasoning. We will describe the development and features of one of these protocols in the area of mathematical biology. The design of the protocols themselves are based on the ideas of Yarden and her colleagues (Baram-Tsabari & Yarden, 2005; Yarden et al., 2001). The radical aspect of that person's thinking is to incorporate into student curriculum materials a series of scientific papers that have been adapted from the original published articles. These pieces of "adapted primary literature (APL)" preserve the canonical structure of the original scientific research article, but have been adapted to be understood by high school students. In preserving the canonical structure, the APL contains research questions, descriptions of method, reports of data, interpretations of the data and arguments meant to impeach alternative interpretations of the data. In our versions, the APL departs from the canonical structure by including where necessary brief explanations of terms or procedures that have not already been covered in the introduction.

We have attempted to build upon this work by moving into a field of interdisciplinary science and by creating APL using hypertext. The model for the spread of the West Nile Virus involves a system of four differential equations that cannot be solved by classical methods. The solution can, however, be approximated through the use of the computer (though we do not go into this detail). Our aim is for students to be able to look at the differential equations and understand their physical interpretation without having to understand the solution method. The module provides the opportunity for students to experience genuine contemporary applications of the science and mathematics that they are studying. The emphasis throughout is on understanding the science and the mathematics and grasping the reasoning. As such, little emphasis is put on symbolic manipulation skills.

The document contains a full table of contents always visible on the left side of the screen. Students are encouraged to work from beginning to end, or to move forward or backward as they desire. Key words, diagrams, tables and variables are usually set up as hyperlinks. By clicking on the links, a definition or other helpful bit of information comes up on the right of the screen. Guiding questions are provided throughout the text, labeled Q1, Q2, etc. The questions focus on the reasoning and understanding that undergird the mathematical model. The aim is to teach students how to make sense of the science and the mathematics, not simply to solve stereotyped problems. The table of contents and the links represent aspects of the adaptation to a curriculum document. In the centre of the screen is the body of the article itself, which, although adapted, preserves the canonical form of the original research papers.

Justification and persuasion about cloning: Arguments in Hwang's paper, journalistic reported versions and students' summaries

María Pilar Jiménez-Aleixandre & Marta Federico-Agraso, University of Santiago de Compostela, Spain

Argumentation and discourse analysis studies are drawing attention to the discursive practices related to learning science, among them the evaluation of knowledge claims, a central feature in argumentative environments (Jimenez-Aleixandre, 2007). Although reading and writing seem implicit in the work of scientists and are taken for granted, the acquisition of reading and writing skills and the development of a critical stance toward scientific communication need instructional scaffolding (Goldman & Bisanz, 2002; Norris & Phillips, 2003).

Our rationale draws from studies about writing and reading scientific texts, in a perspective considering them as part of the social processes involved in the production of knowledge (Myers, 1990). Scientific papers possess an argumentative structure, articulating evidence to support claims at various levels, for instance, about the interpretation of results, or the significance of the study. But they also present persuasive features, as one of their goals is to convince a particular audience. As Myers points out, scientific texts use narrative devices to convey certain meanings and make difficult-to-imagine alternative interpretations. Papers have a role in the construction of knowledge and also in determining the place of the authors in the scientific community. It is worth noting that both justification and persuasion are meanings of argumentation.

In this paper we examine the argumentative and persuasive structure of an original paper about human embryonic stem cells (also called therapeutic cloning) (Hwang et al., 2004), contrasted with the structure of four Journalistic Reported Versions (JRV) of this same paper, and with the structure of students' summaries of one of the JRV. The research reported here forms part of a wider study on students' argumentation about cloning, that was in its preliminary steps when Hwang et al. (2004) reported the first nuclear transfer (NT) in humans on February 12, 2004. The report received wide coverage in the media, part of it analyzed in another paper (Federico-Agraso & Jimenez-Aleixandre, 2008), and it was followed by a second paper in 2005. In December 2005, while our study was progressing, the paper was exposed as a fabrication and subsequently *Science* retracted it in January 2006. This raises the question of whether there is a different reception of the work among the samples working with it before and after this exposure.

The argumentative analysis draws, on the one hand, from studies about the structure of empirical research reports (Bazerman, 1988; Swales, 2001), and about the different structure and organization of these reports compared with JRV (Goldman & Bisanz, 2002; Nwogu, 1991), related to the rhetorical moves in the process of transformation of a research report into a JRV. On the other hand it draws from instruments, schemes and rubrics for analyzing arguments (Kelly, Regev, & Prothero, 2007; Toulmin, 1958; Walton, 1996). The arguments from different sections of the papers are analyzed and then their integration in the overall structure of the text is examined.

The results show differences in argumentative structure among the original Hwang report and the JRV. Some of the differences are: a) most (or all) evidence, supporting that nuclear transfer was performed is omitted in the JRV, or appear only as images that, being impossible to understand for the readership, we interpret as having a symbolic status; b) the modal qualifiers about the possible parthenogenetic origin of the cell lines, or about the potential nature of therapeutic applications, that is references to uncertainty, are also omitted in most JRV; c) there is a stronger emphasis on therapeutic applications on the JRV that on the original paper (at least quantitatively). In the students' summaries (N = 16) the argumentative structure of the JRV that they were asked to summarize was transformed in a narrative.

Some results about the argumentative structure of Hwang et al. (2004): Its 1874 words (excluding abstract and references), are distributed in eight paragraphs (P), corresponding to the canonical structure of research reports (Bazerman, 1988; Swales, 2001): P1 introduction, P2 to P4 methods, P5-P6 results, P7 discussion and P8 implications. We identified 15 arguments in the paper, labelled A1.1 (Argument 1 in paragraph 1), A1.2 etc. In five paragraphs all the sentences contribute to a single argument, while in paragraphs 1, 2 and 5 there are respectively two, four and four arguments. In our opinion, although apparently the main claim of the paper should be that human embryonic stem cells have been produced, its argumentative structure is such that this line of (multiple) evidence constitutes a subsequent argument used as justification for a second claim: the possibility of transplantation medicine and other therapies. This is supported for instance by the position of the paragraphs (first and last) and sentences discussing therapy. The introductory paragraph, rather than setting the research in context or stating the purpose of the study, devotes the first 5 sentences to discuss therapeutic implications. For us these subtle deviations from the canonical structure correspond to rhetorical moves having persuasion as a goal. The exposure of the Hwang paper as a hoax, and the attention drawn to it, uncovered a number of features lending support to this hypothesis. However it is difficult for students to perceive it. We agree with Myers (1990) proposal of five strategies to develop critical reading in the classroom in order to support the apprenticeship of reading and writing science.

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Appendix 3

Yarden, A., Falk, H., Federico-Agraso, M., Jimenez-Aleixandre, M. P., Norris, S. P., & Phillips, L. M. (2009). Supporting teaching and learning using authentic scientific texts: A rejoinder to Danielle J. Ford. *Research in Science Education*, 39 (3), 391-395.

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Supporting Teaching and Learning Using Authentic Scientific Texts: A Rejoinder to Danielle J. Ford

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Abstract In her commentary Danielle J. Ford mainly focused on three issues that highlight the promises and challenges for the use of Adapted Primary Literature (APL) in science curricula: the possible contribution of APL to authentic experiences in secondary schools, implementation issues of APL including the support required for the teachers, and the possibilities to extend the use of APL to younger and older students. In this rejoinder, we first offer some general comments on Ford's commentary. Then we offer more specific comments on two areas of her response, authenticity and the support for teachers.

Keywords Adapted primary literature · Reading scientific texts · Inquiry · Authenticity · Teachers' support

General Comments

Ford sees the use of Adapted Primary Literature (APL) as expanding our notion of scientific inquiry from acting and thinking (which have traditionally been seen as central) to include reading and writing. Ford emphasizes that APL can promote the learning of both science content as well as science epistemology. In addition, Ford points out that in contrast

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to the commonly used textbooks, APL and Journalistic Reported Versions (JRV) introduce learners to contemporary scientific issues and expose them to different genres of scientific writing. This way of framing the overall impact of the collection of papers is useful and insightful.

Ford makes the interesting comment that the use of APL expands the notion of authentic science teaching beyond what was possible with the use of strictly empirical approaches to teaching. Her remark seems to mean that the empirical approaches pose tighter limits for what is possible in school classrooms than is posed by the use of APL. This is an interesting justification for APL that we had not previously considered. Therefore, there is not only the additional possibilities provided for authentic language and discourse practices, but also greater possibilities by the reliance on a less restrictive mode of instruction using text. We will make more detailed comments on the issue of authenticity below.

Ford's questions about the use of APL in other areas of science are very well-founded. We really know little of the potential for expansion of this approach beyond the few cases that have been tried (Falk et al. 2008; Norris et al. 2009; Yarden et al. 2001). Ford also points out the very important issue of teacher support. We have very little information to date on the sort of support that teachers need to use APL and what level of success and frustration they experience. Again, we provide more detailed comments below.

Also interesting to us is Ford's question about the progression of learning to read and write scientific texts. The attention of curriculum developers has for years concentrated on the organization of the substantive knowledge of science into grade to grade sequences that portray some notion of increased understanding and sophistication of students as they grow older. We have nothing equivalent for APL. If we are to use APL of the sort we have tried in high school, then what should precede it in the early years? We simply do not know, and Ford has been astute in recognizing this lack of knowledge, especially for the younger students. At the college and the university level, several attempts were previously made to use primary scientific literature (PSL) as a basis for undergraduate courses (Bandoni Muench 2000; DebBurman 2002; Epstein 1970; Janick-Buckner 1997; Smith 2001). In those cases, PSL was used directly without any adaptation to the knowledge level of the learners, which is an inherent characteristic of the APL genre. Therefore, the possibility suggested by Ford to use APL for introductory and non-major science courses, especially those intended for preservice teachers, is appealing. As Ford suggests such texts can help in the transformation of those courses into inquiry courses and may lead to the use of PSL in advanced science courses.

Authenticity

Although the connection between APL and authenticity is implicit in the set of papers, Ford's commentary offers a welcome synthesis of an issue that still seems to have different meanings for different communities. Building from Ford's discussion, we want to join this dialogue elaborating on one point: the meanings of authenticity, particularly in connection with discourse.

It can be assumed that all the authors of papers and discussions in this issue share a notion of authentic scientific practices as practices aligned with consensual perspectives of scientific work, having as a goal the enculturation of students in them. As Ford points out, APL embraces a concept of authenticity that includes discourse. However, there are still large communities of teachers, scientists, educational authorities and even science educators, which hold a different concept of authenticity, relying solely on one feature:

the students' contact with 'real' scientists, usually in a laboratory context. As a consequence, part of the suggested alternatives for improving students' interest and involvement in science learning, are informal activities, from chats with scientists to performances merging science with art. In our opinion while these are appealing for students, its impact either on motivation or on learning has still to be shown. In terms of authenticity, we contend that many of these informal activities only capture superficial features of scientific work. Science can be dramatic and even sometimes 'fun', but also involves working hard with data series, striving to evaluate claims, reading critically. The extent of this notion, which ignores or downplays the role of discourse (and argumentation) in the construction of scientific knowledge, was recently more prominent to us in several international conferences.

All this could point to a trend in using the notion of authenticity as a desirable feature of science instruction. But we are concerned that sometimes it is used just as a label, without fully acknowledging its implications: the interest of engaging students in posing questions, designing their own paths to solve them, collecting evidence, evaluating claims against evidence, building arguments in a dialogic setting. We need to explicitly discuss with other communities the meaning of a sophisticated concept of authenticity and how to implement it in school. For this purpose, APL and other reading and writing tasks may constitute, as Ford suggests, ways to support authentic science practices in the classroom.

Supporting Teachers

Ford's discussion on the support needed for teachers who use APL in their classrooms is important for two main reasons. The first one is self evident—teachers not feeling confident enough in their APL associated Pedagogical Content Knowledge (PCK) would be reluctant to implement APL based materials. The second reason became evident during the studies by Falk et al. (2008). The results have shown that teachers' APL associated PCK is a critical factor that may tilt the delicate balance between the benefits and challenges of this genre during enactment (Falk et al. 2008). Similarly to Ford, we believe that enacting APL based materials may present a serious challenge to the teachers. Teaching cutting edge science by inquiry is not a trivial task, all the more the additional dimension of doing so using text based learning, that teachers are often considering an antithesis to inquiry learning. Therefore, supporting teachers enacting APL materials is important and might be done using several approaches:

1. An enactment model based on a constructivist dialogue between the students and the article, with the mediation of the teacher, was designed (Yarden et al. 2001) and presented to teachers during professional development workshops and through curriculum guides. During this dialogue the teacher mainly directs her/his students to the article as a main source of knowledge. Analysis of interviews with enacting teachers, their students and class observations has shown that teachers extensively use this model and even transform it in order to include aspects of NOS and explicit analysis of the APL genre (Falk et al. 2008).
2. A multimedia curriculum guide for the developmental biology APL based curriculum was designed (Falk et al. 2005). It includes a rich pool of questions and tasks related to the articles, to be edited by the teachers. The teachers are explicitly guided to use only those questions and tasks suitable for their purposes, their students' level and class context and to further transform them in order to fit their specific needs. The guide

includes also video-taped class enactment sequences, accompanied by pedagogical comments. Enacting teachers have reported (Falk et al. 2005) that these sequences can contribute to their enactment by scaffolding their expectations of students' performance, their teaching plans and appropriation of their teaching strategies and self confidence as novice teachers to APL. The video-taped enactment sequences were also used during workshops with teachers enacting the biotechnology APL based curriculum.

3. Several types of professional development workshops were designed for teachers enacting the biotechnology APL based curriculum: i. a short acquaintance workshop (3 h) presenting the rationale of this genre, its possible benefits and challenges and part of one article; ii. a summer workshop during three subsequent days (24 h), presenting the scientific background of the APL articles, and diverse enacting models, part of them suggested by the teachers themselves; iii. a follow-up workshop (32 h), for teachers during their first year of implementation of the curriculum. This workshop is mainly focused on creating a supportive community, to discuss challenges and answer questions raised by teachers, as well as present several case studies of enactment of APL in classrooms. One of the main goals of the summer and follow-up workshops was to collaboratively design assessment tools at different levels. This practical goal presented a good opportunity to discuss the different aspects of the curriculum rationale, particularities and expectations.
4. A web site dedicated to the biotechnology curriculum presented the teachers with pictures to be used for preparing presentations, animations of the biotechnological methods and a forum where they could ask questions and share didactic materials.

Those four examples can illustrate our attempts to support the teachers in implementing APL in their classes. Nevertheless, we believe this can be viewed only as the "tip of the iceberg" of what is required in order to enable to realize the vision of the use of APL as an authentic inquiry activity in secondary schools. The research that is outlined in this issue, along with other attempts to use authentic scientific texts in secondary schools, can provide a sound basis for designing novel supports for the teaching and learning using such genres in science classrooms in secondary schools.

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Appendix 4

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Reading Science Texts—Epistemology, Inquiry, Authenticity—A Rejoinder to Jonathan Osborne

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Abstract We shall structure this rejoinder around two main sections. In the first, we address three underlying assumptions of our work that Osborne has identified. We indicate points of agreement, disagreement, and clarification. In the second section, we discuss briefly and add our clarifications to three understandings of his that Osborne introduces into the discussion. It should be noted that Osborne's response is grounded in the same basic assumption as our set of papers, namely, the central role played by reading and writing, and communicative activities in general, both in science and in learning science.

Keywords Adapted primary literature · Reading scientific texts · Inquiry · Authenticity · Epistemology

Identification and Critique of Our Assumptions

The core of Osborne's response (2009, this issue) is the identification and critique of several assumptions that underlie our research. As he said in a true Popperian spirit, it is through engagement with contradiction (at least with pointed questioning) that our understanding

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advances. In this frame of mind we take up his questions and attempt to answer them adequately in a short space.

The first assumption identified by Osborne is that "learning to read scientific text leads not only to the possibility of learning the substantive content of science, but also to learning its epistemology". We agree that this assumption underlies our work. Osborne's critique, expressed perhaps more as a concerned question, is whether attempting to teach students through the use of APL is the best use of resources. His concern arises from the observation that the cost of entry into contemporary science, measured in terms of the background knowledge needed, is enormously high, maybe too high to expect most individuals to be willing to pay. Alternatively, he suggests that media reports of science might be a more appropriate focus of science education, given that students would be more likely to encounter these in their futures and it is important for them to be able to read critically such reports.

We need to examine closely these alternatives. First, it is indeed important for citizens to be able to read well media reports. We are in agreement with Osborne on that point. However, we note that media reports often do not portray the epistemology of science well. As demonstrated, for instance, in a study by Federico-Agraso and Jiménez-Aleixandre (2008) showing how tentativeness and uncertainty diminish or disappear in the path from the original paper to the journalistic reported versions (JRV). JRV often do a better job than textbooks of portraying the epistemology of science (Penney et al. 2003), but they do not present as accurate a portrayal as APL (Baram-Tsabari and Yarden 2005; Falk et al. 2008). Therefore, learning to read media reports cannot be seen as a substitute for learning to read APL. Each genre has its lessons to offer and they can be viewed as complementary. We wonder whether we can have the benefits of learning from both. Although we realize that always there will need to be tradeoffs, knowledge of the epistemology of science and ability to read media reports are both important. Perhaps we can agree that at least some time in the curriculum can be found for both by reducing the overwhelming amount of factual content.

We also doubt that the entry cost into APL is as high as Osborne imagines. If, because of the cumulative nature of science, we need to know everything that came prior before we can learn what is new, then the cost surely *is* too high, even for those who would be future scientists. However, we have shown that students can grasp science on the cutting edge—they can read and understand APL on the role of the myogenin protein in the whole organism (Brill and Yarden 2003), on new biotechnological methods for generating transgenic plants (Falk et al. 2008) or bacterial biosensors (Falk and Yarden 2009, this issue), on the mathematical modelling of disease transmission (Norris et al. 2009, this issue), and, in new research that we are now conducting, on how ultraviolet radiation affects the DNA molecule. In each of these cases, the adapted research article was published in a recent issue of a leading scientific research journal. It is of course the case that often the methods were more esoteric than could be presented completely and many compromises needed to be made in the adaptation process from primary scientific literature to APL. Yet, the scientific concepts and, especially, the scientific reasoning (epistemology) were possible to portray in a way that students could understand. We think it likely that students who experience the complexity of scientific inquiry, the ambiguity of data, and the multiple coordination practices needed in order to make meaning of APL; and who as well participate in the argumentation process and criticize the research while suggesting possible improvements to it (Falk and Yarden 2009, this issue) might be better equipped to critically read media reports. This hypothesis can be examined by comparing students that experienced learning using APL with novices while reading media reports of science.

The second assumption is that reading should be seen as an act of inquiry. Osborne's concern here is that "Whilst reading … is definitely a process of inquiring into meaning …

it is difficult to see how it itself can be seen *as inquiry*". Let us say a few things. First, it is because reading is a process of inquiring into meaning that Phillips and Norris concluded that reading is inquiry. Second, by this they did not intend, and have made this explicitly clear, that reading is all of *scientific* inquiry—it is but one important part, although frequently overlooked. Thus, Norris and Phillips have said that reading is "as much a part of scientific inquiry as are observation, measurement, and calculation" (Norris and Phillips 2008, p. 233). Also, "when the reading is of science text, it encompasses a very large part of what is considered doing science. It is not all of science, because it does not include the manipulative activities and working with the natural world that are so emblematic of science" (Norris and Phillips 2008, p. 256). We agree with Osborne that "inquiry is a process requiring a multiplicity of actions". We also agree that reading is but a part of scientific inquiry. Yet, we maintain that reading by itself is inquiry and that it involves "a multiplicity of actions" in the way required by Osborne, and as Norris and Phillips have demonstrated.

In addition to the aforementioned points, when dealing with the APL genre, students read texts that are similar to those written and read by scientists. In the course of learning using APL, the students suggest suitable methodologies, analyze data, and coordinate between theory and data and between different stages of the experimental process (Falk and Yarden 2009, this issue). In so doing, they perform the majority of the processes mentioned by Linn et al. (2003) in their definition of inquiry. It should be kept in mind that learning by inquiry is not a built-in characteristic of APL. Rather, inquiry emerges in association with suitable classroom engagements with the text coordinated by teachers' pedagogical content knowledge.

The third identified assumption is that APL can find at least some of its justification in its authenticity. Osborne is correct to remind us that being authentic to science in some defined way is never sufficient justification by itself for engaging in an educational practice. Authenticity is no guarantee of effectiveness. Furthermore, whatever arguments could be made for the authenticity of APL, there are so many differences between the context of school science and the context of research science that all claims to authenticity must be seriously hedged. Nevertheless, APL does offer a possible way to achieve one part of Osborne's "primary goal of science education", namely, learning the means whereby scientific theories are justified. Thus, from our perspective, APL is worth a try because much else that has been tried for reaching that important goal has failed.

Other Points of Clarification

Osborne introduces a distinction between discovery and justification made by logical positivists to frame a point he makes about the role of science textbooks. Essentially, textbooks capture neither the discovery nor justificatory aspects of science. Like he, we recognize the flaws in the original distinction, and see how it can also be used to frame the use of APL. Logical positivists, including Reichenbach (1938), found it important to distinguish carefully between the tasks of psychology and epistemology. Psychology, they thought, might be able to provide insight into the origin of scientific ideas, that is, the creative thinking processes that led to their construction. However, as epistemologists, Reichenbach and his colleagues judged that they had no significant insights into such discovery processes, and relegated investigation of the context of discovery to empirical psychology. As epistemologists, however, they were concerned to articulate the ideal by which, once ideas were introduced into science, they ought to be tested and justified. They described the process of constructing such an ideal as a rational reconstruction, and said that it fell into the context of justification. As an ideal, a rational reconstruction of scientific justification is not a report of the real processes scientists engaged along the way of a study, but, rather, of those that ideally they should have engaged. Strictly, then, primary literature does not coincide with the positivists' context of justification, because it portrays, or purports to portray, the thinking that scientists actually did in motivating and testing their ideas. Even so, Reichenbach and other positivists did agree that the primary scientific paper does approximate what they meant by rational reconstruction, because the paper is not a literal step-by-step recounting of what the scientists did, but a tidied version made ready for public consumption. As a veridical adaptation of primary literature, APL can be construed in the same way to be a rational reconstruction of the context of justification of scientific work, and, because of this characteristic more than any other, stands in stark contrast to scientific textbooks and demands literacy abilities not normally assumed or fostered by science programs and teachers.

Related to the issue of justification, Osborne notes that "a textbook that began its explanatory account by stating, for instance, that one explanatory account for day and night is offered by the heliocentric view of the world whilst another is offered by the Ptolemaic perspective would simply fail to fulfil its required function even it were it to explain the criteria by which the heliocentric is judged a better explanatory account". We recognize that Osborne actually would be happy to see more such "failed" textbooks make it into the classroom. We would like to offer our support also and to point out that currently many authors (e.g., Duschl 2008; Jiménez-Aleixandre 2008; Kelly 2008) agree on the relevance of supporting students in the development and use of epistemic criteria to evaluate knowledge claims, this evaluation being a central practice in argumentation. An implication would be that, although most scientific models are taught without reference to the evidence supporting them, there is a need for introducing and discussing the processes of evaluation that lead to choosing one explanatory account over others. For this purpose, classroom work, both with APL and with JRV, about how evidence to support claims is articulated, as exemplified in Jiménez-Aleixandre and Federico-Agraso (2009, this issue), could be useful. Textbooks that included activities and discussions about competing explanations could contribute to these goals. Certainly, we agree with Osborne that one of the substantial objectives involved here is not to reveal the distortions in JRV, but rather, as Jiménez-Aleixandre and Federico-Agraso (2009, this issue) propose, how to support students in developing critical reading, as a part of the apprenticeship of reading and writing science.

Thus, Osborne accepts the argument made by Norris and Phillips (2003) that literacy is fundamental to science. Yet, it is important to keep three points separate. First, Norris and Phillips' argument was conceptual in the sense that they argued for the impossibility of conceiving of science without literacy. Literacy, they said, is constitutive of science. That is, just as having atomic number 79 is a constitutive property of gold (unlike, say, being yellow, which is contingent) so is literacy constitutive of science. The second point made by Phillips and Norris (2009, this issue) is based upon the research of Tenopir and King (2004), who have reported empirical data on the enormous amount of time scientists spend on communication activities, of which a large chunk involve the literacy activities of reading and writing. This second point is over and above the conceptual one: namely, it shows in addition that scientists spend a great deal of their time engaged in the literacy activities that are necessary to science. It could have been the case that, although necessary to science, scientists spend but a small fraction of their time pursuing literacy tasks. The empirical data provides a second and supportive reason for spending more time on teaching students to read and write in science classrooms. Third, drawing on Longino (1990), Osborne makes the point that the communal nature of science accounts for the literacy practices found in it. Strictly, however, this is not true. Many communal activities are not also literate ones; consider barn-raising as one example. The influence actually carries in the other direction: that is, it is literacy that largely defines the sort of communal practice that distinguishes science.

We make our final point by agreeing with van Lier (1996) that "the people in the setting … authenticate the settings and the actions in it", and with Osborne that "introducing APL literature into a classroom does not, of itself, transform the student experience into something that is an authentic experience of science". As mentioned above, and detailed in our rejoinder to Ford (Yarden et al. 2009, this issue), teachers play an essential role in the implementation of APL in class. We have developed various means to support teachers in applying suitable pedagogical content knowledge to promote the benefits of APL, including its authentic aspects. Indeed, our results have shown that authentic practices have emerged (Falk and Yarden 2009, this issue). Considering the vast amount of scientific information that students must learn in the course of their secondary school studies, learning through APL might be seen as inefficient and time consuming, because each ALP text deals with a specific piece of scientific information that usually can be summarized in a single sentence (Yarden et al. 2001). However, we do not claim that learning using APL is the ultimate and single means to learn science. Rather, APL can be included as part of the science curriculum in addition to other learning materials and approaches.

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