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Exposing explicit and implicit dimensions of biology teachers' professional knowledge in the course of a long-term professional development program

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אדר תשע"ג

" הדברים החשובים ביותר סמויים הם מן העין"
(הנסיך הקטן, אנסטואן דה סנט אכזופרי)

כמה מילים גלויות שלא יכולות להביע במלואן את עומק תודתי

תודה רבה למנחה שלי פרופסור ענת ירדן , שהייתה לי הזכות הגדולה להיות תלמידתה. בדרכה המקצועית והמעמיקה היא בנתה לי , ללא לאו ת, פיגומים שתרמו להתקדמות האישית שלי ו להעמקת המחקר . בגישתה הייחודית, הנעימה והבלתי מתפשרת , היא אפשרה לי לצמוח אל תוך העולם האקדמי תוך תמיכה מתמדת, מקצועית ואישית.

תודה רבה למלווים האקדמיים של המחקר שלי פרופסור ניר אוריון ודוקטור יעל שוורץ , שהיו לי לעזר רב בכל נקודה לאורך המחקר ותמיד האירו לי נתיבים נוספים, שקידמו רבות את המחקר הזה.

תודה רבה לחוקרים במחלקה להוראת המדעים , לצוות הניהולי , לסטודנטים במחלקה ולסטודנטים של תכנית רוטשילד ויצמן על שיתוף הפעולה הפורה ועל שאפשרו לי להציץ לתוך תחומי המחקר, הלמידה וההוראה שלהם. תרומתם מהווה נדבך מרכזי במחקר זה.

תודה מיוחדת לכל חבר יי בקבוצה : לד"ר גילת בריל חברתי למחקר ולהוראה, שדרכה המיוחדת אפשרה לי ללמוד כל כך הרבה . לד"ר רחל כהן , שתמכה בי ברגישות ובמקצועיות בימי הראשונים בשבילי הנחיית המורים . לד"ר הדס גלברט, שתמכה ועודדה תמיד. לד"ר יוסי מחלוף, שהערותיו המקצועיות ועזרתו לאורך כל הדרך לא תסולא בפז . למוריה אריאלי וללנה ראב"ד, שעזרו לי להתמודד עם הרפרטורי גריד בראשית דרכי . לגליה זר כבוד ולתום ביאליק, על הסבלנות, ההקשבה והתובנות שלהם . העבודה היום יומית אתם היא שאפשרה לי להתקדם בסביבה תומכת ומעצימה.

ותודה לכל אחד מבני משפחתי הקטנה ובמיוחד: להורי, שלימדו אותי שעבודה קשה היא מהות ההגשמה והיא הערובה לכך ש"הכל יהיה בסדר". לסרחיו הצוק האיתן, שמסמן לי מטרות בחיים ושומר עלי בדרכי אליהן ולבניי אלון ומורן, שהם היצירה הכי טובה שלנו.

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List of abbreviations

- PCK- Pedagogical Content Knowledge
- CK – Content Knowledge
- RGT – Repertory Grid Technique

Abstract

Understanding teachers' professional knowledge is not a straightforward enterprise since it is comprised of both explicit and implicit interrelated set of knowledge and beliefs about the teaching and learning.

The main goal of this study was to examine in-service high-school biology teachers' professional knowledge, in the context of a long term professional development program. The study addressed both the explicit knowledge and the implicit knowledge of the participating teachers, using different qualitative methods. Initially, I characterized the biology teachers' professional knowledge using a representation that I developed during the course of this study. Aligning the professional knowledge components that emerged during the course of this study with previously published PCK components and analyzing the frequency of appearance of each PCK component in the teachers' data, enabled me to pinpoint specific PCK components and their expansion in the course of the teachers' professional development program. At the subsequent part of the research, I used the Repertory Grid Technique (RGT) to focus on the tacit biology teachers' professional knowledge and comprised it with the tacit dimensions of professional knowledge of teachers from other scientific disciplines (physics, chemistry, and mathematics).

Examining teachers' explicit knowledge revealed that the biology teachers mostly referred to two PCK components: teaching strategies and meaningful learning. Focusing on these two components revealed that teachers may hold different PCK, namely they refer to the same components but interpreted them differently. Moreover, by tracking teachers' repeated explanations about teaching and learning, I was able to determine each teacher's unique PCK orientation, thus clarifying and providing a practical meaning for the term orientation which was previously reported to be unclear.

Examining teachers' implicit knowledge revealed that CK is an important component of the teachers' professional knowledge although it was not one of the most discussed components in the teachers' episodes. Data analysis revealed that while most of the biology teachers as well as most of the chemistry and physics teachers did not integrate the new subject matter CK acquired during the program into their practice, the mathematics teachers largely connected CK to other categories of professional knowledge elements, especially to teaching strategies elements. That is, although mathematics teachers do not teach high mathematics contents in class their PCK can be meaningfully expanded by studying high level mathematics contents. In contrast, the biology teachers which have to stay updated with

new researches and new findings in biology are very interested in acquiring new CK, but it was probably not the main cause for their PCK expansion.

The conclusions of this thesis are that different teachers may hold different PCK orientations. These PCK orientations do not change over time but they are capable of expanding and may become more sophisticated. The expansion of each teacher's unique PCK orientation was driven by the teachers’ need to examine different teaching strategies and learning abilities while designing the new teaching and learning materials. Retention of major parts of the expanded PCK following the termination of the program implies that designing and implementing new teaching and learning materials accompanied by biology and science education courses might provide a powerful means for PCK expansion. In addition, acquiring subject matter CK during professional development programs may differently influence teachers from different disciplines. Therefore, when discussing the place of CK in teachers' practice we should consider the differences between the various disciplines while referring to each discipline separately because of the unique characteristics of each discipline.

There was no clear correlation between each teacher's repertory grid's outcomes and their PCK orientations. That result reinforces the conclusion that in order to examine teachers' professional knowledge comprehensively, science education researchers should examine both explicit as well as implicit knowledge.

The main implication that can be drawn from this research is that professional development program designers should consider focusing on each teacher's unique PCK orientation in order to appeal to each teacher's cognitive structure, thus minimizing rejection of newly acquired knowledge that does not correspond with the individual's existing constructs. Appealing to each teacher's unique PCK orientation may in turn reinforce effective professional development. In addition, professional development designers should consider not ignoring subject matter CK, which is a very important domain of biology teachers' professional knowledge. However, professional development programs designers should consider promoting the connection between biology teachers’ CK and PCK instead of assuming that increasing CK will automatically improve PCK.

Rationale

Experienced teachers hold a unique teaching knowledge that enables them to operate effectively in the complex situation of the classroom (Ainley & Luntley, 2006). There is a clear need to deepen our understanding of teachers' knowledge, which continues to develop throughout teaching practice years, since it enhances their students' learning as well as their own professional knowledge of practice (Loughran, 2010).

It has been shown that during teaching practice teachers construct intuitive knowledge which is based on their personal experience at school (Loughran, 2003). Different teachers hold different conceptions about teaching, learning and knowing which may lead to different teaching styles (Heimlich & Norland, 2002). In addition, it has been shown that teachers often lack the knowledge of science education theories (Von Glasersfeld, 1989). Moreover, knowledge of the various science disciplines like biology rapidly changes because of the vast amount of scientific discoveries. Therefore, professional development programs are aimed at supplying the theoretical as well as the content knowledge required to enhance teachers' professional development.

A majority of subject matter courses in teacher education programs are often viewed by teachers as having little bearing on the day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball, Thames, & Phelps, 2008). When new knowledge does not correspond with the individual teacher's existing construct (Von Glasersfeld, 1989) he or she often rejects the acquisition of new knowledge or learning programs (Postholm, 2008a). Therefore, supplying a theoretical and practical foundation that seems compatible with their experience may provide an accessible way to make teachers' learning aware of teaching and learning procedures and thus lead to professional development (Parke & Coble, 1997). Yet, little attention has been paid to the expansion of experienced teachers' professional knowledge during a long-term professional development program aimed at designing new teaching and learning materials suggested by the teachers themselves and reflected by them while implementing their designed materials in their class.

Understanding teachers' professional knowledge is not a straightforward enterprise. Science teachers' professional knowledge is comprised of an interrelated set of knowledge and beliefs about the goals and purposes of science teaching, views the of nature of science, and beliefs about science teaching and learning (Friedrichsen, Van Driel, & Abell, 2011). Moreover, this professional knowledge is comprised of both explicit and implicit knowledge (Ainley & Luntley, 2006; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001). That is, examining teachers' knowledge should apply methods to elicit both explicit and implicit knowledge, in order to achieve better understanding of teachers' knowledge. Yet, little attention has been paid to examining both explicit and implicit teachers' knowledge in the context of a long-term professional development program aimed at providing a learning environment that may enrich the participating teachers' professional knowledge in both contemporary topics in science or mathematics and science education theories.

Thus, in order to design professional development programs that will influence teachers' professional development effectively I examined both teachers' explicit and implicit professional knowledge in the context of a long term professional development program. This examination shed some light on important issues of teachers' professional development during long-term professional development programs. The results of my examination enabled me to draw recommendations for designing in-service biology teachers' long term professional development programs.

1. Theoretical framework

1. 1 Teaching, Learning and Knowing

Research about teaching learning and knowing is central to the field of education. Knowledge is a system composed of many interrelated elements that can change in complex ways (Smith, diSessa, & Roschelle, 1993). Researchers agree that knowledge is not the representation of what exists in the world but rather it is the mapping of what, in the light of human experience, turns to be feasible (Von Glasersfeld, 1989). Three general perspectives, the behaviorist, the cognitive and the situative, structure the nature of teaching learning and knowing in a unique and complementary way (Greeno, Colins, & Resnick, 1996).

The behaviorist perspective on teaching and learning is that knowing is the organized accumulation of associations between ideas, and learning can be viewed as building new associations. Knowing can be characterized in terms of observable connections between stimuli and responses, meaning that knowledge is built through connections between neuronlike elements and learning is strengthening or weakening of those connections (Greeno et al., 1996). Learning is reinforced by positive reactions from the teacher who is the dominant person in the classroom. Evaluation of learning comes from the teacher who decides what is right or wrong and focuses on external changes in the learners' behavior (Skinner, 1988). The behaviorist theory on learning is based on experiments on learning of animals, such as the Pavlov's experiment on dog is a response to stimuli. Pavlov demonstrated how a musical tone, which has been paired with receiving food, could elicit similar behavior in humans (Thomas, 1997).

Following Pavlov's experiments and other experiments about learning in animals, Skinner designed a teaching machine in 1958. Skinner’s teaching machine was a rote-and-drill machine which displayed programmed instructions for learning. This teaching machine can be viewed as an early form of today’s basic educational software. Computer software designed for students help to reinforce student behavior because they are designed to reward students through an encouraging comment before moving on to the next learning objective (Weegar & Pacis, 2012).

Taken together, behaviorism refers to teacher centered instructional strategies. In this approach, the teacher is the focus of the presentation and interaction. The student's role is to absorb instructional presentations and material. Structured assignments are directly linked to the learning objectives. Assessment and evaluation are based upon individual tests and performances to demonstrate mastery of entities, activities, and processes.

The cognitive perspective on knowledge construction emphasizes the understanding of concepts, theories and general cognitive abilities such as reasoning, planning, solving problems and comprehending language (Baumert et al., 2010). One central branch of the cognitive perspective is the constructivist theory, that was originally developed by Piaget (1929). The constructivist theory is focused on characterizing the cognitive growth of learner's conceptual understanding through active participation of the learners themselves in the learning process. According to constructivism, humans are unable to automatically understand and use information that they have been given, because they need to "construct" their own knowledge (Von Glasersfeld, 1989). Therefore, the primary role of the teacher should be to help learners to create their own knowledge through reorganization of concepts and growth in general cognitive abilities, such as problem-solving strategies and metacognitive processes (Greeno et al., 1996). The teacher facilitates and negotiates meaning, rather than dictate an interpretation (Brown, Collins, & Duguit, 1989). The cognitive perspective suggests focusing on teaching as a kind of coaching, emphasizing teachers' understanding of students' thinking and existing knowledge (Smith et al., 1993). Teachers should identify potential improvement and help the learners to construct or discover knowledge by gradually adjust the learner's existing conception to a new one. Each new adjustment laying the groundwork for further adjustment where the end result is a substantial reorganization in one's cognitive structure (Chi, 2009; Posner, Strike, Hewson, & Gertzog, 1982). The learning is considered an internal cognitive activity where students construct knowledge from classroom experience.

The situative perspective on knowledge construction views knowledge as distributed among people and their communities of which they are part. Knowing is both an attribute of groups that carry out cooperative activities and an attribute of individuals who participate in the communities of which they are members (Greeno et al., 1996). This perspective contrasts with most classroom learning activities which involve knowledge that are abstract and out of context. Social interaction is a critical component of situated learning. Learners become involved in a "community of practice" which embodies certain beliefs and behaviors to be acquired (Brown et al., 1989). Brown et al. (1989) emphasize the idea of cognitive apprenticeship which supports learning in a domain by enabling students to acquire, develop and use cognitive tools in authentic domain activity. Learning of a group or of individuals involves becoming attuned to constraints and affordances of materials and social systems with which they interact. Knowing how to participate in social practices plays a crucial role in all aspects of students' learning in and out of school (Brown et al., 1989; Greeno et al., 1996).

Cognitive apprenticeship actually leads to cognitive development (Collins, Brown, & Newman, 1989). Vygotsky (1978; 1986) proposed that learning, which he referred to as “social” constructivism, occurs in the "zone of proximal development" (ZPD): "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers". In other words, a student can perform a task within his or her ZPD under guidance of a teacher or with peer collaboration that could not be achieved alone. The ZPD bridges that gap between what is known and what can be known.

The situative perspective suggests a focus on teachers as mentors who represent communities of teaching practice in professional development programs. As such, they engage in the professional activities of creating and using disciplinary knowledge and skills, and guide students as they become increasingly knowledgeable practitioners (Collins et al., 1989; Greeno et al., 1996).

These three general perspectives provide significant means for clarification of teaching and learning processes. There are many factors to be considered when deciding which theory is more valid in certain situations. Though there seems to be a shift toward more constructivist learning, it seems that practically teachers tend to teach in a variety of ways without being cautious to the differences between learning theories (Weegar & Pacis, 2012). Research about teachers' professional knowledge can shed light over possible connections between in-service teachers' prior knowledge, knowledge development in professional development programs and their practice in class.

1.2. Professional teaching knowledge base

Teachers' knowledge base is comprised of two different kinds of information: knowledge and beliefs (Magnusson, Krajcik, & Borko, 1999). Knowledge refers to information that is certain, solid, dependable, verbalized by teachers and supported by research (Smith et al., 1993). Beliefs are what people think they know or may come to know based on new information. Beliefs are supported by experience, and people are strongly committed to them (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). Moreover, knowledge of experienced teachers comprises of both explicit and implicit knowledge. Explicit knowledge refers to knowledge that teachers are aware of and can verbalize. Implicit knowledge refers to experienced teachers' tacit knowledge. The teachers have the feeling what they should do while teaching, but cannot tell explicitly why and they are often unaware of this knowledge (Stolpe & Bjorklund, 2012).

While both explicit and implicit knowledge may be constructed and modified when the learner meets new information or new ideas and as such it may change (Loucks-Horsley et al., 2003; Smith et al., 1993), beliefs are unique, individual, and are more resistant to change (Da-Silva, Ruiz, & Porlan, 2006; Pareja, 1992; Van Driel, Bulte, & Verloop, 2007).

1.2.1. Teachers' knowledge types

Shulman (1986) first suggested that there are three types of knowledge that are required for teaching: pedagogical content knowledge (PCK), subject matter content knowledge (CK) and curricular knowledge. PCK was defined as a special amalgam of content and pedagogical knowledge that is unique, and represents the ways of representing and formulating the subject that makes it comprehensible to others (Shulman, 1986, 1987). CK was defined as the amount and organization of subject matter knowledge per se in the mind of a teacher. Curricular knowledge was defined as the full range of programs designed for the teaching of particular subject and topics at particular level (Shulman, 1986). The first two types of knowledge, CK and PCK, are both considered as critical professional development resources for teachers, each requiring special attention during both teacher training and classroom teaching practice (Baumert et al., 2010).

1.2.2. Pedagogical Content Knowledge (PCK)

According to Shulman (1986; 1987), researchers should refer to PCK as a special knowledge domain which includes understanding how particular topics, problems or issues are organized, represented and adapted to learners' diverse interests and abilities, as well as how they are presented during instruction. Shulman (1986) suggested that PCK is comprised of two components: teaching and learning. PCK of teaching is the knowledge of teaching a specific subject matter: "the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986). PCK of learning is an "understanding of what makes the learning of a specific topic easy or difficult" (Shulman, 1986).

Numerous science educators have discussed and revised Shulman's PCK model, suggesting more detailed representations. Grossman (1990) proposed a model that provides four components of PCK: conceptions of purposes for teaching a subject matter, knowledge of student understanding, curricular knowledge, and knowledge of instructional strategies. Magnusson et al. (1999) changed Grossman’s use of the term 'purposes' to 'orientation', added beliefs to knowledge, and added an additional component—knowledge and beliefs about assessment. Thus, the five modified components of science teachers' PCK suggested by Magnusson et al. (1999) are: (i) orientation toward science teaching; (ii) knowledge and beliefs about science curriculum; (iii) knowledge and beliefs about students' understanding of specific science topics; (iv) knowledge and beliefs about instructional strategies for teaching science; (v) knowledge and beliefs about assessment in science. These five PCK components have served as the basis for analyzing science teachers' PCK in various contexts (Cohen & Yarden, 2009; Eylon & Bagno, 2006; Friedrichsen et al., 2009; Friedrichsen et al., 2011; Henze, van Dreil, & Verloop, 2007; Lee & Luft, 2008; Park & Oliver, 2008a, 2008b).

One PCK component which was suggested by Magnusson et al. (1999): 'orientation towards teaching science' seems to be difficult to define (Friedrichsen et al., 2011). Magnusson et al. (1999) defined orientation as: "an over arching component that shapes, and is shaped by, the other four PCK components…a general way of viewing or conceptualizing science teaching". Magnusson et al. (1999) explained that this component plays a central role in the PCK framework and includes teachers’ knowledge and beliefs about the purposes and goals for teaching science at a particular grade level. This knowledge component serve as a 'conceptual map' that guides instructional decisions about issues such as daily objectives, the content of student assignments, the use of text books and other curricular materials, and the evaluation of student learning" (p. 97). Namely, this component encompasses the four other PCK components to describe the way they all guide the pedagogical knowledge of teaching and learning science. Yet, the orientation component appeared to be unclear (Friedrichsen et al., 2011) mainly because of the dual meaning of this component, which includes both the goals of teaching science and the typical characteristics of instruction that would be conducted by a teacher with a particular orientation (Magnusson et al., 1999).

Numerous studies have either focused on the goals and purposes of teaching science or on the typical characteristics of instruction (Friedrichsen et al., 2011). Moreover, Magnusson et al. (1999) proposed nine different orientations. These nine orientations seem to come from different sources and their theoretical and empirical bases are either weak or does not exist (Friedrichsen et al., 2011). After examining published studies using the term orientation when relating to the PCK model, Friedrichsen (2011) proposed defining science teaching orientation as: "an interrelated set of knowledge and beliefs with the following dimensions: goals and purposes of science teaching, views of nature of science, and beliefs about science teaching and learning" and suggested that there is a need for studies that focus on whether and how the development of PCK affects science teacher orientations.

Researchers agree that PCK is used in the context of teaching a specific content (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran, Mulhall, & Berry, 2008; Magnusson et al., 1999), but the resolution of the term "specific content" is a subject for debate. While some researchers refer to the term "content" of the construct PCK as the knowledge of teaching a specific subject matter (de Jong & Van Der Valk, 2007; Henze, Van Driel, & Verloop, 2008; Loughran et al., 2008; Van Driel, Verloop, & De Vos, 1998), others refer to it as "the knowledge of teaching all the topics they teach" (Magnusson et al., 1999), or "discipline-specific knowledge as well as general science" (Abell, 2008). Berry et al. (2008), quote an interview with Lee Shulman that was conducted at the Annual Meeting of the American Educational Research Association (AERA), in Chicago, April 2007. In this interview Shulman refers to PCK as the knowledge of teaching the whole domain, giving an example of teaching biology: *"Well that's why the pedagogy of biology is an example of PCK. Because you've got to deeply understand what it is that makes evolutionary theory? whether you think ecologically or cellularly*". In other words, teachers need to go beyond knowledge of facts or concepts of a domain to the explanation of the structure of the domain and the basic principles and the rules for determining what is legitimate to say in a disciplinary domain. Therefore, PCK should be considered as the knowledge of teaching a whole domain rather as the knowledge of teaching a specific subject matter within the domain. In this research, I follow Shulman's definition of PCK and refer to PCK as the pedagogical knowledge of teaching biology as a whole domain, rather than the knowledge of teaching a specific subject matter in the biology domain.

1.2.3. Content Knowledge (CK) and its relations with PCK

PCK is not the only type of knowledge necessary for teachers' practice and professional development. Teachers need subject matter content knowledge (CK) as an integral part of their knowledge for practice. Ball et al. (2008) defined CK for mathematics teaching as: "the mathematical knowledge known in common with others who know and use mathematics". Namely, this kind of knowledge is known to all the people that use mathematics aside the knowledge that teachers use in order to explain mathematics. According to Shulman (1986), subject matter knowledge for teaching requires more than knowing its facts and concepts. Teachers must also understand the organizing principles, structures and rules for establishing what is legitimate to do and say in the field. Yet, it is not easy to distinguish PCK from CK for teaching (Kahan, Cooper, & Bethea, 2003).

Several studies examined the relations between CK and PCK and their influence on teaching. Grossman (1990) suggested that beginning teachers tend to rely more heavily on one domain of knowledge, while experienced teachers are able to integrate all the domains in their practice. It has been suggested that the degree of cognitive connectedness between CK and PCK among secondary mathematics teachers is a function of the degree of mathematical expertise (Krauss et al., 2008). Moreover, mathematical CK may enhance mathematics teachers' quality of teaching. The breath, depth, and flexibility of teachers' understanding of the mathematics they teach afford them a broader and a more varied repertoire of teaching strategies (Ball et al., 2008; Baumert et al., 2010; Even, 2011; Krauss et al., 2008) and deepen their understanding of students thinking and conceptual understanding (Borko, 2004), while limited CK may limit the development of PCK (Baumert et al., 2010). Conversely, Hollon et al. (1991) showed that a broad CK in the discipline does not guarantee that teachers use it effectively in class. Galili (2012) suggested that cultural content knowledge in physics education may elevate teachers' awareness of the conceptual scientific tradition. Namely, knowing the philosophy and history of science and physics in particular, may improve teachers' teaching style. Knowing the philosophy and history of science helped teachers to focus on the way that objective scientific knowledge accumulates rather that only concentrating on right or wrong scientific facts. It was also shown that teaching explicit knowledge about the nature of science is positively correlated with better acquisition of content knowledge (Peters, 2012). A study about teaching chemistry showed that strengthening the teachers’ knowledge of chemistry, and the pedagogical content knowledge of chemistry, are prerequisites for becoming a teacher leader (Hofstein, Carmi, & Ben-Zvi, 2003). Yet, little attention has been paid to the influence of biological CK on biology teachers' PCK and professional development. Indeed, examining PCK and CK is not a straightforward process due to the complex nature of these types of knowledge and their internal tacit construct (Loughran et al., 2001).

1.3. Exploring teachers' knowledge

As mentioned above, teachers' knowledge is comprised of explicit knowledge and implicit knowledge (Ainley & Luntley, 2006; Loughran et al., 2001). Examining teachers' knowledge should apply methods to elicit explicit knowledge as well as implicit knowledge in order to achieve better understanding of teachers' knowledge and its influence on teachers' actions in class as well as on professional development programs.

1.3.1 Exploring explicit knowledge

Explicit knowledge is the knowledge that can be verbalized, clearly explained and shared with other individuals (Polanyi, 1966). Little (2002) defined explicit knowledge about teaching as "the face of practice". This knowledge is the part that can be demonstrated and distributed among people. In the effort to explore teachers' knowledge, a variety of methods using explicit data have been used. These methods include meta-analysis (Zeidler, 2002), interviews, knowledge tests like multiple choice and open-ended questionnaires about teaching and learning situations (Baumert et al., 2010; Hill, 2008), as well as class observations (Lee & Luft, 2008; Rozenszajn & Yarden, 2011; Stein & Nelson, 2003; Van Driel et al., 1998). But, the exploration of explicit knowledge may reveal only a part of teachers' knowledge, therefore there is a need to elicit also teachers' implicit knowledge in order to obtain a full picture of teachers' knowledge.

1.3.2 Exploring implicit knowledge

Implicit knowledge is tacit, contextual and situated. The person who holds implicit knowledge about something will be unable to verbalize it and often will be unaware of that knowledge, namely it remains tacit (Polanyi, 1966). Experts usually hold a lot of tacit knowledge. As much as one repeatedly experiences certain experiences he or she gradually becomes experts in that field. Experts are usually able to recognize meaningful patterns faster than novices (Chi, 2006; Dreyfus, 2004). An expert, who is facing an unfamiliar situation, intuitively identifies what should be done. It seems that he or she does not even think, just does what normally works and, of course, it often normally works (Dreyfus, 2004). Usually, an expert is unable to verbalize the 'know how' (Bjorklund, 2008), meaning that one knows more than one can tell (Polanyi, 1966). Polanyi (1966) argued that tacit knowledge involves functional relations between an awareness of a phenomenon, which he defined as the 'proximal terms' of tacit knowledge and attending to its consequences, the 'distal terms'. The way one moves from the proximal terms to the distal terms, thus achieving an integration of particulars to a coherent entity, constitutes his or her tacit knowledge. Since one is not attending to the particulars in themselves, he or she cannot identify them but may be aware of them in their bearing of a comprehensive entity which they constitute. It may be said that it is not by looking at particulars, but by dwelling into them, or in other words by interiorizing them, that one may understand their joint meaning without being able to specify each one of them in particular (Polanyi, 1966).

Experienced teachers hold implicit knowledge therefore, they are usually able to function automatically (Ainley & Luntley, 2006; Stolpe & Bjorklund, 2012). Much of their activities in class, such as the interaction between teachers and students, are patterns of behavior that teachers could invoke and perform without any conscious effort. Experienced teachers appear to have organized their knowledge of students and classrooms in particularly effective patterns that could be retrieved unconsciously from their long term memory via classroom cues (Johansson & Kroksmark, 2004).

The American psychologist, George Kelly, formulated a psychological theory which may explain the notion of the tacit knowledge as a non verbal, unconscious knowledge that controls the expert's decisions and actions. George Kelly (1955) argued that people have different views towards events in the world. These views are organized uniquely within each person's cognitive structure. Kelly (1955) established a psychological theory, the Personal Construct Psychology (PCP) theory which argues that each person makes use of personal unique criteria, or constructs, which help him to construe meaning to events. The personal construct theory states that people's view of objects and events they interact with is made up of a collection of related similarity-differences dimensions, referred to as personal constructs (Kelly, 1955, 1969).

Kelly drew explicit parallels between the processes that guide scientific research and those involved in everyday activities (Bezzi, 1996; Bradshaw, Ford, Adams-Webber, & Boose, 1993). Like scientists, people tend to predict and control the course of events in their environment by controlling mental models of the world. These mental models then enable individuals to formulate testable hypotheses about future events, and then test and revise them against their experience (Duit & Glynn, 1996; Duit & Treagust, 2003). Such acts or judgments of events are often experienced as intuition or gut feelings (Jankowicz, 2001) because of their tacit notion.

Following the consolidation of the Personal Construct Psychology theory Kelly designed a method to elicit personal constructs, namely tacit knowledge, which is known as the Repertory Grid Technique (RGT). RGT has been used in clinical psychology for more than 50 years but has recently found new use in a variety of research areas. The methodology and the use of the RGT are described in details in the methodology section (pp. 29-34).

1.4. Teachers' beliefs

Beliefs are what people think they know or may come to know based on their experience, and they are strongly committed to them (Loucks-Horsley et al., 2003). Teaching beliefs, from a constructivist point of view, are regarded as conceptions about the nature of science, about scientific concepts, and about how to learn and teach them. A conception is stable over time. It is the result of a constructive process, which is connected to other aspects of a student's knowledge system, robust when confronted with other conceptions, and widespread (Smith et al., 1993). Experienced science teachers have conceptions about teaching and learning that have been consolidated by their own professional experience, and these are usually stable and resistant to change. Sometimes, this is because they feel satisfied with their conceptions about teaching and learning, and there is coherence between their conceptions, their goals, their educational practice and their perception of their students (Da-Silva et al., 2006). When the conception is associated with a positive mood or if it was critical to the individual's survival, the individual may also have a high degree of commitment to it. Strongly committed conceptions are highly resistant to change in part due to this commitment and in part due to their likely rich interconnections with other conceptions (Sinatra & Mason, 2008).

Examining teaching conceptions led scholars to suggest that different teachers can hold different conceptions about teaching, learning and knowing which may lead to different teaching styles (Heimlich & Norland, 2002). A conception on teaching is defined as an interrelated set of beliefs and intentions that gives direction and justification to a teacher's actions (Pratt, 2002). Glasson and Lalik (1993) reported that during a professional development program, teachers may develop either a positivist conception, namely a belief that the goal of science instruction is that students arrive at scientifically acceptable conclusions, or a constructivist conception - that a teacher gives students the opportunity to develop their own understanding.

The terms "belief" and "conception" about teaching and learning are used in the literature in different contexts but they describe the same phenomenon. Both belief and conception refer to the same 'resistant to change unique idea' that each teacher may hold about teaching and learning and that may lead her or his teaching in class (Da-Silva et al., 2006; Lotter, Harwood, & Bonner, 2007; Murphy & Alexander, 2008; Sinatra & Mason, 2008). Therefore, in this thesis I used the term 'conception' to describe both conceptions and beliefs about teaching and learning.

Understanding teaching knowledge base and how it is acquired is central for establishing meaningful means for further developing teachers' knowledge.

1.5. Teachers' professional development

A professional development process is rather complex and the process of teachers' empowerment within a long-term professional development program is not straightforward (Van Dreil & Beijaard, 2003). During professional development programs teachers experience development of several dimensions of their professionalism (Bell & Gilbert, 1996; Even, 1999; Hewson, 2007). Initially they see themselves as competent professionals who nevertheless have room for growth in some aspects of their practice. Next they learn new ideas, approaches and activities, and become more self-aware, they reconstruct aspects of their practice, and they develop a new sense of being a teacher of science within their collegial group (Bell & Gilbert, 1996; Hewson, 2007). Moreover, it is important to be aware of three dimensions of professional development that may add value to the teachers who participate in the process: personal, professional and social development (Bell & Gilbert, 1996; Even, 1999): i) *Personal development* means an affective development that involves attending to feelings about the change process, of being a teacher leader, and about teacher education; ii) *Professional development* involves changing concepts and beliefs about science education and teacher education, and changing teacher education activities; iii) *Social development* involves working with and relating in new ways to other teacher leaders and educators, to teachers, principals, and superintendents (Even, 1999).

Experienced science teachers often lack the knowledge of science education theories. A majority of subject matter courses in teacher education programs are viewed by teachers as having little bearing on day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball et al., 2008). Supplying a theoretical and practical foundation that seems compatible with their experience may provide an accessible way to make teachers' learning aware of teaching and learning procedures and thus lead to professional development (Parke & Coble, 1997). Moderators of professional development programs have to construct a relatively reliable and coherent model of the teachers' individual experiential worlds (Von Glasersfeld, 1989).

If the professional development program suggests a change of teachers' knowledge and beliefs about their practice it may be viewed as irrelevant by the teachers. The concept of change itself denotes a "disruption in the status quo" (Smith et al., 1993). Individuals possess a natural tendency to remain in a steady state, so any changes that disrupt this status quo are viewed with caution and are only accepted if the perceived outcomes add value to the individuals (Hanley, Maringe, & Ratcliffe, 2008). That way, rejection of acquisition of new knowledge or learning programs (Postholm, 2008b), that may appear when new knowledge does not correspond with the individual's existing construct (Von Glasersfeld, 1989), may be minimized.

In accordance with the situative perspective on teaching and learning, teacher learning can be enhanced by interactions that encourage them to articulate their views, challenge those of others, and come to better understandings as a community (Bransford, Brown, & Cocking, 1999). It has been suggested that effective professional development programs should focus on teacher learning communities which supply intellectual, social and material resources for teacher learning and innovations in practice (Little, 2002). Moreover, participating in a teacher learning community enables establishment and maintenance of communication norms and trust, as well as collaborative interactions that occur when groups of teachers work together to examine and improve their practice (Borko, 2004; Little, 2002). Additionally, it is suggested to engage the teachers' knowledge and experience in decision-making for new curriculum and instructional issues, as they reflect on the connections between theory and practice (Parke & Coble, 1997).

To design an effective professional development program, it is recommended that the designers take also into account both the teachers' PCK (Magnusson et al., 1999) and their teaching conceptions (Da-Silva et al., 2006; Henze et al., 2008; Henze & Verloop, 2009). The ability to design and implement various types of science teaching initiatives, in order to align them with different teachers' PCK and different students' cognitive abilities and learning styles, is an important component in professional development (Hofstein et al., 2003). That is, teacher learning is enhanced by interactions that encourage them to articulate their views, challenge those of others, and come to better understandings as a community of practice (Bransford et al., 1999). Moreover, engaging teachers in inquiries based on real classroom context can enhance their awareness of the need to learn (Eylon & Bagno, 2006).

Magnusson et al. (1999) argue that each PCK component of knowledge has a different influence on further development of that PCK due to differences in the amount of knowledge that each teacher holds in each component. In addition, there are different routes or multiple pathways for PCK development. Magnusson et al. (1999) recommend using the teachers' PCK to examine their pre-existing knowledge and beliefs, address the relationships between subject matter knowledge and PCK, situate the learning experiences in meaningful contexts, and use the PCK components in helping teachers develop their PCK.

Although previous studies have examined teachers' PCK in the course of professional development programs (Bybee, Short, Landes, & Powel, 2003; Cohen & Yarden, 2009; de Jong & Van Der Valk, 2007; Friedrichsen et al., 2009; Loughran et al., 2008; Schneider & Plasman, 2011; Van Dijk & Kattmann, 2007; Van Driel & Beijaard, 2003; Van Driel, Beijaard, & Verloop, 2001), little attention has been paid to the influence of different conceptions about teaching and learning held by experienced teachers on their PCK expansion in the course of a long-term professional development program aimed at designing new teaching and learning materials.

2. Research goals and questions

The main goal of the study is to examine in-service high-school biology teachers' professional knowledge, in the context of a long term professional development program. The study addressed both the explicit knowledge and the implicit knowledge of the participating teachers.

Initially, I characterized biology teachers' professional knowledge using a representation that I developed during the course of this study. This representation was also used to characterize PCK components that emerged during the analysis, the expansion of two main PCK components: teaching strategies and meaningful learning, and their retention following the termination of the program. At the subsequent part of the research, I focused on the tacit dimensions of biology teachers' professional knowledge as well as on the tacit dimensions of professional knowledge of teachers from other scientific disciplines (physics, chemistry, and mathematics). I used the Repertory Grid Technique (RGT) which was especially designed to elicit personal tacit knowledge. I characterized the elements that were elicited in the course of tacit knowledge elicitation using the RGT, and performed a cluster analysis in order to expose the tacit dimensions of the teachers' professional knowledge.

The following research questions addressed the exploration of biology teachers' professional knowledge using explicit data:

1. How the professional knowledge of in-service biology teachers who participated in the "Designing New Teaching and Learning Materials in Biology" workshop can be represented?
2. What is the alignment between the PCK components that emerged in the course of this research and the representations of PCK that are suggested in the current literature?
3. What are the most frequent PCK components and their possible expansion while designing and implementing new teaching and learning materials in biology?
4. Was the PCK expansion retained following termination of the program?

The following research questions addressed the exploration of biology teachers' professional knowledge using tacit implicit data:

5. What is the biology teachers' professional knowledge repertoire?
6. What are the relationships between biology teachers' professional knowledge and their CK?

The following research question addressed the exploration of various science and mathematics teachers' professional knowledge using the tacit implicit data:

7. Does the relationship between professional knowledge and CK differ between various science and mathematics teachers that participated in the Rothschild-Weizmann program?

3. Research context

The context of this study is a unique professional development program for outstanding high-school science teachers, entitled "The Rothschild-Weizmann Program for Excellence in Science Education", given at the Weizmann Institute. The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science or mathematics and science education theories. Supplying a theoretical and practical foundation that seems compatible with teachers' experiences may provide an accessible way to make teachers' learning aware of teaching and learning procedures (Von Glasersfeld, 1989), and thus may lead to professional development (Parke & Coble, 1997). That way teachers may construct a relatively reliable and coherent model of their individual experiential worlds (Von Glasersfeld, 1989).

The "Rothschild-Weizmann" program is divided into two paths, A and B. Path A, which served as the main context for exploring implicit teachers' knowledge, is especially designed for outstanding Israeli high-school science (physics, chemistry, biology) and mathematics teachers who hold a Bachelor of Science (BSc) degree and study towards a Master of Science (MSc) degree in science education without thesis in the course of the program. The program's curriculum runs for eight hours twice a week for four to five semesters (the program was shortened from five to four semesters after the first class had finished its studies). Each semester, the teachers participate in different courses in science or mathematics according to their professional discipline and in science or mathematics education courses (Table 1).

Five science education courses (two academic points each) are offered to the students from all disciplines. The courses focus on introduction to science education, on cognition learning and instruction, on quantitative research methods, on the integration of learning technologies and on philosophy and history of science. These courses also provide the teachers with the opportunity to meet other disciplines teachers' needs, requirements and objectives. In addition, each group of teachers study between 9-12 disciplinary courses aimed at enriching the teachers' content knowledge. The courses, which include contemporary topics in science or mathematics, are taught by leading scientists in science or mathematics from the Weizmann Institute of Science. In addition, the participating teachers study between 2-5 courses in science education which were aimed at enriching the teachers' knowledge in science education in their related discipline. Most of these courses are taught by leading science education researchers from the Weizmann institute. The aim of these courses is to enrich teachers' professional knowledge in their discipline (Table 1). One of the Path A biology teachers courses is a workshop entitled "Designing New Teaching and Learning Materials in Biology", or in its short name:"Initiatives Design" workshop. The Path A biology teachers participate in the workshop during three semesters. This workshop is aimed at bridging the gap between theory of science education and practice.

Path B is designed for outstanding Israeli high-school science teachers who already hold a masters degree (MSc) or a PhD. The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science or mathematics according to their professional discipline and in science or mathematics education theories. The program's curriculum runs for 8 hours once a week for four semesters. The Path B biology teachers' program, which served as a context for exploring explicit biology teachers' knowledge, studied four contemporary biology courses together with the Path A teachers as follows: laboratory activities for microbiology teaching, experiencing contemporary research in the life sciences, stem cells biology and selected topics in ecology (see Appendix 1). In addition, the Path B biology teachers participated in three joint science education courses: Introduction to science education, cognition learning and instruction, and selected topics in teaching and learning biology. In addition they participated in one long term, four semesters workshop, entitled: "Designing New Teaching and Learning Materials in Biology" (see Appendix 1).

The "Designing New Teaching and Learning Materials" workshop served as the main context of exploring the explicit biology teachers' proffesional knowledge. It was based on eliciting teachers' previous experiences and knowledge with the aim of advancing their deep understanding of their practice (following Schneider & Plasman, 2011), as well as enriching their subject matter content knowledge. This approach is based on Park and Oliver (2008a) who reported that one of the salient effects on the development of in-service science teachers' PCK is making them more reflective and analytical about their own practices. During this workshop the teachers first elicited their professional knowledge through reflections on their practice and then examined their knowledge and beliefs through the design, implementation and assessment of new teaching and learning materials suggested by the teachers themselves. The ability to design and implement new teaching and learning materials that are aligned with the different teachers' PCK is seen as an important component of teachers' professional development (Hofstein et al., 2003), especially since the level of a teacher's PCK has recently been shown to be highly connected with the degree to which his or her instruction is reform-oriented (Park, Jang, Chen, & Jung, 2011). Thus, teachers' learning can be further enhanced by interactions that encourage them to articulate their views, challenge those of others, and come to a better understanding as a community (Bransford et al., 1999).

Table 1: The learning program of the science teachers of Path A who participated in this study

Courses type / Discipline	Total number of academic points for the entire program	Number of academic points in each of the disciplinary courses	Number of academic points in science education courses
Biology	46	28	18
Chemistry	44	26	18
Physics	44	26	18
Mathematics	44	26	18

The path B biology teachers' "Designing New Teaching and Learning Materials in Biology" workshop was divided to four stages according to the themes that were taught in the workshop as follows. A detailed outline of the workshop appears in Table 2.

Stage 1: Eliciting prior knowledge. In this stage the teachers described in various ways their teaching experiences, teaching needs and teaching goals. In addition, the teachers expressed their expectations from the program and general ideas about designing new teaching and learning materials in biology (Aug-Nov 2008).

Stage 2: Planning the new teaching and learning materials. In this stage the teachers designed the general idea of their new teaching and learning materials, the materials' goals and wrote the preliminary part of the materials and one assessment method of this preliminary part. In addition, they presented the materials' ideas to the group members, to researchers of science education and to the chief supervisor of biology education in Israel. At the end of this stage the teachers experienced teaching of the preliminary part of their teaching and learning materials in their classes (Dec 2008-Feb 2009).

Stage 3: Assessing the design of the new teaching and learning materials. In this stage the teachers learned different subjects in science education relating directly to their design of new teaching and learning materials in biology. The teachers reflected on their and on their colleagues' experience of teaching and assessing the preliminary part, in light of the various lectures, and presented their conclusions (Mar-Jul 2009).

Stage 4: *Writing and distributing* the designed new teaching and learning materials in biology to other teachers and researchers. Lessons about writing a teacher's guide, presentations of the designed new teaching and learning materials in biology, possible rejections to implement the newly designed materials in biology in other classes, variability of teaching and learning styles (Oct 2009-May 2010).

Table 2: Outline of Path B "Designing New Teaching and Learning Materials" workshop that ran for two academic years

Details of the "Initiatives Design" workshop			
Meeting no.	**Stage number**	**Stage focus**	**Special activity**
1-3	1	Eliciting prior knowledge	What is your teaching dream?
4			What is your idea about a teaching initiative?
5			What are your expectations from this program?
6			What defines initiatives in high-school?
7-10	2	Planning the new teaching and learning materials	Design your initiative's idea
11			Prepare your initiative's idea presentation
12			Presentation of the initiative's idea to other teachers and researchers
13			Presentation of the initiative's idea to the chief inspector of biology education
14			Presentation of the initiative's idea to different science teachers and science education researchers
15			What did you learn from the presentations?
End of semester			Assignment: Teach your initiative in Class and assess it
1	3	Assessing the design of the new teaching and learning materials	What did you learn from teaching the activity?
2			What does science education know about APL?
3-4			Evaluation of teaching programs
5			Reflect on your assessment
6			Rewrite your initiative's goals
7			Assess your students' arguments
8			What does science education suggest to do with argumentation?
9			Design a poster that reflects your initiative and the initial's part assessment
10			An alternative way of teaching APL
11-13			Design a poster that reflects your initiative and the assessment of the initial's part
14			Reflection on the first year initiatives' program
End of First year			Written assignment about the initiatives' design implementation and assessment
1	4	Writing and distributing the "Designing New Teaching and Learning Materials in Biology"	Meeting expectations: writing and distributing the whole initiative – time table plan
2	4		What does science education tell us about written teachers' guides?
3-4	4		Writing the whole initiative's activities
5-7	4		Presentation of the new initiative to the workshop members
8	4		Define your initiative's model
9	4		Refining the initiative
10	4		Planning of the presentation of the initiatives to the chief inspector of biology education
11	4		Presentation of the initiatives to the chief inspector of biology education
12	4		Professional development programs: how does it help teachers
13	4		Why your initiative will not "work" in my class? Teachers reflect on each other's initiative
14	4		Reshaping the initiatives in light of the teachers' reflections
15	4		What is the DNA of your initiative?
End of semester			Assignment: write your full initiative's plan
1	4	Writing and distributing the "Designing New Teaching and Learning Materials in Biology"	What is the biology teachers' role and does the initiative meets it?
2	4		Different professional development models
3	4		What does science education tell us about professional development programs
4-5	4		Design your distribution
6-7	4		Presentation of the distribution plan to the initiatives' group members
8-9	4		Presentation of initiatives to biology teachers and science education researches
10	4		Reflection on the presentations
11-12	4		Presentation of the initiatives to biology teachers and science education researches
13	4		What did the distribution contribute to you personally and professionally?
14	4		Reflection: evolution from a teacher to the initiatives' designers and back to class
		End of program	

4. Methodology

4.1. Research Population

The population of this study consisted of a total of 50 teachers who participated in the "Rothschild-Weizmann" program described above. Four out of these teachers participated in exploring explicit professional knowledge and all of the 50 teachers participated in exploring implicit professional knowledge as follows:

4.1.1 The population that served for exploring teachers' explicit knowledge

The population that served for exploring teachers' explicit knowledge included four experienced in-service high-school biology teachers that were selected to participate in this study. Twenty seven teachers applied to join the Path B program during the academic years 2008-2010. Five in-service experienced high-school biology teachers who hold an MSc in biology were selected. The selection was based on the teachers' academic achievements, their excellence in the teaching realm and their motivation to develop initiatives that can be implemented into the educational system. One of the five teachers missed numerous lessons in the first year and chose not to participate in the second year. Thus, I chose to focus on four teachers who fully participated in the professional development program during the entire two years. These four teachers fully participated in the "Designing New Teaching and Learning Materials in Biology" workshop which served as the main context for exploring teachers' explicit knowledge (see Research context section and Table 2). These four teachers had between 6-17 years of teaching experience at the beginning of the program. Two of them taught in national high-schools and two of them taught in religion oriented high-schools (Teachers B1, B2, B3 and B4, Table 3).

4.1.2 The population that served for exploring teachers' implicit knowledge

The population that served for exploring teachers' implicit knowledge included fifty experienced in-service high-school science and mathematics teachers. This population included biology teachers from Path A and Path B (n=20), chemistry teachers from Path A (n=8), physics teachers from Path A (n=9) and mathematic teachers from Path A (n=13). All the teachers participated in the "Rothschild-Weizmann Program for Excellence in Science Education" (see Research context section and Table 1). The science and mathematics teachers were selected on the basis of high academic achievements, their motivation for professional development and their will to broaden their knowledge in science or mathematics and in science education, thus having the potential to become teacher leaders.

At the beginning of the program, the Path A teachers held a BSc degree in science or mathematics or science education and had between 3-28 years of teaching experience. The Path B biology teachers held an MSc degree in biology. The teachers taught in a variety of high-schools: national high-school, religion oriented high-school, boarding high-school, Arab high-school and Bedouin high-school. The number of years of teaching experience and the type of school at which the teachers taught during the period of this research are summarized in Table 3.

The first group of biology teachers from Path A studied over five semesters during the years 2008-2011 towards an MSc in science education degree without thesis (teachers A1-A4, n=4). The second group of biology teachers from Path A studied the same courses over four semesters during the years 2010-2012 (teachers A5-A16, n=12). All Path A biology teachers participated in a shorter version of the "Designing New Teaching and Learning Materials in Biology" workshop which consisted of the three first stages of the workshop (Table 2) and lasted over the three last semesters of their studies. During the design workshop, the biology teachers from both paths were encouraged to use the new knowledge acquired during the courses given in the program in the design of their new teaching and learning materials. The teachers implemented the new materials they had designed in their classes, giving them the opportunity to assess the feasibility of the new materials in their everyday practice. The products of this longitudinal workshop were the biology teachers' final projects of their studies.

The Path B group of biology teachers (teachers B1-B4, n=4) consisted of in-service biology teachers. These teachers also served as the population of exploring explicit professional knowledge as described above. The Path A group of chemistry teachers (Teachers C1-C8), consisted of in-service high-school chemistry teachers. They studied courses in chemistry and in science education (Table 1) and had one long term course which was aimed at bridging the gap between contemporary topics in chemistry and the teaching practice. The Path A group of physics teachers (Teachers P1-P9) consisted of nine in-service physics teachers. They learned courses in physics and in science education (Table 1) and had one long term course which was aimed at learning issues referring to teaching physics in high-school. The Path A group of mathematics teachers (teachers M1-M13) consisted of thirteen in-service mathematics teachers. They studied courses in mathematics and in science education (Table 1) and had one course that was aimed at bridging the gap between studies that explore the teaching of geometry and the teaching practice. Another course was aimed at bridging the gap between studies that explore the teaching of algebra and their teaching practice.

Table 3: The professional experience and types of schools of the science teachers who participated in this study teach

Teacher's no. (symbol)	Path of professional development (PD) program	Discipline	Years of high-school teaching experience at the beginning of the PD program	Type of school
1 (A1)	A	Biology	11	National high-school
2 (A2)	A	Biology	14	National high-school
3 (A3)	A	Biology	7	Religion-oriented high-school
4 (A4)	A	Biology	9	Religion-oriented high-school
5 (B1)	B	Biology	17	National high-school
6 (B2)	B	Biology	17	Religion-oriented high-school
7 (B3)	B	Biology	12	Religion-oriented high-school
8 (B4)	B	Biology	6	National high-school
9 (A5)	A	Biology	22	National high-school
10 (A6)	A	Biology	8	Religion-oriented high-school
11 (A7)	A	Biology	18	Religion-oriented high-school
12 (A8)	A	Biology	4	Bedouin high-school
13 (A9)	A	Biology	22	National high-school
14 (A10)	A	Biology	13	Boarding high-school
15 (A11)	A	Biology	5	Religion-oriented high-school
16 (A12)	A	Biology	17	National high-school
17 (A13)	A	Biology	17	National high-school
18 (A14)	A	Biology	4	National high-school
19 (A15)	A	Biology	5	National high-school
20 (A16)	A	Biology	22	National high-school
21 (C1)	A	Chemistry	5	National high-school
22 (C2)	A	Chemistry	19	National high-school
23 (C3)	A	Chemistry	19	Arab high-school
24 (C4)	A	Chemistry	3	Arab high-school
25 (C5)	A	Chemistry	16	National high-school
26 (C6)	A	Chemistry	7	Arab high-school
27 (C7)	A	Chemistry	15	Arab high-school
28 (C8)	A	Chemistry	4	National high-school
29 (P1)	A	Physics	22	National high-school
30 (P2)	A	Physics	5	National high-school
31 (P3)	A	Physics	27	Arab high-school
32 (P4)	A	Physics	14	National high-school
33 (P5)	A	Physics	5	National high-school
34 (P6)	A	Physics	20	National high-school
35 (P7)	A	Physics	21	Religion-oriented high-school
36 (P8)	A	Physics	3	Religion-oriented high-school
37 (P9)	A	Physics	15	National high-school
38 (M1)	A	Mathematics	5	National high-school
39 (M2)	A	Mathematics	28	National high-school
40 (M3)	A	Mathematics	9	National high-school
41 (M4)	A	Mathematics	6	Arab religion-oriented high-school
42 (M5)	A	Mathematics	15	National high-school
43 (M6)	A	Mathematics	15	National high-school
44 (M7)	A	Mathematics	17	Arab high-school
45 (M8)	A	Mathematics	5	National high-school
46 (M9)	A	Mathematics	18	National high-school
47 (M10)	A	Mathematics	17	Religion-oriented high-school
48 (M11)	A	Mathematics	6	Religion-oriented high-school
49 (M12)	A	Mathematics	18	National high-school
50 (M13)	A	Mathematics	8	Religion-oriented high-school

4.2. Data Sources

4.2.1 Data sources for exploring explicit professional knowledge

The data sources of this part of the study were collected as follows: (i) All group discussions were recorded using a digital tape recorder; (ii) All the lessons that included discussions about the new teaching and learning materials design, implementation and distribution were fully transcribed (a total of 21 lessons, about 2 hours each); (iii) Relevant parts of the teachers' e-mails and assignments were collected (a total of 64 e-mails and 28 assignments); (iv) Interviews with the teachers were transcribed. The interviews took place at three time points during the program: at the end of the first year of the program, at the end of the program, and a year following the termination of the program (a total of 9 interviews); (v) All the teachers' presentations of their new materials design to the other teachers, academic staff and policy makers were recorded, videotaped and transcribed.

4.2.2 Data sources for exploring implicit professional knowledge

The data sources of this part of the study were collected as follows: (i) All Repertory Grid's elements and constructs were collected; (ii) All Repertory Grids' rating tables (for example see Table 4) were collected and the data were uploaded to the REPGRID, version 5 software (http://gigi.cpsc.ucalgary.ca:2000/); (iii) Interviews with five biology teachers and four mathematics teachers were recorded and transcribed; (iv) Interviews with the head of the mathematics group in the science teaching department and with two mathematics education researchers were recorded and summerized; (v) A focus group disscusion of six mathematics education researchers and two biology education researchers (including me) was recorded. The focus group discussion was carefully examined to and the researchers' assumptions were summarized.

4.3. Data analysis

Since the uniqueness and complexity of teaching knowledge must be understood in context (Stake, 1995), I used the ‘grounded theory’ methodology which states that human behavior cannot be understood without reference to the meanings and purposes attached by human players to their activities (Lincoln & Guba, 1994). The grounded theory focuses on the attempt to derive the representativeness of concepts, not persons, as viewed by the participants in a study. This process involves multiple stages of data collection and the refinement of interrelationship of components and of information. The constant comparison of data with emerging components and the theoretical sampling of different groups are aimed at maximizing the similarities and differences of the information (Corbin & Strauss, 1990). In this thesis, I used the mixed-methods approach, which involves gathering both numerical information and text information so that the final database represents both quantitative and qualitative information in which the results from one method help inform those of the other (Creswell, 2003). Accordingly, data were analyzed qualitatively following Shkedi (2003) and then a quantitative dimension to the qualitative approach was added following Chi (1997) and Kelly (1955), within the context of the professional development program.

4.3.1 Qualitative Data Analysis

The qualitative data analysis was carried out following Shkedi (2003). In addition, two methods of qualitative data analysis with quantitative dimensions were used: (i) In order to explore teachers' explicit professional knowledge I added the verbal analysis which is a qualitative method with quantitative dimensions following Chi (1997); (ii) In order to explore teachers' implicit professional knowledge I used The Repertory Grid Technique (RGT) following Kelly (1955), which is a qualitative method with quantitative dimensions that was specially designed for probing implicit tacit knowledge.

Initially, a qualitative data analysis following Shkedi (2003) was performed on Path B biology teachers' data in order to explore teachers' explicit professional knowledge and whether the developed professional knowledge was retained following termination of the program. Thus, we attempted to assess whether meaningful professional knowledge expansion had occurred.

Data were divided into different episodes, which were classified according to the themes discussed. One episode consisted of a section in which a single teacher was talking or writing about one theme. If the same teacher spoke several times sequentially about the same theme, even though others interrupted, it was still considered one episode. For example, the next episode began when the subject of the discourse changed. The episode describes Teacher B2's belief about means for meaningful learning:

Teacher B2: "Through the stories they will remember biology."

Workshop moderator: "Do you mean that it elevates their motivation for learning?"

Teacher B2: "I see that they remember emotional experiences. It is only when they go through an emotional experience that they remember."

Teacher B1: "Do you have some spare time?"

Teacher B2: "Although it seems like I am wasting time, I think that if the story causes an association in the students' minds they will remember it."

The next episode, which comes right after the previous episode, describes Teacher B4's belief about the syllabus. It begins with the sentence:

Teacher B4: "By the way, did you see how long and difficult the syllabus is?"...

The qualitative analysis of the episodes was performed while allowing components of teachers' professional knowledge to emerge from the data. The transcripts were read several times and searched for recurrent components and ideas as recommended by Shkedi (2003).

The following five steps were then taken: (i) primary components were formed from the collected data; the data were segmented into episodes, and every episode was categorized according to its content (i.e., subject matter, Figure 2); (ii) more general domains were developed (i.e., Teaching domain, Learning domain, New materials design domain, Figure 2); (iii) all the episodes were mapped according to the chosen domains; (iv) episodes were reorganized according to the chosen domains; (v) assertions were then proposed about the teachers' professional knowledge components, and their possible relations with previously published PCK components have been examined. PCK components were distinguished in order to be further examined (marked in grey in Figure 2).

4.3.2 Verbal analysis

A possible expansion of the teachers' professional knowledge over the course of the program was subsequently examined using verbal analysis of the data following Chi (1997), which added quantitative dimension to the qualitative analysis. To reveal each teacher's main PCK components and the possible expansion of those PCK components along the four stages of the workshop, the number of episodes in each component was counted. The proportion of the number of episodes of each component, out of the total number of episodes of each teacher's professional knowledge domain, during each stage of the workshop was examined. It was assumed that the frequency of appearance of each component in the data would provide rich data and may reflect its concern or importance within the speaker's PCK. For example, a component which repeats more frequently was assumed to represent a more pronounced PCK component which may be of higher concern and may provide rich data about a specific teacher than other components.

4.3.3 The Repertory Grid Technique (RGT)

The RGT is designed to elicit and probe personal tacit knowledge. It is a phenomenological approach which sits more within the grounded theory and interpretive research rather than with positivist, hypothesis-proving, approaches. The focus is on understanding, before developing theories that can be subsequently proved (or disproved) (Edwards, McDonald, & Young, 2009). The technique appeals to the present person's tacit knowledge on a given topic and encourages him or her to confront his or her intuitions; to make the tacit explicit (Jankowicz, 2001). In order to clarify the RGT, I describe first the general principles of the technique and then the details of the method used in this study.

Kelly (1969) assumed that the meaning we attach to events or objects defines our subjective reality, and thereby the way we interact with our environment. Kelly's own characterization of his theory was to see it as an expression of "constructive alternativism": that is, there is never a single "correct" way of seeing things. Existence and our understanding of it is something we have to negotiate between ourselves, whether we call ourselves scientists or ordinary people, managers or otherwise, seeking to make sense of what is going on. There is no absolute right or wrong answers. It is best used when participants have practical experience with the studied domain because they must be able to identify representative elements and be able to compare them through a set of their own criteria (constructs).

Researchers choosing to use the RGT argue that this elicitation technique is free from external influences (Ben-Zvi Assaraf & Damri, 2009; Bezzi, 1999; Fransella, Bell, & Bannister, 2004; Henze, Van Driel, & Verloop, 2007; Jankowicz, 2004). The RGT overcomes the difficulties inherent in the collection of data with "traditional" instruments of investigation, in which interviewees are supposed to perceive and interpret the researcher's questions with the same meaning as given by the researcher. Problems of interpretation also exist in the clarification of observations or questionnaires, because these may force responders into predetermined channels dependent upon cultural assumptions and purposes designed by researchers (Bezzi, 1999). The RGT allows expression of the interviewees' views by means of their own constructs. It allows the investigator to identify what the other person means when she or he uses the terms suggested as an element or a construct. Each element is rated on each construct, to provide a picture of his personal mental model: a statement of the way in which the individual thinks of, give meaning to, *constructs* the topic in question (Jankowicz, 2004).

Tacit dimensions of PCK were analyzed according to the RGT based on George Kelly's Personal Construct Psychology theory (Kelly, 1955). Every grid consists of four components: topic, elements, constructs and ratings. These components are usually elicited in a four steps procedure between an interviewer and an interviewee. Eliciting of elements (alternative events, states, or entities) and constructs (dimensions of similarity and difference between elements) are central to knowledge representation in repertory grids (Bradshaw et al., 1993).

In recent years some researchers using repertory grids have deviated from Kelly's underpinning assumption that each individual personally constructs his world model. This has led to the emergence of three types of grids: (i) *Full repertory grid*: where the individual identifies both the elements and the constructs; (ii) *Partial repertory grid*: where the individual is supplied with the elements and then identifies his personal constructs; (iii)

Fixed grid: where the individual is supplied with both the elements and the constructs (Edwards et al., 2009).

I followed the four steps of the full RGT, with each group of teachers (the biology, chemistry, physics and mathematics teachers) separately, during the second semester of the first or second year of the Rothschild-Weizmann program. The four steps that were taken are:

Step 1- Introducing the topic

The topic of this research is teachers' knowledge. As such, my interest in teachers' knowledge was first declared to each group of teachers. I then briefly introduced the main rationale of the Personal Construct Theory (Kelly, 1955, 1969) and the idea that experts hold tacit knowledge (Polanyi, 1966) using a PowerPoint presentation that was especially designed for this introduction. The presentation included slides that presented the term PCK and the idea of 'teachers' professional knowledge' that combines knowledge and beliefs about teaching and learning following Shulman (1986) theory and some examples of teachers' professional knowledge. Then the notion of experts' tacit knowledge (Polanyi, 1966) was explained as well as Kelly's Personal Construct Psychology theory (1955). At the end of the presentation, I emphasized that there is no 'right' or 'wrong' answers and that we are interested in each teacher's unique professional knowledge. After the termination of the presentation, which lasted approximately half an hour, I asked each group of teachers the same question according to each group's discipline: What does a biology/chemistry/physics/mathematics teacher need to know in order to be a good biology/chemistry/physics/mathematics teacher?

Step 2 – Choosing the elements

From this step on each teacher performed the RGT individually but in each group of teachers stayed in the same classroom. Each teacher was asked to write down on 12 separate cards elements that represent biology/chemistry/physics/mathematics teachers' knowledge (according to their discipline) and that a teacher should hold in order to be a good teacher. I was present in the class and answered questions about the method if some teachers needed help (for an example of elements that were elicited by one of the teachers see Table 4).

Step 3 – Elicitation of personal constructs

The constructs in this research were elicited following Kelly's method of triads (Kelly, 1955). Each teacher was asked to fold each element card so that he or she could not see what was written on it, place all 12 cards on the table and randomly pick three cards. Then, each teacher was asked to write down the contained elements in a four-column table, each element in a separate column, and to choose the exceptional element of the three, circle it, and write down in the fourth column the reason that two of the elements were similar and the third is exceptional. The teachers were then asked to refold the cards, return them to the table, mix them and then again randomly choose three cards. This action was repeated 10 times with each interviewee.

Step 4 – rating

At this stage each teacher was briefly interviewed individually in order to define his or her constructs. Repeated explanations for choosing the exceptional elements were defined as constructs, which is why there are only a few constructs (usually between 4 and 6) in each cluster. Each teacher was then asked to write down the opposite of a given construct, meaning that he or she had to define the construct poles (for an example of construct definitions and their opposites see the right and left columns in Table 4). Then the teacher was handed an empty table (similar to the one presented in Table 4) and asked to write the poles of each construct at opposite ends of each row. On the right-hand side, the teacher was asked to write the definition of each construct and on the left-hand side, the opposite of the construct's definition. Each teacher was also asked to write his or her 12 elements, each as a header of a separate column. Then each teacher was asked to rate the correlation between each element and each construct on a five-point scale in which '1' means 'totally agree with the left pole of the construct' and '5' means 'totally agree with the right pole of the construct' (for an example of a full table see Table 4). The full tables constructed by each teacher were handed to the researcher for computed data analysis. The analysis is described in detail in the cluster analysis section below.

4.3.4 Content analysis

For content analysis of the repertory grid data, all of the interviewees' elements were pooled and categorized according to the meanings they expressed. The categories were derived bottom-up from the elements themselves, by identifying the various themes they expressed (Jankowicz, 2004). The content analysis enabled characterization of the teachers' repertoire of knowledge elements as a community of high-school biology teaching experts.

4.3.5 Cluster analysis

Once the constructs were elicited and rated, the cluster analysis calculations were performed with REPGRID version 5 software (http://gigi.cpsc.ucalgary.ca:2000/). This program provides a two-way cluster analysis that reorders the teacher's original table (Table 4, for example). The rows of constructs and the columns of elements are rearranged to produce a grid in which there is the least variation between adjacent constructs and elements. The relationships between elements and constructs are visualized as tree diagrams arranging, in close proximity, the most similar rows and the most similar columns in the cluster. The tree diagram presents the elements at the bottom of the diagram (1, in Figure 4, page 64) and the coherence rate between the elements (the percentage of similarity between columns) at the top of the diagram using the coherence scale between elements which appears on the upper right side of the diagram (2, in Figure 4). The constructs are presented on the right and left (4, in Figure 4 opposite to each other), and their coherence rate (the percentage of similarity between lines) is presented on a scale on the right side of the diagram (5, in Figures 4).

Over 80% similarity is considered high coherence between the repertory grid's elements or constructs (Kelly, 1969). The distance between elements or between constructs is considered a 'safe' measure for examining the association among elements or constructs (Fransella et al., 2004). The meaning of the high coherence between elements or constructs allowed us to identify cognitive links between elements and between constructs, thus presenting an image of each teacher's personal mental model—a precise statement of the way in which the teacher thinks of or gives meaning to the topic in question (Jankowicz, 2004). Subsequently, we searched for more than 80% coherence between CK elements and other elements, and more than 80% coherence between the CK constructs and other constructs, thus allowing us to identify the teachers' tacit knowledge about the relationships between CK and teaching knowledge. Each teacher's data were analyzed individually and a repertory grid tree diagram (similarly to those presented in Figs. 4 and 6) was drawn. Each repertory grid tree diagram that was formed for each teacher was called a cluster, and it was formed using the cluster analysis between elements and constructs.

In order to better understand the RGT results I interviewed (via telephone conversation) five biology teachers and four mathematics teachers. I asked them if the advanced biology or mathematics courses that they learned in the "Rothschild-Weizmann program" contributed to their practice, and if so, how did it contributed? During the interview I wrote their answers and later I tried to find similar answers that clarified the question in subject. In addition I performed a focus group of six mathematics science education researchers and two biology education researchers, including me. In the focus group meeting I explained the principles of the RGT and presented the RGT results of the mathematics teachers. I asked the focus group to discuss the results of the mathematics teachers' clusters. In addition I interviewed separately the head of the mathematics group of the science education department. The researchers' assumptions were analyzed and summarized.

Table 4: Teacher A3's table of elements and constructs assembled at the end of the RGT

Element [a] / Construct [b]	Cell	Inquiry	Computer	Modeling	The human body	Volume	Transfer skills	Critical thinking	A controlled experiment	Experiment	Laboratory	Ecology	Element [a] / Construct [b]
Not a content knowledge	5	3	3	4	5	5	4	4	5	4	4	5	Content knowledge
Not an inquiry, practical for teaching	4	5	4	3	2	2	4	3	5	5	5	4	Inquiry, practical for teaching
Not a skill	1	5	3	5	2	1	5	5	5	5	5	1	A skill
Not a teaching tool	1	4	5	5	2	1	3	4	4	4	5	1	A teaching tool

The numbers represent the rate of correlation between elements and related construct '1' means 'totally agree with the left pole of the construct'; '5' means 'totally agree with the right pole of the construct' and the other numbers. A teacher can choose any number between 1-5 which expresses the rate of correlation between constructs and elements.

a. Element: component of teaching knowledge
b. Construct*:* dimension of similarity or difference between elements

I assumed that the above mixed-methods analysis could capture the teachers' professional knowledge, although the data were not based on observations of the teachers' practice. This assumption is based on Van Der Valk and Broekman (1999) who claimed that teachers produce "rich" information about their professional knowledge while reporting on their lesson design and teaching.

4.4. Validation

4.4.1 Validation of the qualitative data analysis

Part of the data of the biology teachers' conversations was presented to science education researchers for peer validation, twice in the course of the data analysis. The first peer validation was aimed at validating the emerging professional knowledge domains and their related components. The mean identity rate between five science education researchers and the emerged classification of the three main professional knowledge domains and their specific components (see Results pp 38-42) was 92.3%. The second peer validation was aimed at validating the analysis of the teachers' professional knowledge during the program. Twenty-five episodes were given to three science education researchers who were asked to classify each episode according to the suggested professional knowledge classification. The overall validation rate was 85.6%. In addition, interviews were used for interpretive validity with the participants. During an interview, the qualitative result of a teacher's conception about teaching and learning was presented to her and she was then asked to express her view of the accuracy of the presentation. The overall validation rate was 94%.

4.4.2 Validation of the Repertory Grid Technique

According to Kelly (1969), validity of the RGT is equated with usefulness. Thus many studies are performed using the Personal Construct Psychology theory and the RGT as a way of exploring whether or not the grids are of value for them. Fransella et al. (2004) presented a massive assortment of studies performed since 1977 which found the RGT useful in clinical settings, education, language acquisition, forensic work, market research, politics, and organization and business applications. Moreover, I performed interviews for interpretive validity with five biology teachers and four of the mathematics teachers. During the interviews, the grid map of the individual teacher and my interpretations of it were presented to each teacher, and he or she were asked to express their views on the accuracy of the results. The overall validation rate was 100%, meaning that each of the nine teachers agreed with the RGT results and the interpretations.

5. Summary of research goals, research questions and methods

The summary of the research's goals, questions that addressed those goals and the methods that were applied in this study are summarized in Table 5.

Table 5: the procedures and outcomes of this thesis aligned with the main goals

Main goal	Research question	Teachers' sample	Research methods	Publications
Exploring biology teachers' explicit professional knowledge	1. How the professional knowledge of in-service biology teachers who participated in the "Designing New Teaching and Learning Materials in Biology" workshop can be represented?	Path B biology teachers (n=4)	Qualitative categorization following Shkedi (2003); Verbal analysis following Chi (1997)	Rozenszajn, R., & Yarden, A. (2011). Conceptualization of in-service biology teachers' pedagogical content knowledge (PCK) during a long term professional development program. In A. Yarden & G. S. Carvalho (Eds.), Authenticity in biology education: Benefits and Challenges; A selection of papers presented at the 8th Conference of European Researchers in Didactics of Biology (ERIDOB); (pp. 79-90), Braga, Portugal. Rozenszajn, R., and Yarden, A., Expansion of biology teachers' pedagogical content knowledge (PCK) during a long-term professional development program (submitted).
	2. What is the alignment between the PCK components that emerged in the course of this research and the representations of PCK that are suggested in the current literature?		Literature review and comparison to the enlarged representation	Rozenszajn, R., and Yarden, A., Expansion of biology teachers' pedagogical content knowledge (PCK) during a long-term professional development program (submitted).
	3. What are the most frequent PCK components and their possible expansion while designing and implementing new teaching and learning materials in biology?	Class B1 teachers (n=4)	Qualitative categorization following Shkedi (2003); Verbal analysis following Chi (1997)	
	4. Was the PCK expansion retained following termination of the program?	Class B1 teachers (n=4)	Qualitative categorization following Shkedi (2003);	

Main objective	Research question	Teachers' sample	Research methods	Publications
exploring biology teachers' implicit professional knowledge	5. What is the biology teachers' professional knowledge repertoire?	Classes A1, A2 and B1 teachers (n=20)	Repertory grid technique (Kelly, 1969); analysis following Chi (1997)	Rozenszajn, R., and Yarden, A. (2013). Characterizing the tacit relationships between biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK) in D. Krüger & M. Ekborg (Eds). A selection of papers presented at the 8th Conference of European Researchers in Didactics of Biology (ERIDOB); Berlin, Germany (accepted for publication). Rozenszajn, R., and Yarden, A., Tacit relationships between biology teachers' content knowledge (CK) and their professional knowledge (submitted).
	6. What are the relationships between biology teachers' professional knowledge and their CK?	Classes A1, A2 and B1 teachers (n=20)	Repertory grid technique (Kelly, 1969); Qualitative analysis of teachers' interviews following Shkedi (2003)	
Exploring science and mathematics teachers' implicit professional knowledge	7. Does the relationship between professional knowledge and CK differ between various science and mathematics teachers that participated in the Rothschild-Weizmann program?	Biology, chemistry, physics and mathematics teachers that participate in R.W. program (n=50)	Repertory grid technique (Kelly, 1969); Qualitative analysis of teachers' and researchers' interviews and focus group discussion following Shkedi (2003)	Rozenszajn, R., and Yarden, A., Differences in the tacit relationships between professional knowledge and CK among biology and mathematics teachers (in preparation).

6. Results

6.1 Exploring biology teachers' explicit professional knowledge

6.1.1 Representation of the professional knowledge of in-service biology teachers

The first research question addressed the professional knowledge of four in-service biology teachers in the course of a professional development program aimed at designing new teaching and learning materials suggested by the teachers themselves. Seventeen professional knowledge components emerged bottom-up in the course of the data analysis. Those components were grouped into three main domains: teaching, learning and new teaching and learning materials design.

Each of the 17 components is described in details below and summarized in Figure 2.

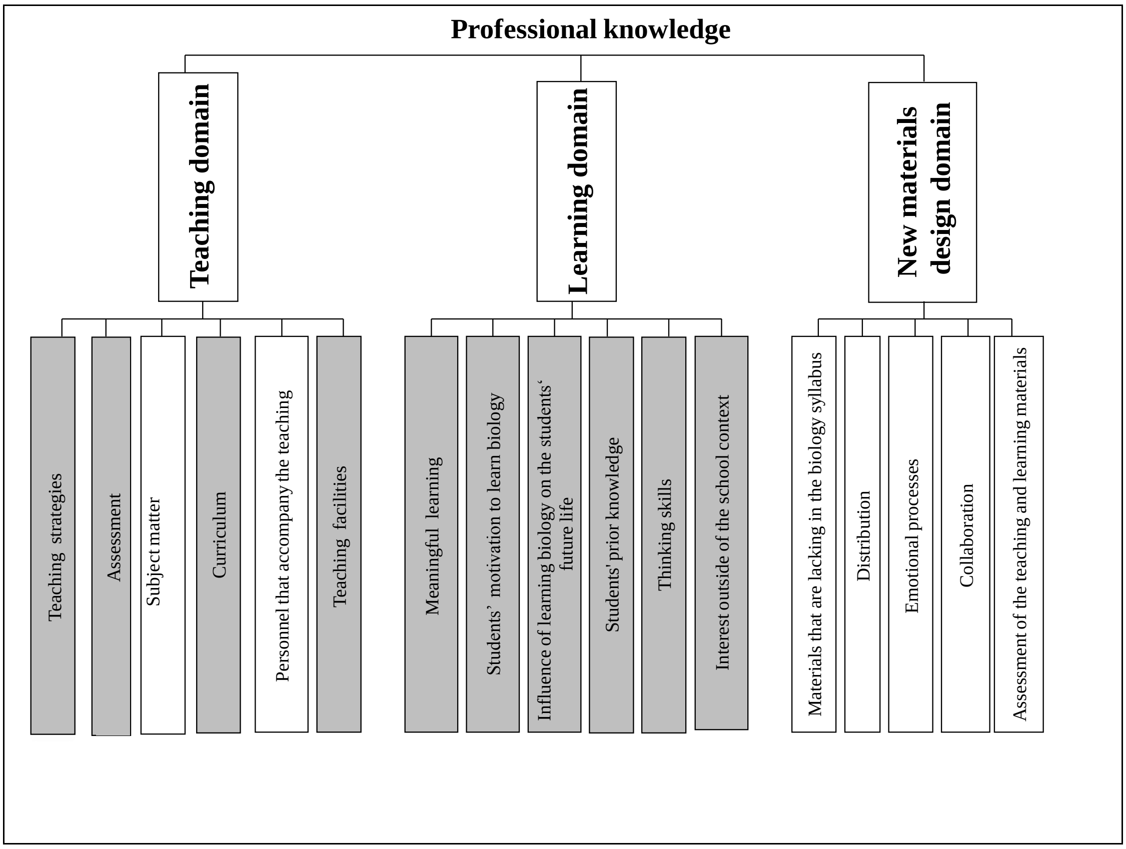

Figure 2: Professional knowledge domains and their related components. The grey rectangles mark the PCK components that are mentioned in the literature (i.e. Magnusson et al., 1999)

1. **The Teaching domain.** This domain includes six components of teachers' knowledge and beliefs as follows:

i) *Teaching strategies*: Knowledge and beliefs about the ways a teacher should teach. The best ways of representation of biological concepts and contents and the best ways of inducing meaningful learning, namely the teaching technique. For example, Teacher B2 said at the second stage of the workshop: "My strategy is to insert into my lesson stories that are not connected to the subject matter. That way my students think: 'Oh! This is not connected to learning, we better listen'".

ii) *Assessment:* Knowledge and beliefs about the dimensions of scientific literacy that are important to be assessed, knowledge of the methods by which that learning can be assessed and the knowledge of which contents may be assessed. For example, Teacher B3 said while to designing new teaching and learning materials in bioethics: "I don't know how we can assess students' argumentations". Although this sentence was said with regards to designing new teaching and learning materials, it represents the teacher's knowledge about the subjects that may be assessed in class.

iii) *Subject matter*: Knowledge and beliefs of science contents, central ideas and scientific concepts that should be taught in a certain grade level and context. For example, Teacher B3 said at the fourth stage of the workshop: "You need to know whether this is a recessive or dominant trait in order to express your position in this bioethical discussion".

iv) *Curriculum:* Knowledge and beliefs of the curriculum including knowledge of the general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals. This component includes also the goals for teaching science at a particular grade level due to specific curricular demands. For example, Teacher B2 said while designing new teaching and learning materials in bioethics: "It's a demand of the curriculum to teach bioethics, but teachers don't have materials and they don't know how to teach it". Here again, although it was said with regards to designing new teaching and learning materials, it represents the teacher's knowledge about the syllabus of the high-school biology program.

v) *Personnel that accompany the teaching:* Knowledge and beliefs about the various experts that accompany the teacher in his or her work, and that may influence the teacher's practice in class, such as: the school principal, supervisors or other biology teachers. For example, Teacher B4 said at the second stage: "I need to know the supervisor's attitude in order to know if I can teach the innovative program in my class".

vi) *Teaching facilities*: Knowledge and beliefs about the availability of appropriate resources for teaching. This component includes physical recourses like a projector, computers or teaching time, the resources that help to be up-dated with new biological knowledge and the over load of new teaching programs. For example, Teacher B1 said during the first stage: "We will never have enough time to teach all this innovations in science".

2. The Learning domain. This domain includes six components of knowledge and beliefs as follows:

vii) *Meaningful learning:* Knowledge and beliefs about the factors that promote meaningful learning in the students' mind namely, the ways that students may understand and remember biology like connecting new knowledge to prior knowledge. For example, Teacher B3 said in stage three: "The adapted article helped the students establish their prior knowledge. They learned in the genetics lessons about PCR, now when reading the article they understand what is the use and implications of PCR in the real world, that way they better understand what PCR is".

viii) *Students' motivation to learn biology*: Knowledge and beliefs about factors that influence students' motivation to learn specific themes or contents in science. For example, while designing new teaching and learning materials in bioethics Teacher B2 said: "I think that curiosity reinforces students' will to learn".

ix) *Influence of learning biology on the students' future life:* Knowledge and beliefs about the effect of the topics learned in class on the students' future life like their future preferences of academic studies or better understandings of medical situations. For example, Teacher B1 said in the fourth stage of the workshop: "I think that if we will elevate interest in biology the students will learn science in the university and may become researchers".

x) *Students' prior knowledge:* Knowledge and beliefs about the knowledge and conceptions that students bring with them to the lessons from their former studies. For example, Teacher B3 said in stage three of the workshop: "That's why we can teach bioethics only in high-school, after the students learned genetics".

xi) *Thinking skills*: Knowledge and beliefs about students' thinking skills that are important for learning and their possible ability to use high order thinking skills. For example, in stage four of the workshop, Teacher B1 said: "In laboratory lessons students often don't understand why they have to set the control component. We have to teach them high order thinking skills".

xii) *Interest outside of the school context*: Knowledge and beliefs about students' concerns, hobbies or activities during their after school hours that may affect learning. For example, Teacher B4 said during the first stage of the workshop: "We forget that this is a new generation. They are very individualists. Each one is staying at home with his computer or mp3. They barley meet after school. Collaborative learning will be difficult".

3. The "New materials design" domain. This domain includes five components of knowledge and beliefs as follows:

xiii) *Materials that are lacking in the biology syllabus*: Knowledge and beliefs about content knowledge in biology as well as about learning skills that are missing in the present syllabus, and are the rationale behind choosing them for the new teaching and learning materials. This component integrates the teachers' knowledge, beliefs and experience in biology teaching and formulates knowledge about the important missing parts in the biology teaching program. For example, Teacher B3 tried to convince the other biology teachers that it will be easy to insert bioethical contents, which are missing in the current program, following their new teaching and learning materials model: "Teachers may easily agree to insert a variety of innovative bioethical contents and teach biology and bioethical dilemmas according to our model".

xiv) *Distribution*: Knowledge and beliefs about distributing new teaching and learning materials. The teachers that designed novel teaching and learning materials were asked to distribute their materials to other teachers. Teachers are usually not required to distribute their ideas in a way that will suit a diverse population of teachers. This kind of knowledge acquisition required "breaking the barriers" of their personal professional knowledge. Thus, the teachers needed to develop various ways of distribution, like writing a teachers' guide and designing professional development programs. The distribution means had to suit a variety of teachers that hold a variety of PCK. For example, while introducing her new teaching and learning materials to other teachers Teacher B2 said: "The teacher doesn't have to use all the materials of our teaching guide. We insert a lot of teaching materials and each teacher may choose his preferences. We think it can enhance the teachers' confidence in teaching a new theme such as bioethics".

xv) *Emotional processes:* Knowledge and beliefs about emotional feelings that are involved in becoming a program designer, like the expectations, disappointment or satisfaction that are related to the design of new teaching and learning materials. The teachers that participated in this study went through a structured process of designing new teaching and learning materials for the first time in their career. The process of becoming a designer of new teaching and learning materials required from the teachers new skills and knowledge acquisition to suit the demands of the Israeli educational system alongside advancing their academic knowledge. The teachers described various "emotional processes" that they experienced during the new teaching and learning materials design to other teachers that were in the beginning of the same process. For example, Teacher B1 said to other teachers in the fourth stage of the workshop: "You will experience a lot of frustrations and difficulties during this year but you should remember that you will grow out of these difficulties".

xvi) *Collaboration*: Knowledge and beliefs about possible collaboration between the participating teachers during the new teaching and learning materials design workshop as a means to create a valuable innovative teaching program. The teachers and the instructors of the workshop served as a community of practice that enabled the teachers to share ideas, critically evaluate them, openly discuss their suggestions, difficulties and successes, and reach conclusions that eventually led to complete the design of their new teaching and learning materials. For example, at the end of the program Teacher B2 said: "I came to this program as an individual and leave it as a 'team'".

xvii) *Assessment of the teaching and learning materials*: Knowledge and beliefs about the methods of assessing educational activities. Teachers are well familiar with assessing students' knowledge, but assessing new teaching and learning materials is not familiar to them and requires new knowledge and skills. During the "Designing New Teaching and Learning Materials in Biology" workshop the teachers learned about various modes that suit the assessment of their materials. Each teacher implemented at least one mode of assessment in order to reveal the efficiency of their new teaching and learning materials. For example, Teacher B4 wrote in an e-mail in stage two of the workshop:" I need some help with the evaluation of my materials. I can do pre-test and post-test that will assess the students' knowledge acquisition. You proposed to record the lesson but they will do an individual work with the article. So, what should I record? Should I record our conversations when I answer their questions about unclear points of the article? I feel a little "stuck" with the new materials' evaluation".

All the five components of the 'New materials design' domain were part of the professional development program that served as the context of this research. Designing new materials is not part of the everyday biology teachers' practice. Therefore, from this point on I focused on the analysis of the professional knowledge components related to the teaching and learning domains.

6.1.2. The alignment between teachers' professional knowledge and PCK

A close examination of the correlation between the professional knowledge components suggested herein (see 6.1.1 above) and various professional knowledge representations suggested in the current literature, showed that most of the representations of professional knowledge about teaching and learning science in the literature refer to PCK. Shulman (1986) suggested that PCK is comprised of two domains: teaching and learning. According to Sulman (1986) PCK about teaching is the knowledge of teaching a specific subject matter: "the ways of representing and formulating the subject that make it comprehensible to others".

PCK about learning is an "understanding of what makes the learning of specific topic easy or difficult" (Shulman, 1986). Correspondingly, the analysis described above lead to the identification of two main professional knowledge domains, teaching and learning.

Ten out of the seventeen professional knowledge components suggested herein represent teachers' PCK (see grey rectangles in Figure 2). Four components are from the teaching domain: Teaching strategies; Assessment; Curriculum; and Teaching facilities. Six components are from the learning domain: Meaningful learning; Students' motivation to learn biology; Influence of learning biology on students' future life; Students' prior knowledge; Thinking skills; and Interest outside of the school context. The alignment between the professional knowledge components suggested herein and PCK components suggested in the literature is summarized in Table 6.

The alignment between the components show that although the professional knowledge components that emerged in the course of this study and comprise the teaching and learning domains were in line with PCK components previously suggested in the literature (Table 6 and Figure 2), some of them were more detailed and specific. For example, the component Teaching facilities is part of a broader component that was termed by Fernandez-Balboa & Stiehl (1995) as "knowledge of context: knowledge of the context in which students are most likely to acquire knowledge such as relevance of the subject to the students' everyday life, students' prior knowledge, knowledge of teaching barriers like time limitations, scarcity of appropriate resources etc.". The analysis performed here suggests dividing the component 'knowledge of context' (Fernandez-Balboa & Stiehl, 1995) into four different components: 'Interest outside of the school context' which is aligned with the 'context' instance: relevance of the subject to the students' everyday life; 'Students' prior knowledge' which is aligned with the literature 'context' component: students' prior knowledge; 'Teaching facilities' which is aligned with the 'context' component: knowledge of teaching barriers like time limitations, scarcity of appropriate resources; and 'Influence of learning biology on the students' future life' which is also aligned with the 'context' component: 'relevance of the subject to the students' everyday life' (Table 6).

Table 6: Alignment between professional knowledge components suggested in this study and the PCK components suggested in the current literature

Main domain	Professional knowledge components that emerged in this study	PCK components suggested in the literature
Teaching domain	Teaching strategies - Knowledge and beliefs about the ways a teacher should teach. In other words: the teaching technique.	Knowledge and beliefs about representations and instructional strategies (Magnusson et al., 1999); knowledge and beliefs about ways of formulating the subject that make it comprehensible to others (Shulman, 1986).
	Assessment - Knowledge and beliefs about the dimensions of scientific literacy that are important to be assessed and knowledge of the methods by which that learning can be assessed.	Knowledge and beliefs about assessment (Magnusson et al., 1999).
	Curriculum - knowledge of curriculum including knowledge of the general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals.	Knowledge and beliefs about curricula, including knowledge of the general learning goals of the curriculum as well as of the activities and materials to be used in meeting those goals (Magnusson et al., 1999; Tamir, 1988).
	Teaching facilities - knowledge and beliefs about the availability of appropriate resources for teaching.	Knowledge and beliefs about context; knowledge and beliefs about teaching barriers such as time limitations, scarcity of appropriate resources (Fernandez-Balboa & Stiehl, 1995).
Learning domain	Meaningful learning - Knowledge and beliefs about the factors that promote meaningful learning in the students' mind.	Knowledge and beliefs about student learning and conceptions (Shulman, 1986); knowledge and beliefs about students' understanding of specific science topics (Magnusson et al., 1999).
	Students' motivation to learn biology - Knowledge and beliefs about factors that influence student's motivation to learn specific themes or contents in science.	Knowledge and beliefs about student learning and conceptions (Shulman, 1986); knowledge and beliefs about students' understanding of specific science topics (Magnusson et al., 1999).
	Influence of learning biology on the students' future life.	Knowledge and beliefs about context (Fernandez-Balboa & Stiehl, 1995).
	Students' prior knowledge - Knowledge and beliefs about the knowledge and conceptions that students bring with them to the lessons.	Knowledge and beliefs about the conceptions and preconceptions that students of different ages and backgrounds bring with them to the lessons (Shulman, 1986); students' prior knowledge (Fernandez-Balboa & Stiehl, 1995).
	Thinking skills - Knowledge and beliefs about students' thinking skills while learning and their possible ability to use high order thinking skills.	Knowledge and beliefs about student learning and conceptions (Shulman, 1986); knowledge and beliefs about students' understanding of specific science topics (Magnusson et al., 1999).
	Interest outside of the school context - Knowledge and beliefs about students' concerns, hobbies or activities during their after school hours that may affect learning.	Knowledge and beliefs about context (Fernandez-Balboa & Stiehl, 1995).

Seven components that emerged in the course of the data analysis described here represent other types of professional knowledge (see white rectangles in Figure 2). The component 'content knowledge' (from the Teaching domain) and its connection to PCK is a subject of debate (Fernandez-Balboa & Stiehl, 1995; Grossman, 1990; Krauss et al., 2008; Lederman & Gess-Newsome, 1992; Loughran et al., 2008; Magnusson et al., 1999; Marks, 1990; Shulman, 1987). In the subsequent section I show that the CK of thirteen out of twenty participating biology teachers is a different professional knowledge component, distinct from their PCK (See question 6.2.2 pp.63-68). Therefore it was not concluded as part of PCK in thisthesis. The component 'Personnel that accompany the teaching' (e.g., school principal or chief supervisor of biological education, Figure 2, the Teaching domain) refers to all the teachers and staff that work in school. Thus, it is distinguished from the specific knowledge of teaching biology, namely biology teachers' PCK.

Due to the alignment between this study's professional knowledge components and PCK components suggested in the literature, in the next two research questions I focused on PCK components.

6.1.3. The most frequent PCK components and their possible expansion

Frequency of PCK components

The frequency of appearance of each teacher's PCK components from the teaching domain and the learning domain was examined (following Chi, 1997). Some topics associated with certain PCK components appeared to be more frequently mentioned by the teachers during the workshop of designing new teaching and learning materials (Figure 3). I assume that the frequency of appearence of topics in the teachers' discourse may reflect their relative importance and concern about teaching and learning among the teachers. I followed the appearance of the most frequent components along the four stages of the program in each teacher's data. Monitoring the frequency of each teacher PCK components and repeating explanations relating to these components enabled me to identify patterns that are unique to each teacher's PCK (see below).

I focused on four teachers of Path B that fully participated in the "Designing New Teaching and Learning Materials" workshop (see Research population section in pp.24-26). These teachers participated in the first workshop of the "Rothschild-Weizmann" program and I was one of the moderators that accompanied them along the whole workshop as well as during the year following the termination of the program.

Within the Teaching domain, the four teachers (Teacher B1-B4) related most to the teaching strategies component (51%–65%, Figure 3) and to the teaching facilities (16%-34%, Figure 3). The other components were mentioned less than 19% of the time in the teachers' episodes. Within the Learning domain, all four teachers related most to meaningful learning (38%-64%, Figure 3). The most frequent components discussed by all four teachers were teaching strategies and meaningful learning (Figure 3). Assuming that the high frequency of these components may provide rich qualitative data and may imply of the teachers' concern about teaching strategies and meaningful learning, I subsequently performed an in-depth qualitative analysis of these two PCK components for each of the four teachers along the four stages of the workshop. Differences between the four teachers' PCK and the unique expansion of each teacher's PCK that appeared to emerge during the workshop, as described in detail below and exemplified in Tables 7-10. Each teacher is described individually as a case-study in the next section.

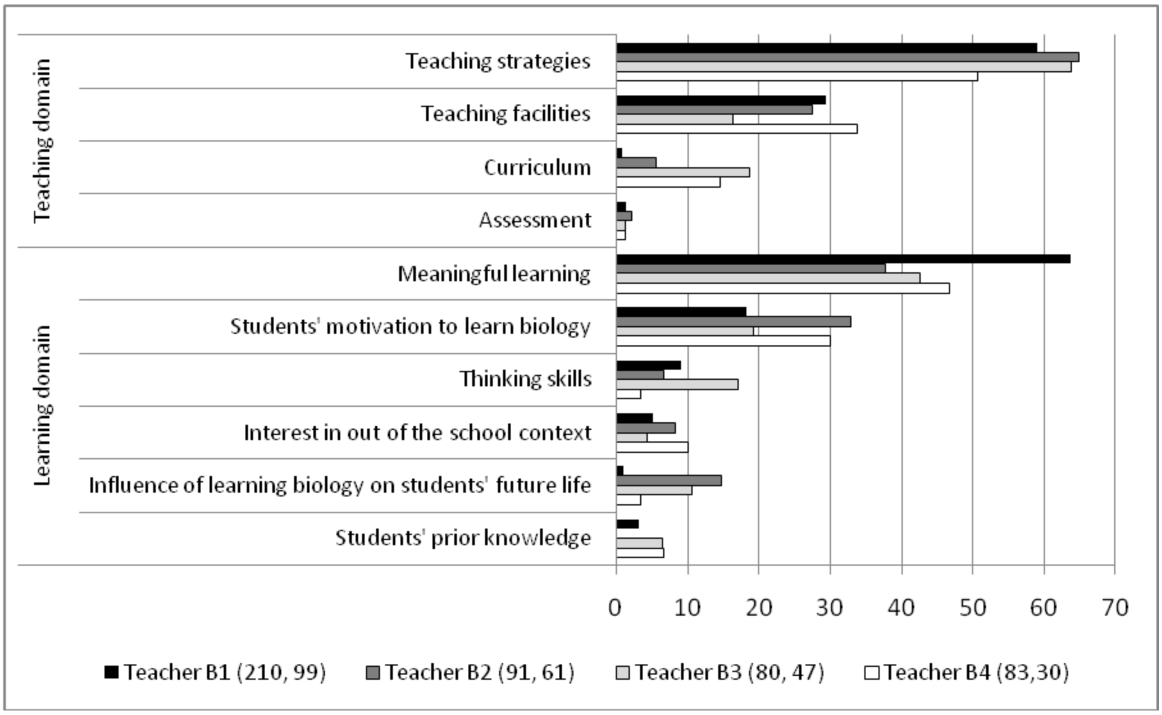

Figure 3: Distribution of the PCK components from the Teaching domain and the Learning domain (in percentage, n1 = number of episodes in the Teaching domain, n2 = number of episodes in the Learning domain)

The possible expansion of each teacher's PCK

Teacher B1. Teacher B1 had 17 years of experience in teaching biology at the beginning of the program in one of the leading high-schools in the center of the country. The school is well known for the high success rates of its students in the matriculation exams in general and in biology in particular. She repeatedly declared that she asks her students a lot of questions during her lessons in order to induce thinking procedures and in order to scaffold their learning.

During the workshop on designing new teaching and learning materials, Teacher B1 mostly referred to teaching strategies (59% out of all her episodes about the Teaching domain) and to meaningful learning (64% out of all her episodes about the Learning domain) (Figure 3). At the beginning of the program, during stage 1, Teacher B1 hardly mentioned teaching strategies but she expressed her belief that her students are not able to use high-order thinking skills for acquiring knowledge during her lessons. She believed that using high-order thinking skills requires a lot of teaching time, which she claimed she does not have (Table 7). At this stage Teacher B1 repeatedly elicited a teaching problem: constrains of time that should be devoted to high-order thinking skills and about her lack of confidence in her students' cognitive abilities to use high order thinking skills. Repeated reference to students' thinking skills implies that Teacher B1's conception about teaching and learning is that meaningful learning occurs via cognitive procedures but it demands a lot of teaching time and high cognitive capabilities.

During stage 2, the episodes of Teacher B1 about teaching strategies related to her ideas on means to promote meaningful learning. She began to express the idea that meaningful learning occurs when new knowledge is connected to existing knowledge (Table 7). She expressed the idea of knowledge construction via connections of existing knowledge to new knowledge, after learning about cognitive procedures of learning in the "Introduction to science education" course (see Appendix 1). During stage 2, Teacher B1 developed teaching and learning materials that make use of laboratory experiments aimed at strengthening biological knowledge that has been previously learned in class. At this stage, Teacher B1 tried to use a new teaching strategy: connecting existing knowledge to newly acquired knowledge using high-order thinking skills through laboratory experiments in order to enhance meaningful learning. It seemed that she kept holding her initial PCK about using high-order thinking skills for meaningful learning and tries to use the new teaching strategy in order to solve the teaching and learning problem she elicited in the first stage.

During stage 3, Teacher B1 made her first attempt to use her newly designed teaching and learning materials in her class and felt that the materials needed improvement. At that point, Teacher B1 experienced knowledge construction herself during the 'Experiencing contemporary research in the life sciences' course (see Appendix 1). In this course the teachers were encouraged to read scientific articles and then experience laboratory experiments in the biological laboratories of the Weizmann Institute. She reported that reading and understanding scientific articles and then experiencing contemporary research procedures were hard but rewarding since she enjoyed the success of acquiring new up-to-date knowledge using high order thinking skills activities. At this point she was also introduced, in the 'Introduction to science education' course, to adapted scientific articles (Yarden, 2009) that are part of an elective program for high-school biology students. During the third stage she decided to develop new materials, based on the conclusions that she reached from experiencing the new materials in her class and the knowledge she acquired in the various courses. She mainly concentrated on a reading comprehension activity using adapted article that related to previously learned content, but she was still unsatisfied.

During stage 4, Teacher B1 had developed different teaching and learning materials that were aimed at using laboratory experiments in order to facilitate new knowledge construction. The new materials are designed differently from her previous design. In the previous design laboratory activities were used to strengthen biological knowledge previously learned in class. The new teaching and learning materials were designed so that students would be required to use high-order thinking skills, in order to construct new knowledge, knowledge that was not previously learned in class (Table 7). At this stage, she decided to ask her students to use high order thinking skills, expressing her confidence in her students' ability to use skills such as inquiry skills during her lessons. She elaborated upon a strategy of scaffolding students' knowledge construction via inquiry, thus enabling her students to achieve meaningful learning (Table 7). This development in her confidence in her students' capability of using high-order thinking skills represents an expansion of her PCK.

At the workshop of designing new teaching and learning materials Teacher B1 gained the opportunity to self-examine her PCK about teaching and learning. She began to learn in the program declaring that meaningful learning occurs via cognitive procedures such as high-order thinking skills that may secure knowledge, but that she is not able to teach that way and her students are not capable of using high-order cognitive procedures. In the course of the program she designed new teaching and learning materials using high-order thinking skills that scaffold new knowledge construction. She began declaring that she trust her students' capabilities to use high-order thinking, and that it is possible to teach that way despite the time constrains, thus demonstrating an expansion of her PCK.

Teacher B2. Teacher B2 also had 17 years of experience in teaching high-school biology toward the national matriculation exams, at the beginning of the program. She teaches in a religious high-school for boys, in which students devote most of their days to religious studies and learn science only during the afternoon hours. This led her to develop a teaching strategy using interesting stories from everyday life in order to induce an emotional effect that would capture her students' attention.

Teacher B2's discussions related mostly to teaching strategies (65% out of all her episodes about the Teaching domain) and to meaningful learning (38% out of all her episodes about the Learning domain) during the workshop (Figure 3). She developed teaching and learning

Table 7: Quotations on teaching strategies and meaningful learning taken from Teacher B1's episodes during the four workshop stages. The numbers in brackets indicate the components' distribution in percentages in each stage, n=numbers of episodes.

Stages in the workshop / PCK component	Stage 1	Stage 2	Stage 3	Stage 4
Teaching strategies (*n* = 137)		*"I would like to hand them [the students] an article that has four types of links: 1. connections to their knowledge; 2 connections to research data; 3 connections to laboratory instructions; 4. connections to an additional related article*."	*"This article is short. They read it in class and I think this is a good opportunity to exercise reading comprehension to be added to their knowledge expansion*."	"*In the new initiative I suggest using the laboratory lessons as sources for knowledge construction*."
Meaningful learning (*n* = 63)	*"I don't think that teaching the nature of science is important. Two preconditions are required before teaching it: a lot of content knowledge and basic thinking capability. But not everyone can reach it, and it requires a lot of time to teach high-order thinking skills. It is not intuitive. I don't have time."*	*"The connection between the knowledge acquired in class and the laboratory activities will make them understand that the things they learned are really done."*		*"I think that challenging a student's thinking when he watches a phenomenon in the laboratory and trying to find an explanation is motivating and a great science thinking practice. When learning becomes active it is remembered better…The student is experiencing the laboratory activity before learning the content in class. He uses the laboratory activity as a source of learning."*
Summary of data analysis	Teacher B1 believed that students have difficulties to use high-order thinking skills and that there are times constrains to teach through high high-order thinking skills.	Teacher B1 suggested connecting prior knowledge to newly acquired knowledge using high order thinking skills through laboratory experiments in order to enhance the establishment of previously learned contents.	Teacher B1 attempted to use high-order thinking skill as a teaching strategy for meaningful learning via reading comprehension.	Teacher B1 taught using inquiry and expressed confidence in her students' ability to use high-order thinking skills aimed at knowledge construction.

materials that focus on bioethical dilemmas, together with Teacher B3. During the first and second stage of the workshop, her episodes about teaching strategies described her teaching strategy as a random one, not ordinate according to the syllabus but rather, as she declared, associative. She believed that using exciting stories in her lessons motivates her students to listen to her and that learning means remembering via emotional experiences which induces long-term memory (Table 8). In the teaching and learning materials that she designed during stage 2, a bioethical dilemma about 'whether the government should require genetics testing from a couple before the marriage?' she insisted on using a dramatic story about a family with a genetic disease. Her discourse about meaningful learning demonstrated her conception that dramatic stories should be the main issue of a teaching and learning program which is aimed at scaffolding students' knowledge through emotional experiences.

As the workshop continued, she learned in the 'Introduction to science education' course about the importance of connecting prior knowledge to newly acquired knowledge. She began to understand the importance of teaching according to a teaching sequence and of planning the lessons in advance. That idea was reinforced after the implementation of the new materials she designed in her class. She then declared that she is busy ordering all her stories according to a 'rational sequence'. Still, at stage 3, her discourse mainly focused on her belief that using interesting, dramatic stories will lead to meaningful learning (Table 8).

The main evidence of the expansion of Teacher B2's PCK appeared in stage 4, where she expressed her realization of the importance of sequential and coherent teaching. In parallel, her episodes about meaningful learning included concerns about students' misconceptions (Table 8). This realization occurred after reflecting on the assessment of her newly designed materials in her class. During stage 4 Teacher B2 presented her design and the results of the assessment of her design in her class to the other participating teachers and the workshop moderators. During the presentation she reflected on her knowledge about teaching and learning via interesting stories. In addition, her exposure in the 'Cognition, Learning and Instruction' course to misconceptions seemed to make a meaningful influence on her PCK. She began to speak about her concern that the stories she tells at class may induce misconceptions (Table 8). She also declared that she was very impressed of the teaching strategy of the lecturer in the 'Biology of Stem Cells' course. The lecturer of this course taught with the help of very interesting scientific articles (primary scientific literature) and combined interesting stories about the various studies and the scientists involved. Nevertheless, the lectures' contents were very ordinate and always referred to previous knowledge that was taught in the course. At this stage, Teacher B2 improved the contents of her teaching and learning materials by bringing stories that better demonstrated the biological dilemmas in question followed by questions that clarify whether misconceptions had occurred in her students' minds.

It seems that the program, including the design of new teaching and learning materials, provided the opportunity for Teacher B2 to self examine her knowledge about teaching and learning. By the end of the program, she was still looking for "interesting stories" to insert into her new materials, meaning that her PCK may have not change, but she began to prepare to her lessons, in advance in contrast to her initial random choice of stories for her teaching. In addition, she began to be cautious about misconceptions that might occur among her students while learning through interesting stories. Thus, Teacher B demonstrated an expansion of her PCK.

Teacher B3. Teacher B3 had 12 years of experience in teaching high-school biology toward the national matriculation examinations, at the beginning of the program. She teaches in a rather small religious school for girls located in a remote village. Teacher B3was Teacher B2's partner in developing teaching and learning materials focused on bioethical dilemmas. During the workshop Teacher B3 repeatedly declared that she teaches biology as a means of educating her students about human values. Her main focus during the workshop was on collecting arguments for and against the dilemmas from various aspects: religious, economic, legal, moral and political.

Teacher B3's episodes mostly referred to teaching strategies (64% out of all her episodes about the Teaching domain) and to meaningful learning (43% out of all her episodes about the Learning domain, Figure 3). During the first and second stages of the workshop, Teacher B3's episodes emphasized her role in class in promoting human values among her students via biology. She repeatedly declared that her main goal in class is to educate her students to be good citizens (Table 9, stage 1). During these stages, Teacher B3's episodes referring to meaningful learning focused on the importance of the relevance of biological contents to everyday life as a means of promoting meaningful learning (Table 9).

At the end of stage 3 and during stage 4, Teacher B3 began to refer to the scaffolding of biological content knowledge as an additional goal of her teaching and learning materials, as well as of her practice: her episodes about meaningful learning in stage 3 and in stage 4, focused on reporting that she was establishing students' understanding while teaching with the help of leading questions, in addition to promoting human values (Table 9, stage 3).

Table 8: Quotations on teaching strategies and meaningful learning taken from Teacher B2's episodes during the four workshop stages. The numbers in brackets indicate the components' distribution in percentages in each stage, n=numbers of episodes.

Stages in the workshop / PCK component	Stage 1	Stage 2:	Stage 3:	Stage 4:
Teaching strategies (n = 59)	*"I teach associatively. My strategy is to insert stories into my lessons that are not connected to the subject matter. That way my students think: 'Oh! This is not connected to learning; we should listen'."*	*"I teach them until six o'clock in the evening, so I 'feel' them. If something upsetting happened to them during the day, I immediately change my plans. I may tell a joke or some interesting story to 'wake them up'."*		*"I have two good nature movies…I also have leading questions that I prepared in advance. It is an excellent way to summarize the subject of relationships between organisms."*
Meaningful learning (n = 23)	*"Through the stories they will remember biology…I see that they remember emotional experiences. It is only if they go through an emotional experience that they remember…Although it seems like I am wasting time I think that if the story causes an association in the students' minds they will remember it."*	*"When learning, our students should have a 'wow!!!' feeling. Like the other day a student told me at the end of my lesson: 'wow! Today's lesson was worthwhile!'"*	**"***At 5.00 pm there is no meaningful learning. They wish to sleep or play basketball. I need a dramatic story in order to make them listen to me and remember the lesson's content"*	*"I paid attention that sometimes students think that what I tell them, let's say about C-4 plants, is the norm. I tell a story and they think this is the norm, so we have to be very careful not to induce misconceptions."*
Summary of data analysis	Teacher B2 believed that students are not interested in learning biology therefore, she used dramatic stories in order to enhance motivation to listen to her**.** She declared that dramatic stories may induce emotional feelings that may in turn lead students to long-term recall of the biological contents**.**			Teacher Bs spoke about the importance of teaching according to a teaching sequence. She prepared teaching activities in advance and paid attention to students' misconceptions.

Table 9: Quotations on teaching strategies and meaningful learning taken from Teacher B3's episodes during the four workshop stages. The numbers in brackets indicate the components' distribution in percentages in each stage, n=numbers of episodes.

Stages in the workshop / PCK component	Stage 1:	Stage 2:	Stage 3:	Stage 4:
Teaching strategies (n = 51)	"*My main goal in class is to educate my students to be a part of the community, part of the environment and the universe. I like biology and I insert examples from everyday life to exemplify the importance of human values through biology*."		*"Now, when a student answers me it doesn't satisfy me. I keep asking her to explain her answer in a more detailed way and I listen carefully to see if she really understands. I keep asking her until I am sure she understands. I am also more alert to misconceptions."*	"*We basically intended to design a dilemma for the core contents. Here we demonstrate how to summarize the 'human body' content. I ask my students :'If no insulin is secreted, how does it affect the body?' I use the dilemma as an additional tool for teaching biological contents."*
Meaningful learning (n = 20)	"*They need to understand the relevance of biological processes to everyday life."*	*"It broadens the students' horizons. The beauty is that they understand that there is no definite answer. There are no yes-or-no answers. We all know the same facts but decide differently. I think it is of very important educational value."*		"*Here we built a worksheet with questions that lead the students to understand the biological basis of the dilemma. Furthermore, it summarizes the homeostasis topic which is also an important issue for the discussion."*
Summary of data analysis	Teacher B3 declared that her role in the class is promoting human values among students via biology. She believed that emphasizing the relevance of biological contents is a valuable way for promoting meaningful learning.		Teacher B3 scaffold biological content knowledge and established students' understanding while teaching with the help of leading questions as an additional goal of her teaching.	

During her interview, Teacher B3 pointed out that both the 'Cognition, Learning and Instruction' course, and listening to Teacher B1 while presenting the implementation of her newly designed materials, influenced her to broaden her teaching strategies.

During stage 4, Teacher B3 continued reporting on inserting questions related to biological contents into her teaching and learning materials, in order to establish students' knowledge, in addition to promoting human values. Following this expansion of her teaching strategy she added questions to her dilemma that may scaffold students' meaningful learning (Table 9).

The program of designing new teaching and learning materials provided the opportunity for Teacher B3 to self examine her PCK. By the end of the program, she was still emphasizing the importance of the relevance of biological contents to everyday life and human values as a means of promoting meaningful learning. But, in addition she paid attention to inserting questions that may scaffold the addition of knowledge in biology, demonstrating an expansion of her PCK.

Teacher B4. Teacher B4 was the youngest teacher in the study group, with only 6 years of experience at the beginning of the Rothschild-Weizmann program. She teaches biology in high-school toward the matriculation examination in one of the big high-schools located in a city in the center of the country with mid-to-high socioeconomic status. Teacher B4 was the least experienced teacher among the four, and it is possible that she had not yet developed her unique PCK. During the workshop she developed teaching and learning materials in ecology based on adapting a scientific article (following Yarden, 2009).

Teacher B4's data show that although 51% of her episodes about teaching focused on the teaching strategies component and 47% of her attention about learning was focused on the meaningful learning component, unlike the other three teachers, she did not appear to hold a unique PCK about teaching and learning. Teacher B4 experienced many teaching difficulties. It seems that she had not found a satisfactory teaching strategy to solve these difficulties. Because of the lack of repeated explanations or in other words, 'often used' teaching strategy, and a lack of 'often used' kinds of explanations about meaningful learning, we concluded that Teacher B4 did not hold a unique PCK. During stages 1–3, Teacher B4 mainly asked the others about their teaching strategies. During stage 1, she did not relate to teaching strategies at all but instead she related to her students' difficulties in learning biology (Table 10). During stage 2 she began to ask the other teachers questions about their teaching strategies (Table 10). Even in stage 3, after she finished adapting the first article of her new teaching and learning materials with the intent of using them in her class, she did not know how to teach them (Table 10). At the same time, during stages 2-3 she continued to speak about her students' difficulties to learn meaningfully and repeated several times during stage 3 to express her belief that students are having difficulties to learn biology (Table 10).

During stage 4, Teacher B4 described her new teaching strategy. She decided to hand out the adapted article in parts and to ask the students questions following each part as a means of content knowledge acquisition (Table 10). She reported that she decided to use this strategy after the workshop meeting during stage 3 about: "What does science education know about adapted primary literature?" (see Table 2) in which a similar strategy was suggested by the moderators of the workshop. In addition, during stage 4, Teacher B4 reported several times that she had a good experience in teaching her materials. She also reported that for the first time her students had shown interest in the content of the article from her new materials design. She mentioned that during a school trip to the desert, her students were able to apply the knowledge they had acquired in class to other contexts (Table 10).

It is worth noting that although Teacher B4 experienced many difficulties teaching her students at the beginning of the workshop, she discovered a satisfactory teaching strategy during the workshop, namely the possibility of acquiring content step by step with the help of leading questions. The new teaching strategy that she developed, along with her satisfaction with her students' interest, demonstrate the possible expansion of her PCK during the workshop.

Taken together, the data show that during the course of the professional development program, the unique PCK of the three experienced teachers who participated in this program (B1-B3) expanded. Although all the teachers related mostly to the same components, each teacher held a unique PCK about teaching strategies and meaningful learning. Although Teachers B1-B3 did not change their initial conception about teaching and learning, each one demonstrated an expansion of her unique PCK. Teacher B4, who appeared not to hold a unique PCK about teaching and learning at the beginning of the workshop, started to examine a new teaching strategy and was satisfied from it, implying that she may established one along with a possible expansion of her PCK.

Table 10: Quotations on teaching strategies and meaningful learning taken from Teacher B4's episodes during the four workshop stages. The numbers in brackets indicate the components' distribution in percentages in each stage, n=numbers of episodes.

Stages in the workshop / PCK component	Stage 1	Stage 2	Stage 3	Stage 4
Teaching strategies (n=42)	**(0%)**	*"How do you teach the laboratory experiments? Do you teach 2-3 laboratories and then stops and summarize them?"* **(12%)**	*"How do you intend to teach the article?" "I don't know yet… although I will soon have to teach it… These days, if you don't "feed" the students they don't "eat". I have to dictate everything; otherwise they don't know to summarize alone".* **(12%)**	*"I handed the students the article in parts. First I gave them only the article's title cut out of the whole article and I asked questions about the article's title".* **(76%)**
Meaningful learning (n=14)	"*We are teaching students that learning genetics will be very hard for them…most of the students do not see a book or an article, at all!... today's students are missing a vast of knowledge base".*	*"My daughter, she is in the fourth grade, I only have to remind her and she knows it perfectly but, the students in high-school, they forget it all!"*	*"On the one hand the level of the contents in the syllabus is very low. On the other hand if you tell them something new from the latest research they get confused. I don't know but there is some kind of a problem here"*	*"A week after we learned the article, we went on a field trip and I asked them: 'what do you see here?' Not only that they said: a-biotic and biotic factors, but also mentioned artificial a-biotic factors like buildings and roads".*
Summary of data analysis	Teacher B4 asked the other participating teachers a lot of questions about their teaching strategies and found it hard to formulate a teaching strategy for her new materials design. It seems that she did not have a leading teaching strategy. Teacher B4 declared that her students have difficulties to learn biology. These repeating complains imply of her difficulties in her teaching practice.			Teacher B4 found a satisfactory teaching strategy that she developed, along with her satisfaction with her students' interest.

6.1.4. Long term retention of PCK expansion

In order to examine the possible retention of the teachers' PCK expansion I used several criteria. Initially, I looked for possible retention of the two PCK components that were examined in this study: teaching strategies and meaningful learning. Therefore, in the interview that was conducted a year following the termination of the program I looked for the teachers' reports about (i) their use of the teaching strategies that were acquired during the Rothschild-Weizmann program, and (ii) their awareness of high order thinking skills used for meaningful learning. The results of the teachers' reports about these two components are summarized in Table 11 and detailed below. In addition I examined the teachers' use of new teaching and learning materials that were designed during the program, in order to better understand the design's role in the teachers' professional development process.

The interviews were semi-structured. All the interviews included the following questions: (i) Can you tell me about any influence of the Rothschild-Weizmann program on your practice in the last year?; (ii) Do you teach any of the new materials that were designed during the program? It is worth noting that I am aware that it would have been better to observe the teachers' practice in their classes a year following the termination of the program in order to make informed conclusions about the retention of the PCK components' expansion. The analysis of the interviews is presented below according to the two main PCK components examined above:

(i) *Teaching strategy*: Teacher B1 reported that she continues to encourage knowledge construction via high order thinking skills questions that she asks her students, and via inquiry. Teacher B2 reported that she continues to insert interesting stories to her lessons but that she tells stories that are connected to the contents of her lessons. She added that she had started to dedicate more time to human values in her teaching and that she had learned this approach from Teacher B3 during the workshop. Teacher B1 and Teacher B3 reported that they would sometimes tell interesting stories in order to motivate their students to learn, similarly to the strategy reported by Teacher B2 during the workshop. Teacher B3 reported that she still thinks that her main role as a biology teacher is to educate her students for human values via biology. Teachers B2, B3 and B4 reported that they began to ask more questions in their lessons in order to understand their students' level of comprehension. Understanding their students' level of knowledge helped them to further plan their lessons (Table 11).

(ii) *Meaningful learning*: Teacher B1 reported that she believes that using high order thinking skills questions promotes meaningful learning and knowledge construction. She told that she received a letter from the chief supervisor of biology education about the high achievements of her students and that she is sure that her high order thinking skills questions created meaningful learning in her students' minds. Teacher B2 reported that she is participating in scientific and popular lectures in order to collect interesting stories for her students. That way, she believes, her students are motivated to learn biology. Teacher B3 reported that she still thinks that her main role is to educate her students for human values. Teachers B2, B3 and B4 reported asking their students questions in order to facilitate knowledge comprehension. They reported having learned this strategy from Teacher B1 during the workshop (Table 11).

The use of new teaching and learning materials: Teachers B1, B2 and B3 reported that they were continuing to teach the teaching and learning materials they had developed during the workshop. In contrast, Teacher B4 reported that she had not continued to teach the materials she developed during the workshop, but intended to do so in the coming year. A year following the last interview (two years following the termination of the program), Teacher B4 reported that she was teaching the learning materials that she had developed after improving them during the recent year. The four teachers noted that they were not teaching the teaching and learning materials that were developed by the other teachers.

In addition, during the interviews all the teachers reported applying contents and skills which they had learned in the various courses of the program. They all reported mentioning updated biological contents into their lessons, which they learned in the biological courses during the two-year program. Moreover, they all noted that the science education courses had made them more aware of their teaching and their students' learning, and that they felt that as a result, they had become 'better teachers'.

Table 11: the teachers' PCK at the end of the Rothschild Weizmann program and its retention a year following the termination of the program

PCK component	Stage of the program	Teacher B1	Teacher B2	Teacher B3	Teacher B4
Teaching strategy	At the end of the program	Asking high-order thinking skills questions	'Interesting stories related to lessons' contents	Promoting human values via biology	New teaching strategy: teaching adapted article in little parts
	A year following the termination of the program	Asking high-order thinking skills questions; Paying attention to human values; Inserts 'interesting stories'	Inserts interesting stories related to lessons' contents; Paying attention to human values; Asking questions	Promoting human values via biology Inserts 'interesting stories'; Asking questions	Asking questions
Meaningful learning	At the end of the program	Confidence in her students' abilities to use high order thinking skills questions for knowledge construction	Interesting stories related to lessons' contents aimed at knowledge establishment and paying attention to students' misconceptions	Human values are relevant therefore induces learning	Not reported
	A year following the termination of the program	Confidence in her students' abilities to use her high order thinking skills questions for knowledge construction	Telling interesting stories related to lessons contents, asking questions aimed at knowledge establishment and paying attention to students' misconceptions	Relevance of contents via human values and asking questions aimed at knowledge establishment	Asking questions aimed at knowledge establishment

Taken together it seems that major parts of the teachers PCK expansion retained following the termination of the Rothschild-Weizmann program. The participating teachers reported that they enlarged their repertoire of teaching strategies and used some new strategies that they learned from their partners during the design workshop. These reports may imply that these teachers did experienced professional development. Nevertheless, teachers are usually not qualified to develop new teaching and learning materials that are generic, i.e. for other teachers' use. Developing new teaching and learning materials was not the aim of the professional development program described above. Rather, the aim of this program was to develop each teacher's unique PCK by means of designing new teaching and learning materials. The fact that these teachers did not use the other teachers' materials emphasizes the uniqueness of each teacher's PCK: each teacher developed the new teaching and learning materials using her unique PCK which made it difficult for the other teachers with other PCK to use them. However, all of the teachers did use other teachers' strategies and applied contents and skills that they learned from each other or from the program, implying expansion of their PCK.

6.2 Exploring biology teachers' implicit professional knowledge

Implicit knowledge is the kind of tacit knowledge that expert hold which is usually not verbalized. Therefore I used the RGT, a method that was designed in order to elicit tacit knowledge, as detailed in the data analysis section pp. 29-34.

6.2.1 The biology teachers' professional knowledge repertoire

Initially I attempted to probe all the participating in-service biology teachers' knowledge components (n=20). The teachers were asked to name 12 knowledge components that they believed a good biology teacher should possess (steps 1 and 2 in the RGT). These components served as the repertory grid's elements in the subsequent analysis, but they were first used for content analysis of the teachers' repertoire of knowledge elements regarding high-school biology teaching.

Each teacher managed to elicit between 9 and 12 elements, for a total of 230 elements. The 230 elements included 148 different elements, i.e. 82 of the elements were mentioned by 2 to 10 different teachers. Examples of the different elements that different teachers elicited appear in Figures 4 and 5. Thus, the teachers who participated in this study possessed a diverse repertoire of biology teaching elements.

The elements were categorized according to their content. Six main groups of elements emerged in the course of the content analysis: (i) CK, namely knowledge of science contents. (i.e., 'biological knowledge', 'knowledge about levels of organization' and 'deep knowledge in science') (ii) teaching skills, namely knowledge and beliefs about the ways a teacher should teach (i.e., 'clear explanations', 'the ability to simplify complex processes' and 'the ability to guide inquiry'); (iii) teacher's personality, namely knowledge and beliefs about personal characteristics of the teacher that may influence teaching (i.e., 'creative', 'moral personality' and 'loves people'); (iv) learning skills, namely knowledge and beliefs about the factors that influence meaningful learning (i.e., 'students' misconceptions', difficulties in comprehending a specific idea' and 'motivation to learn science'); (v) learner's personality, namely knowledge and beliefs about personal characteristics of students that may influence learning (i.e., 'understands students' personality') (vi) relevance, namely knowledge and beliefs about the connection between contents taught in class with the students' everyday life (i.e., 'updated in the students' world and respects it' and 'uses concepts of the students' everyday life'). Three of these categories were aligned with PCK components that had been previously suggested in the literature: (i) teaching skills was aligned with the component 'knowledge and beliefs about instructional strategies for teaching science' (Magnusson et al., 1999); (ii) learning skills was aligned with the component 'knowledge and beliefs about students' understanding of specific science topics' (Magnusson et al., 1999) and Knowledge and beliefs about student learning and conceptions (Shulman, 1986); (iii) relevance was aligned with the component knowledge and beliefs about curricula, including knowledge of the general learning goals of the curriculum as well as of the activities and materials to be used in meeting those goals (Magnusson et al., 1999; Tamir, 1988).

The first category that emerged in the context of this study was CK. As already noted, CK is a controversial category. Some researchers refer to it as part of PCK, while others consider it a separate component. The two categories: teacher's personality and student's personality were not aligned with previously suggested PCK components. They are more likely to be professional knowledge which might influence PCK rather than PCK (Table 12).

A close examination of the data revealed that each teacher possesses a different repertoire of biology teaching knowledge elements within these categories.

Elements of the CK category were mentioned by all of the teachers, whereas the other elements from the other categories were mentioned only by several teachers (Table 12). Examining the diversity of the elicited elements revealed that most were from four categories: CK (28%), teaching skills (24%), teacher's personality (21%) and learning skills (20%); in other words, the CK category included the most diverse elements among the six groups of elements (Table 12). In addition, the CK category seemed to be the most frequently mentioned category (33% of all of the elements), meaning that one out of each three elements that were elicited by all of the teachers was a CK element (Table 12). The second most frequently mentioned category was teaching skills (23%) followed by teacher's personality (21%) and then learning skills (17%), learner's personality (3%) and relevance (3%), (Table 12).

Because all the teachers mentioned CK elements and with high diversity and high frequency I focused on analyzing the coherence rate between elements from the CK category and other professional knowledge elements in the teachers' repertory grid clusters.

Table 12: Diversity of elements in the participating biology teachers' data

Element category	Number of teachers who mentioned the category (n = 20)	Number and percentage of different elements in each category (n = 148 different elements)	Number of times elements were mentioned (n = 230 elements in total)
Content knowledge	20	42 (28%)	76 (33%)
Teaching skills	17	36 (24%)	54 (23%)
Teacher's personality	17	32 (21%)	49 (21%)
Learning skills	11	30 (20%)	38 (17%)
Learner's personality	4	4 (3%)	7 (3%)
Relevance	4	5 (3%)	6 (3%)

6.2.2 The relationships between biology teachers' professional knowledge and their CK

Analysis of elements

During step 3 of the RGT, the teachers were asked to select the exceptional element among three randomly selected ones, explain their selection and repeat this step 10 times. Constructs were then defined based on repeated explanations of the exceptional element. In step 4, each teacher was asked to fill out a table with ratings of each element relative to each construct (similar to Table 4). The computed outcome of the ratings given by each teacher was a two-dimensional tree diagram—a cluster—which represents similarities between rating patterns of the elements and similarities between rating patterns of the constructs (for examples see Figures 4 and 5).

Teacher A3's cluster is shown here as a case study (Figure 4). Twelve elements that were elicited by Teacher A3 during step 2 of the RGT are slanted at the bottom of the diagram (1, in Figure 4). The rate of similarity (in percentage) between the different elements appears at the top of the diagram on the element coherence rate scale (2, in Figure 4). The graph to the left of the element coherence rate scale shows the similarity rate between the elements that are attached to each line (2, in Figure 4). For example, the elements: 'The human body', 'volume', 'cell', and 'ecology' (3, in Figure 4) are similar with 85% coherence (2, in Figure 4). This means that these four elements constitute a group of elements that are considered similar by Teacher A3 with respect to biology teaching, since more that 80% of coherence between elements are considered as high coherence between the repertory grid's elements (Kelly, 1969).

To examine the significance of CK for high-school biology teachers, we looked at the CK elements and searched for high coherence (more than 80%) between these and other elements mentioned by the teachers. Analysis of each teacher's tree diagram revealed that all 20 teachers participating in this study mentioned CK elements as elements that they believed that a high-school biology teacher should possess (Table 12). All of the teachers connected between different CK elements (Figure 6) with high coherence (more than 80%) but not with other elements' categories, namely, the CK elements appeared to be a separate group of elements. In addition, 7 out of the 20 teachers demonstrated high coherence between elements from the CK category and elements from the other categories as follows: Five teachers connected elements of CK to elements of teaching skills (Figure 6), such as the ability to demonstrate biological knowledge, to characterize students' understanding and to teach in an experiential way. Two teachers connected CK elements to those of teacher's personality (Figure 6), such as enthusiasm for the wonders of nature, curiosity and openness to students' questions and ideas, and personal interest in science.

An exceptional example of a repertory grid tree diagram the repertory grid tree diagram of Teacher A2 is shown in Figure 5. Most of this teacher's elements are CK elements and which appear in two groups (3, in Figure 5). The first group with 100% of coherence between CK elements (correlation between structure and function; content knowledge; ratio between surface and volume; uniformity and differences) and the second group with more than 80% of coherence between two elements of CK: knowledge beyond the curriculum and knowledge update, and four elements from the personality category: 'creativity', 'enthusiasm for the wonders of nature', 'curiosity', 'openness to new ideas and questioning' and one element from the learning skills category: 'scientific literacy (2, in Figure 5).

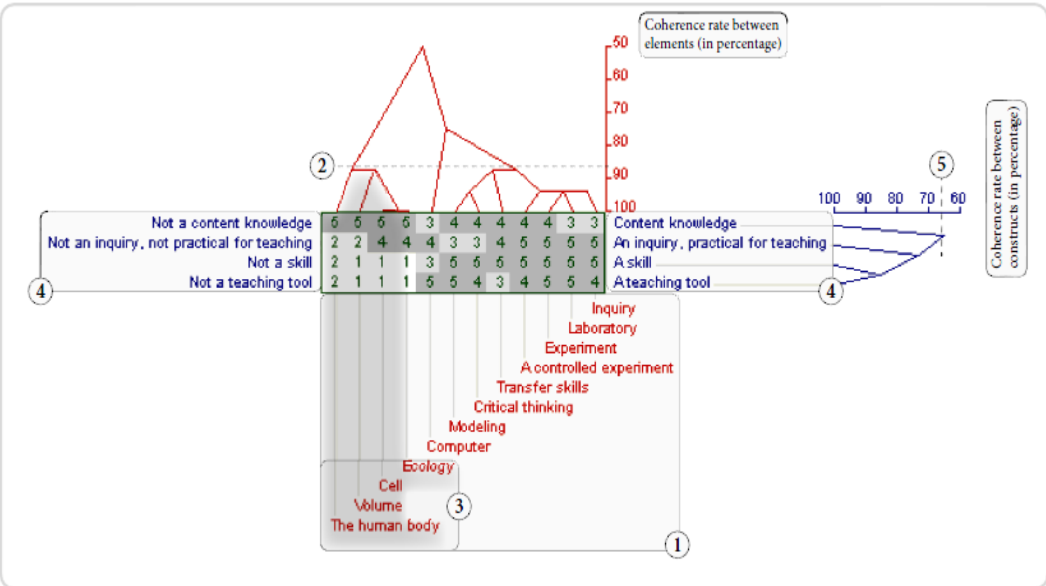

Figure 4: Analysis of Teacher A3's data using a repertory grid tree diagram (1) Elements; (2) coherence scale and its use in defining a group of elements (3) with more than 80% coherence; (4) constructs; (5) coherence scale and its use in defining coherence rate of the construct 'content knowledge' and other constructs (lower than 80% coherence)

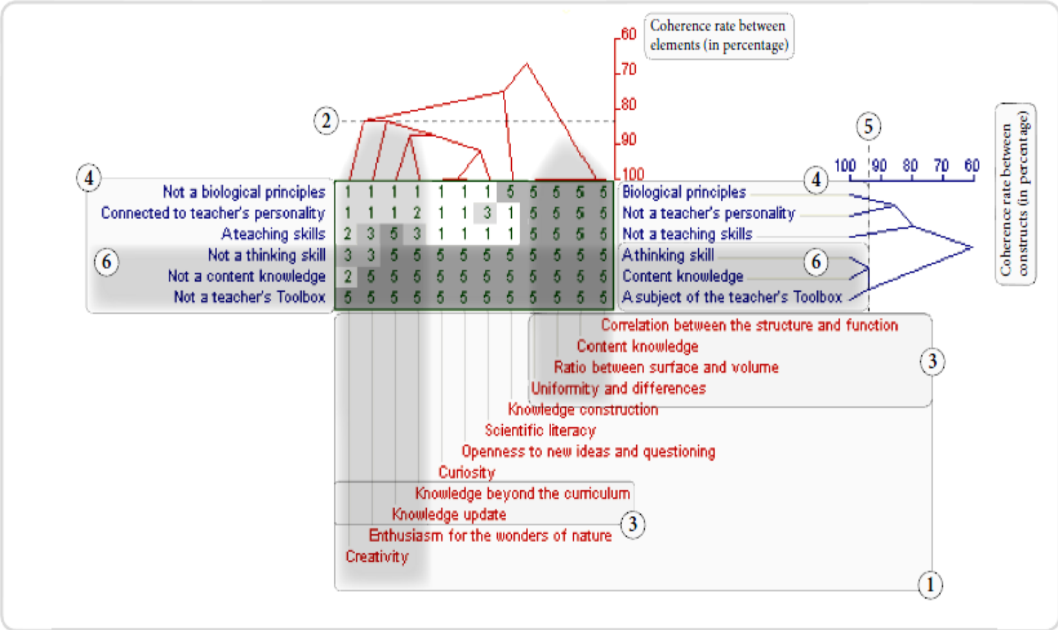

Figure 5: Analysis of Teacher A2's repertory grid tree diagram

(1) Elements; (2) coherence scale; (3) two groups of elements relating to CK with more than 80% coherence; (4) constructs; (5) coherence scale and (6) its use in defining more than 90% coherence between CK and other constructs

As mentioned above, connecting CK elements with other category's elements was rather rare. Most of the teachers did not connect CK elements with other category's elements. These results suggest that CK might form a separate group of elements within most of this research's biology teachers' knowledge structure.

The connections between content knowledge elements and the other elements are shown in Figure 6.

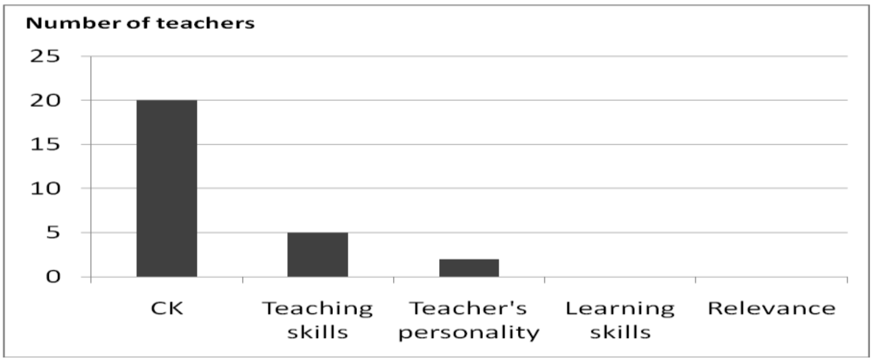

Figure 6: Number of teachers that connected content knowledge elements to different elements' categories

Analysis of constructs

A similar analysis was performed for the constructs formed by the teachers. The constructs that were defined in step 4 of the RGT are listed opposite each other (4, in Figure 4). The coherence rates between the constructs (in percentages) appear on the right side of the diagram (5, in Figure 4). The graph on the right shows the similarity rates between the constructs corresponding to the graph. For example, the construct 'content knowledge' is 65% similar to the other constructs (5, in Figure 4). This means that 'content knowledge' is a different and separate construct within Teacher A3's cognitive structure regarding biology teaching, since less than 80% similarity was identified between this construct and the others (following Kelly, 1969).

Similar analyses of the RGT data collected from each of the 20 teachers revealed that 15 of them (75%) elicited the CK construct during step 3 of the RGT (not shown, see Figures 4 and 5 for examples). Five teachers did not use the CK construct (step 3 in the RGT). Fourteen out of fifteen clusters that included CK constructs demonstrated CK as a separate construct with a low coherence rate (less than 80%) with the other constructs (for example, 5 in Figure 4).

Only one teacher, Teacher A2, connected the construct 'content knowledge' and the constructs: 'a subject of the teacher's Toolbox' and 'A thinking skill' with over 90% coherence (5 and 6 in Figure 5). Since I was the moderator of the workshop of all the biology teachers participating in this research throughout the program and a tutor for the final projects I was very familiar with the participating teachers. Therefore, I can conclude that Teacher A2 is unique in her approach to CK. This teacher designed a teaching program that included a lot of detail on protein structure. She holds the unique PCK that acquiring up-to-date biological CK is very important and very interesting and that it may motivate students to learn biology.

Taken together, the analysis of the elements elicited by each of the participating teachers and the analysis of the constructs suggest that by and large CK is a unique category of biology teachers' knowledge and that CK is not integrated as part of their PCK or as part of their professional knowledge.

In addition, it is worth noting that the RGT of the four teachers that served as the population of the explicit professional knowledge (Teacher B1, Teacher B2, Teacher B4 and Teacher B4) did not clearly reveal their unique PCK about teaching strategies and meaningful learning. For example, Teacher B1's explicit knowledge analysis revealed that she used high order thinking skills questions as a leading teaching strategy in order to facilitate knowledge construction (see section 6.1.3. pp.45-48). Implicit knowledge analysis of Teacher B1's cluster revealed that although she sorted the elements according to the construct thinking skills, it has low coherence with other constructs (less that 80%, see Figure 7). A clue about her unique PCK may exist in the correlation between the elements: 'students' critical thinking', 'inclusion and summary skills' and 'laboratory as a tool for developing thinking skills', but it is far from being clear that using high order thinking skills question as a teaching strategy in order to facilitate meaningful learning describes her unique PCK about teaching strategy and meaningful learning. Moreover, the explicit data analysis revealed that CK was hardly discussed by the teachers. Its importance to the teachers' practice emerged in the context of implicit knowledge analysis.

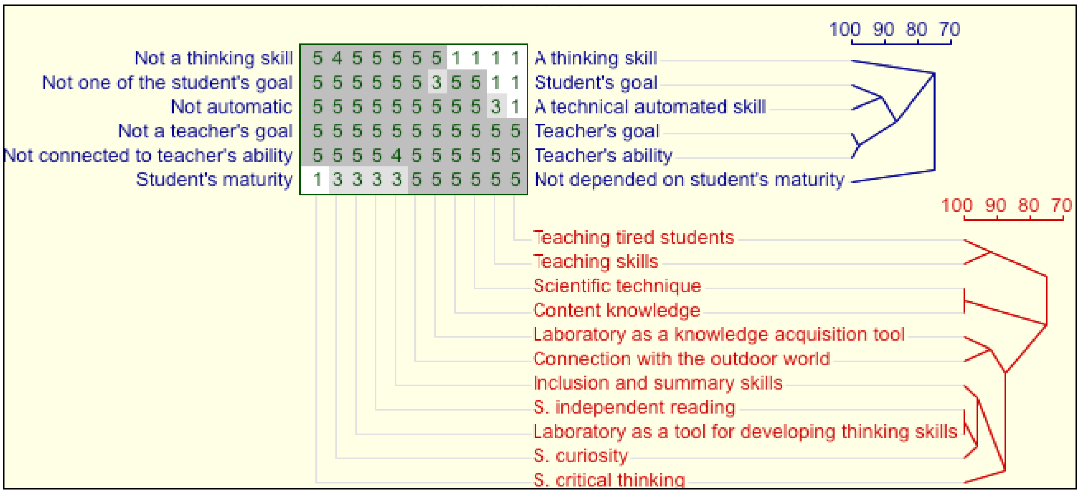

Figure 7: Analysis of Teacher B1's repertory grid tree diagram

6.2.3 The relationships between various science teachers' professional knowledge and their CK

In order to explore the relationships between professional knowledge and CK among teachers of other disciplines, the full RGT was also performed with chemistry (n=8), physics (n=9) and mathematics (n=13) teachers that participated in Path A of the "Rothschild-Weizmann program for excellence in science education" at the termination of the first or the second year of the program.

A close examination of each of the teacher's cluster revealed the similarities as well as the differences between clusters of teachers from different disciplines regarding the relationships between professional knowledge and CK as follows:

Mathematics teachers: All the mathematics teachers elicited CK elements (100%, Table 13). Most of the mathematics teachers' clusters (77%) showed high coherence between CK elements and elements from other categories (Table 13). Seventy seven percent of the mathematics teachers (10 teachers) connected CK elements with teaching skills elements, namely PCK elements (Figure 8) as follows: the ability of diverse teaching methods (7 teachers), construction of mathematical discourse (1 teacher), the ability to integrate means of demonstration (1 teacher), the ability to be accurate (1 teacher), and the ability to simplify knowledge (1 teacher). In addition, 31% of the teachers (4 teachers) showed high coherence between CK elements and learning skills elements, namely PCK elements (Figure 8) as follows: misconceptions (2 teachers), diversity of learning abilities (1 teacher) and accessibility to learners (1 teacher).

Physics teachers: Eight out of nine physics teachers (89%, Table 14) elicited CK elements. Four teachers (44%) connected CK elements to other professional knowledge elements (Table 13). These four teachers connected between CK elements and teaching strategies elements, namely PCK elements with high coherence (44%, Figure 8) as follows: the ability to perform nice laboratory activities (1 teacher); the ability to simplify knowledge (1 teacher), and teaching strategies (1 teacher) accessibility to learners (1 teacher). One physics teacher also connected a learning skills element: tools for independent learning namely, PCK element to CK element (11%, Figure 8). One teacher did not mention CK elements (11%, Figure 8).

Chemistry teachers: Four out of eight chemistry teachers (50%, Table 13) elicited CK elements. Two chemistry teachers' clusters showed high coherence between CK elements and elements from other categories (25%, Table 14). Two teachers (25%, Figure 8) connected between CK and the following teaching skills elements namely, PCK elements: diverse teaching strategies and diverse questions in class and in the exams. Another teacher connected between CK element and teacher's personality element (13%, Figure 8): serious. Two chemistry teachers did not mention CK elements (25%, Figure 8).

Data analysis of the constructs reveals that the majority of teachers in each discipline (between 63%-92%) sorted their elements with the construct CK, but in each discipline only 1 teacher connected between CK construct and other constructs (Table 13).

Table 13: Science teachers' number of CK elements and CK constructs and their connection to other elements or constructs

Number of elements or constructs / Discipline	Number of participating teachers	Number and percentage of teachers that elicited CK elements	Number and percentage of teachers that connected CK elements to elements from other categories	Number and percentage of teachers that elicited CK constructs	Number and percentage of teachers that connected CK constructs to constructs from other categories
Mathematics	13	13 (100%)	10 (77%)	12 (92%)	1 (8%)
Biology	20	20 (100%)	7 (35%)	15 (75%)	1 (5%)
Physics	9	8 (89%)	4 (44%)	7 (78%)	1 (11%)
Chemistry	8	4 (50%)	2 (25%)	5 (63%)	1 (13%)

Taken together, these results may imply that CK is a significant component of professional knowledge of all the science and mathematics teachers but that it has a special meaning to mathematics teachers' practice which may be different from its meaning to the other science teachers (physics, chemistry, or biology teachers). The mathematics teachers were the only group of teachers who largely connected CK to other categories of professional knowledge elements, especially to teaching strategies elements (Figure 8). This result stands in contrast to the biology teachers' results. While all the biology and all the mathematics teachers' elicited CK elements in the course of the RGT, the majority of the biology teachers separated the CK elements from other elements' categories, while the majority of mathematics teachers connected CK with teaching strategies elements (Figure 8).

In order to understand the special meaning of CK to mathematics teachers' practice, and especially to their teaching strategies, I conducted interviews with four of the mathematics teachers that their clusters showed high coherence between CK and teaching strategies elements.

Data analysis of interviews with the mathematics teachers who were asked to explain their views about the possible connections between mathematical CK and their teaching practice revealed that the courses with mathematical contents that they took during the program were very challenging for them. The courses' contents were not part of the themes that they teach in school and required a lot of complex exercises in mathematical problem solving. However, acquiring deep mathematical knowledge helped them to learn different ways of finding solutions to mathematical problem solving tasks, enabled them to be more accurate while teaching, and enabled them to understand a variety of thinking paths of their students, namely that there might be more than one solution to mathematical problems. Moreover, it enabled them to identify and deal with learning difficulties, more effectively. Thus, their studies in the mathematical courses enabled them to better understand the diversity of their students' cognitive procedures and apply different teaching strategies to meet the diversity of their students' learning paths. In addition, the teachers emphasized that the mathematics education courses focused on connecting the contents that were studied in the mathematics courses with their practice in class.

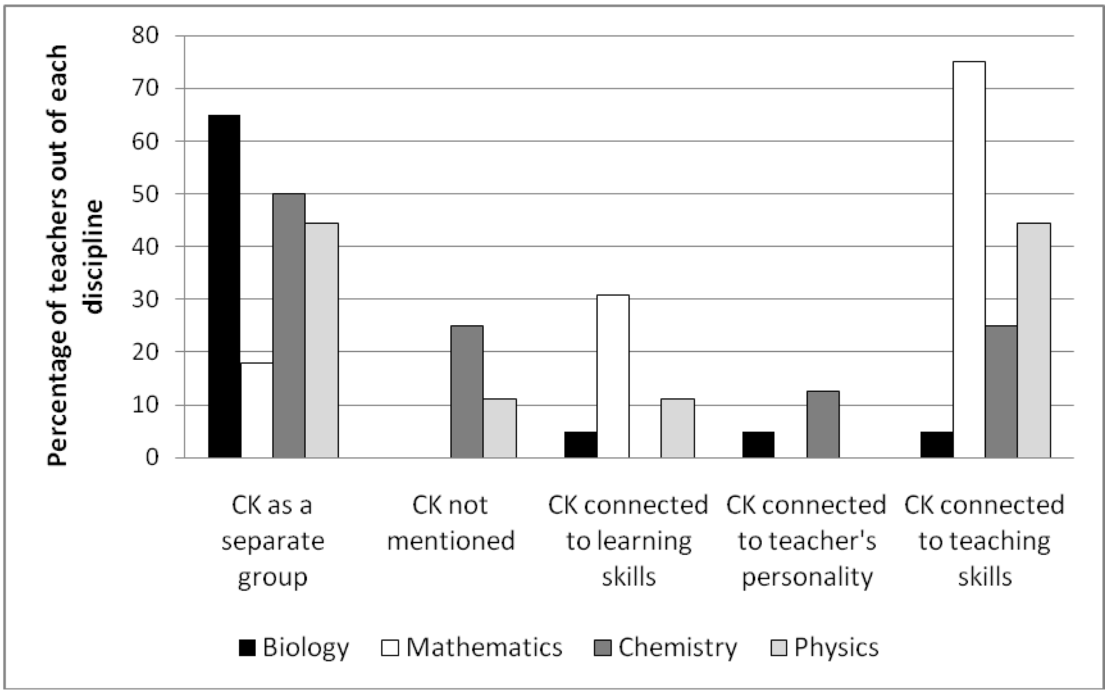

Figure 8: CK elements and their connections to other elements' categories in each discipline

Data analysis of a focus group conversation with six mathematics education researchers revealed that dealing with high level mathematical problems in the course of the Rothschild-Weizmann program challenged the teachers. That challenge may have made a dramatic shift in these teachers' status: from being an experienced teacher to a student with difficulties to understand and solve new problems. This shift in turn may enable the mathematics teachers to better understand their students' difficulties in solving new mathematical problems. Moreover, learning high level mathematical contents may enabled the teachers to understand mathematics at the conceptual level, and therefore may enabled them reorganize their knowledge to be more open to different solutions to mathematical problems and also may had caused them to be more creative in their teaching, using different teaching strategies in order to appeal to different learning styles.

To summarize, it seems that although mathematics teachers do not teach high mathematics contents in class their PCK can be meaningfully expanded by studying high level mathematics contents. In contrast, the biology teachers which have to stay updated with new researches and new findings in biology are very interested in acquiring new CK, but it was probably not the main cause for their PCK expansion.

7. Discussion

In this thesis I was able to show that in order to understand teachers' professional knowledge it is important to examine both their explicit as well as implicit knowledge. Examining teachers’ explicit professional knowledge revealed that the most frequently used knowledge components were teaching strategies and meaningful learning. Focusing on these two knowledge components revealed that teachers may hold different professional knowledge, namely they refer to the same components but interpreted them differently. Examining teachers' implicit knowledge revealed that CK is an important component of the teachers' professional knowledge. Biology teachers must acquire new biology subject matter CK throughout their entire teaching career because of the rapid development of knowledge in biology. Because of its importance for the biology teachers' practice, the Rothschild-Weizmann program included courses in biology with updated contents. Data analysis revealed that most of the teachers did not integrate the new subject matter CK acquired during the program into their practice. Moreover, while also other science teachers (physics and chemistry) showed a similar pattern of distinguishing CK from professional knowledge elements, the mathematics teachers were the only group of teachers who largely connected CK to other categories of professional knowledge elements, especially to teaching strategies elements.

For many teachers, professional development programs are an opportunity for professional renewal (Tytler, Symington, & Smith, 2009), whereby they become students themselves and thus engage their own existing knowledge in the course of acquiring new knowledge. The main means for professional development used in this study was the design of new teaching and learning materials. The rationale behind this approach was that by making use of the teachers' practical knowledge and concerns, supported by a commitment to their own views for improving science education in schools, along with the exposure to other teachers' knowledge and beliefs, teachers' professional development will be encouraged. The teachers who participated in this study gained new biological and science education knowledge, while being engaged in designing new teaching and learning materials on the basis of their existing knowledge, professional experience and needs. As such, the "Designing New Teaching and Learning Materials in Biology" workshop requirements combined newly acquired knowledge with the teachers' prior knowledge and it was therefore expected that the teachers' professional knowledge would further develop during the program.

In an effort to characterize the participating teachers' professional knowledge and its possible expansion, both explicit and implicit knowledge were examined.

Explicit professional knowledge

The explicit professional knowledge examination revealed seventeen teaching knowledge components that emerged from the data collected during the program. The components were grouped to three main knowledge domains: teaching, learning, and new materials design including their related components. Ten out of these seventeen components were identified as PCK components. This research broadens previous PCK representations. It focuses on a detailed representation of two main PCK domains: teaching and learning and their related components. This detailed representation revealed the complexity of the participating teachers' PCK and its expansion during a longitudinal professional development program and shed light on the teachers’ orientations toward teaching science.

Aligning the professional knowledge components that emerged during the course of this study with previously published PCK components and analyzing the frequency of appearance of each PCK component in the teachers' data (following, Chi, 1997), enabled me to pinpoint specific PCK components and their expansion in the course of the teachers' professional development program. The teachers participating in this study were found to relate mainly to two PCK components: teaching strategies and meaningful learning. This observation is similar to findings by Park et al. (2011), who stated that knowledge of students' understanding in science and knowledge of instructional strategies are positively related to the reform-oriented nature of instruction. Park et al. (2011) suggested providing teachers with opportunities to analyze students' understanding of a science concept and come up with teaching strategies to confront students' misconceptions and to meet their learning difficulties. Teachers' knowledge of students' understanding and of instructional strategies was suggested as critical in shaping the structure of teachers' PCK (Park et al., 2011). The context of this study, namely the "Designing New Teaching and Learning Materials in Biology" workshop that offered teachers the opportunity to design new teaching and learning materials and assess them in their classes, provided a special opportunity to discuss various teaching strategies and confront students' learning difficulties. The relatively high proportion of episodes in which the teachers related to teaching strategies and to meaningful learning, imply that the "Designing New Teaching and Learning Materials in Biology" workshop served as a meaningful platform for the assessment of these teachers' PCK. Although all of the teachers related at most to the same components, each teacher held a unique PCK about the teaching strategies and meaningful learning components.

The detailed PCK representation suggested in this study enabled me to carefully characterize the unique PCK about teaching strategies and about learning skills and track the development of each teacher's specific PCK. Moreover, the characterization of unique teachers' PCK about teaching and learning in this study might help better explain the orientation component, which is one of the five PCK components suggested by Magnusson et al. (1999). Orientation toward teaching science was defined as: "an over arching component that shapes, and is shaped by, the other four PCK components…a general way of viewing or conceptualizing science teaching" (Magnusson et al., 1999). Magnusson et al. (1999) explained that "these knowledge and beliefs serve as a 'conceptual map' that guides instructional decisions about issues such as daily objectives, the content of student assignments, the use of text books and other curricular materials, and the evaluation of student learning" (p. 97). This component was later reported to be unclear (Friedrichsen et al., 2011). After examining published studies using the term orientation relating to the PCK model, Friedrichsen et al. (2011) proposed defining science teaching orientation as: "an interrelated set of beliefs with the following dimensions: goals and purposes of science teaching, views of science, and beliefs about science teaching and learning." Following Friedrichsen et al.'s (2011) recommendation to track patterns of distinctly different science teaching orientation, I focused on one orientation dimension: knowledge and beliefs about science teaching and learning. I also followed Magnusson et al's (1999) point of view about the over arching characteristic of the orientation towards teaching science. As such I suggest the following definition of 'PCK orientation' for this thesis: 'knowledge and beliefs about the best characteristics of instruction that may promote meaningful learning'. Each teacher's orientation reflects on the unique instructional ways he or she uses, according to his or her believes about the best strategy for promoting meaningful learning.

The orientation definition suggested here enabled me to track for patterns of different orientations toward teaching and learning. Friedrichsen et al. (2011) suggested sorting through complex belief sets, and investigating orientations from multiangle points of view in order to allow comparisons that distinguish among different sets of teachers' beliefs. Here I describe how by tracking teachers' repeated explanations about teaching and learning, it is possible to determine each teacher's unique PCK orientation, thus clarifying and providing a practical meaning for the term orientation.

Following the analysis of the different PCK components of the participating teachers, I noticed that these teachers hold orientations that may be characterized according to different teaching and learning theoretical frameworks. Specifically, Teacher B1 probably holds a cognitive (following Greeno et al., 1996) orientation towards teaching and learning. Her unique knowledge and beliefs served as a "conceptual map" guiding her to use high-order thinking skill questions in order to scaffold her students' knowledge construction. That is, her PCK orientation is that the best learning occurs when the students construct their knowledge with the help of their teacher's scaffolding questions. During the design workshop, Teacher B1's PCK orientation became more sophisticated, leading her to add requirements for high-order thinking skills to her lessons as well as to the new teaching and learning materials she designed during the workshop.

Teacher B2 probably holds a behaviorist (following Greeno et al., 1996) PCK orientation towards teaching and learning. This suggestion is based on Teacher B2's use of interesting stories to elicit emotional feelings that might increase her students' motivation to listen to her and may lead them to long-term recall of the biological contents. Teacher B2's PCK orientation is that the best learning occurs when the student is stimulated by interesting stories. During the initiatives workshop, Teacher B2 started to examine her students' cognitive structures, and tried to avoid the occurrence of misconceptions among her students during her lessons. Although she did not neglect her leading behaviorist orientation, a cognitive dimension was added to her practice.

Teacher B3 probably holds an a socio-cultural (following Greeno et al., 1996) orientation towards teaching and learning, one that emphasizes the connection between biological contents that have been learned in class and relevant social aspects from the students' everyday lives, such as legal, religious and ethical aspects. Her PCK orientation is that the best learning occurs when the students succeed in connecting the contents that are learned in class with everyday social life experiences. During the design workshop, Teacher B3 dedicated time to supporting her students' deep understanding of biological contents, adding high-order thinking skill questions, and thus added a cognitive dimension to her sociocultural orientation.

Analysis of the data from Teacher B4 did not reveal a leading PCK orientation. She was the least experienced teacher participating in this research. She reported on difficulties in her practice in class and also experienced difficulties in designing her teaching and learning materials during the workshop. This lack of leading PCK orientation may imply that Teacher B4 had not yet found her "comfort zone" in teaching, which caused her teaching difficulties in class. At the end of the program, she reported on a new teaching strategy that she had used in class which satisfied her and her students. Thus, this positive experience might have induced further expansion of her PCK.

PCK orientations do not change over time but they are capable of expansion and may become more sophisticated. The term expansion stands in contrast to the term change to emphasize our understanding that the teachers' PCK orientation does not change but rather expands to a more sophisticated one. The expansion of each teacher's unique PCK orientation during the "Designing New Teaching and Learning Materials in Biology" workshop was driven by the need to examine different teaching strategies and learning abilities while designing the new teaching and learning materials. As a result, the teachers read materials developed by others and discussed the ideas with them with the help of the workshop moderators. This, in turn, led to exposure to other teachers' orientations, which might have facilitated the expansion of their own PCK orientation. The teachers and moderators served as a community of practice in which points of view were formulated and defended, listened to and evaluated by others (Vygotsky, 1978). The expansion of the teachers' orientations probably took place within their zone of proximal development (Vygotsky, 1986), and assisted them in expanding their own PCK orientations. In addition, the teachers reported that they were influenced by some topics discussed in other courses given in the program. As a consequence, their PCK orientation expanded and the teachers implemented new activities in their designed teaching and learning materials and incorporated them into their practice.

Each teacher was influenced at different stages and by different activities during the first three stages of the workshop, while all four teachers experienced meaningful expansion of their PCK during the final stage (stage 4). In this last stage, the teachers finished the implementing and analyzing their new teaching and learning materials in their classes and were asked to think about ways of distributing their materials to other biology teachers who had not participated in the program. It seems that reflecting on the experience of designing, implementing and assessing their projects made a significant contribution to their PCK expansion. This was also the stage at which they became aware of the differences between their PCK and were asked to relate to different teachers' PCK while explaining their teaching and learning materials to large and diverse teachers' groups in order to distribute them.

Retention of major parts of the expanded PCK a year following the termination of the program implies that designing and implementing new teaching and learning materials accompanied by biology and science education courses might provide a powerful means for PCK expansion.

Implicit professional knowledge

The uniform patterns of professional knowledge also emerged in the course of the analysis of the tacit dimensions of teachers' professional knowledge. It was George Kelly (1955) who first argued that people have different views towards events in the world. These views are organized uniquely within each person's cognitive structure which is tacit and as such difficult to examine. Investigating the interrelationships between various professional knowledge components may shed additional light on the nature of PCK and its role in teachers' practice (Abell, 2008; Friedrichsen et al., 2011; Park et al., 2011). Here I examined the possible tacit relationships between CK and other professional knowledge components of biology teachers by means of full RGT and showed that CK is by and large not integrated as part of their PCK. This finding indicates that CK should not be considered as an integral part of biology teachers' PCK, as suggested by Lee and Luft (2008) and others (Ball et al., 2008; Hill, 2008), but can be considered as a separate entity, as suggested by Shulman (1986, 1987).

A group of 20 high-school biology teachers were asked to intuitively elicit knowledge elements that refer to biology teaching practice. Intuitive elicitation of elements is important because the elements come from the teacher's cognitive structure with minimal impact from the researcher (Bezzi, 1999; Fransella et al., 2004; Henze, Van Driel et al., 2007; Jankowicz, 2004). The elements of biology teachers' knowledge that were intuitively elicited in the course of this research raise three major issues: (i) knowledge is personal (following Kelly, 1955) in the sense of biology teaching. Appealing to the biology teachers' tacit knowledge, I found that 65% of the elements that were elicited by the teachers were unique. Each teacher who participated in this research thus possesses a unique repertoire of what he or she considered as important knowledge elements, and these elements are uniquely distributed among the element categories in each teacher's cognitive structure. This result reinforces the conclusion of this thesis that biology teachers are a heterogeneous group with respect to their professional knowledge. This may also emphasize the importance of considering diverse knowledge about teaching and learning during planning professional development programs (Rozenszajn &

Yarden, 2011) ; (ii) knowledge is socially distributed (following Collins et al., 1989). Pooling together all of the elements that were elicited by the various teachers demonstrated the variety and large scope of knowledge within the area of biology teaching, thus emphasizing this thesis conclusion about the importance of sharing knowledge between teachers during professional development programs such as the workshop that served as the context of this thesis; (iii) CK is an important factor of biology teachers' professional knowledge. Of all of the elements that were elicited by the teachers, CK was the only element that all the teachers mentioned. In addition, my analysis revealed that the CK category of elements was the most variable and the most frequently mentioned category by the teachers in the course of implicit knowledge analysis. Although the cognitive structure of the teachers is variable, the relatively high frequency of elicitation of CK elements within all the teachers' data suggests that CK is an important factor in these teachers' knowledge for practice (following Fernandez-Balboa & Stiehl, 1995; Marks, 1990).

The analysis of CK constructs reinforces the conclusions regarding the analysis of CK elements. Constructs regarding teaching are the ways teachers make sense of their practice. Constructs are frequently expressions of intuitions, "gut feelings", and perceptions which the individual uses as a guide to action (Bjorklund, 2008). The fact that all the biology teachers chose to elicit CK elements and that 75% of them sorted the elements using a 'CK' construct reinforces the idea that CK is an important factor in biology teachers' practice. But is CK an integral part of teachers' PCK or is it an independent knowledge type? This question has been vastly discussed in the literature (Fernandez-Balboa & Stiehl, 1995; Grossman, 1990; Krauss et al., 2008; Lederman & Gess-Newsome, 1992; Loughran et al., 2008; Magnusson et al., 1999; Marks, 1990; Shulman, 1987) and the debate continues. Analysis of the repertory grid data revealed that the biology teachers' CK was in most cases a different component of knowledge, distinct from other professional knowledge components of these teachers, including their PCK. The coherence rate of CK elements with other elements was low, less than 80% on average. Seven teachers connected CK elements to elements that describe teaching skills. This might imply that although CK forms a different knowledge group in the RGT, there are teachers who consider CK as an important part of their PCK. Therefore, these teachers hold a model of knowledge in which content and pedagogy are integrated and transformed into practice (Gess-Newsome, 1999; Krauss et al., 2008). It is possible that these teachers did integrate their CK with PCK following their learning in academic biology courses and science education courses during the professional development program that they had participated in (Krauss et al., 2008), while the other teachers did not assimilate new CK into their existing PCK. One possible explanation for not integrating newly acquired CK into practice may lie in the fact that some teachers need to be encouraged to assimilate new CK into their practice. Another possible explanation may be that different teachers hold different PCK orientations. Some teachers believe that teaching and learning biology should be mainly based on subject matter CK, while others believe that teaching and learning biology should depend on cognitive procedures such as encouraging high order thinking skills (Rozenszajn & Yarden, 2011). It depends on each teacher's PCK orientation.

Data analysis of various science and mathematics repertory grids points that acquiring subject matter CK during professional development programs may differently influence teachers from different disciplines. While a few biology, chemistry and physics teachers gain from the CK courses especially the ability to better demonstrate knowledge, the majority of mathematics teachers reported that they developed their teaching strategies during the CK courses in mathematics. Researchers report that mathematics teachers with an in-depth mathematical training exhibit a higher degree of cognitive connectedness between CK and PCK (Krauss et al., 2008). The breath, depth, and flexibility of teachers' understanding of the mathematics they teach afford them a broader and a more varied repertoire of teaching strategies (Ball et al., 2008; Baumert et al., 2010; Even, 2011; Krauss et al., 2008), while limited CK has been shown to limit the scope of PCK development (Baumert et al., 2010). It has been suggested that the degree of cognitive connectedness between CK and PCK among secondary mathematics teachers is a function of the degree of mathematical expertise (Krauss et al., 2008). The advanced mathematics courses can serve as a resource (i) for teaching secondary school mathematics; (ii) for improving understanding about what mathematics is; and (iii) for reminding teachers what learning mathematics feels like (Even, 2011).

In order to explain the differences in the influence of CK on PCK between the mathematics teachers and science teachers, it is possible to assume that either the mathematics education courses stressed the connection between CK and PCK while the other disciplines' courses did not stressed this connection, or that there are differences between the characteristics of each discipline. This is an issue for further examination. However, the main conclusion from the fact that mathematics teachers may differ from science teachers regarding the connection between CK and PCK is that when discussing the question about the place of CK in the teachers' practice we should consider the differences between the various disciplines and discuss it referring to each discipline separately because of the unique characteristics of each discipline.

Taken together, in the course of explicit professional knowledge categorization, CK was one of the professional knowledge components that the teachers elicited. Data analysis revealed that CK was mentioned only a few times in the teachers' discussions. In addition, after aligning the professional knowledge components with PCK components that appear in the literature I revealed that most researches do not refer to CK as a PCK component. Therefore, I did not track and analyze CK while examining teachers' explicit professional knowledge. Nevertheless, CK was largely elicited in the course of implicit data analysis. Implicit data analysis revealed that by and large CK is indeed distinguished from PCK. However, there is no clear correlation between each teacher's repertory grid's cluster and his or her PCK orientation. The clusters' analysis did not clearly showed the teachers' PCK orientations, but rather showed meaningful connections or disconnections between different elements or different constructs. That result reinforces the conclusion that in order to examine teachers' professional knowledge comprehensively, science education researchers should examine both explicit as well as implicit knowledge.

8. Implications

One of the basic biological principles is: uniformity and diversity in the living world. This thesis can be framed around the same idea. Teaching biology in Israel is dictated by a national syllabus, standards and requirements and all the high-school biology teachers teach almost "the same" biology. Although teaching biology is a uniform profession, each in-service high-school biology teacher holds a unique experience and a unique set of professional knowledge and beliefs which shape his or her teaching style to be as effective an educator as possible (Heimlich

& Norland, 2002). The uniqueness of each biology teacher's professional knowledge enabled to expose her unique orientations towards teaching and learning. That is, each teacher has a unique PCK orientation about the best characteristics of instruction that may induce meaningful learning. Moreover, although all the participating biology teachers share the idea that acquiring updated biology subject matter CK is of major importance, it seems that the new CK was not integrated within most teachers' practice. These differences challenge professional program developers to design programs that suit diverse PCK orientations of their target audience. Therefore, being aware of the diversity of biology teachers' PCK orientations and of the role of CK in their practice should be of main concern.

In order to appeal to each teacher's cognitive structure and minimize rejection of newly acquired knowledge (Postholm, 2008a), that does not correspond with the individual's existing construct (Von Glasersfeld, 1989), we were aware of the unique PCK orientation held by each teacher while designing and guiding the workshop that served as the context of this thesis. For example, while discussing the design of the new teaching and learning materials, we emphasized points related to each teacher's orientations in order to apply them to his or her cognitive structure. In addition, the teachers discussed the implementation in a group that obviously included other teachers with different PCK and different orientations. The meeting of the different PCK orientations allowed the construction of new knowledge within the zone of proximal development (Vygotsky, 1986) of each teacher's unique cognitive structure. The exposure to other teachers' orientations enabled the teachers to improve their design of teaching and learning materials, while further improving their teaching practice and subsequently expanding their PCK.

It is recommended that program designers also focus on helping teachers that do not yet established orientation to establish one. This is a subject for further research, which might provide a better understanding of the influence of professional development programs that focus on designing new teaching and learning materials suggested by the teachers themselves, on improving novice biology teachers' PCK and practice.

In addition, an examination of the "New Materials Design" domain could potentially reveal additional important factors that might challenge teachers' current knowledge and beliefs about teaching and learning science. This, in turn, could push teachers to explore ways to learn about, experiment with, reflect on, and share information on learning and teaching in the context of implementing new curriculum materials with colleagues (Bybee et al., 2003; Tytler et al., 2009).

Another aspect of biology teachers' professional knowledge is the role of CK in the biology teachers' practice. Professional development designers should not ignore subject matter CK, which is a very important domain of biology teachers' professional knowledge, especially because of the rapid advance of biological knowledge. The biology teachers that participated in this study were selected on the basis of high academic achievements and on their potential to become teacher leaders. Still, most of the teachers' although reporting on the high importance of the courses in biology, did not integrate CK into their practice and new materials design. Thus, professional development programs should consider promoting the connection between biology teachers’ CK and PCK instead of assuming that increasing CK will automatically improve PCK. Moreover, it is likely that even if teachers do link between CK and PCK to some degree in their practice it is important to bring to mind the ability to recognize this link and articulate it during professional development programs, such as designing new teaching and learning materials. Making the tacit link explicit may further promote teachers' professional development. The question of what is the added value of the assimilation of new CK into biology teachers' PCK is a subject for further discussion.

I realize that although the results may imply that by and large the participating biology teachers did not connect CK to other professional knowledge dimensions, including PCK, it is possible to assume that the RGT failed to reveal some hidden links in the teachers' cognitive structure. Therefore, further research which will employ various methods, including class observations, and a larger investigated teachers' population should be carried out in order to answer the subject in question, which subsequently may help to design effective professional development programs.

The variety of teachers' professional knowledge reinforces the idea that investigating teachers' knowledge should be based on both explicit data as well as on implicit data. In this thesis I showed that while investigating explicit data various teachers' orientations towards teaching and learning emerged, investigating tacit knowledge enabled to show another aspect that is of major importance for teaching knowledge: the possible links between CK and PCK. Because of the complexity of teachers' professional knowledge, science education researchers should consider employing various methods that can probe both explicit and implicit knowledge in order to better understand in-service high-school teachers' professional knowledge.

The main contribution of this research is the idea that in-service high-school biology teachers, which may be regarded as a uniform population of teachers that may have in fact some uniform professional knowledge components, diverse in their PCK orientation towards teaching and learning biology. Therefore, educators should consider designing professional development programs that relate to various PCK orientations in order to achieve meaningful professional development. Guidance in these programs should be more personal and appeal to each teacher unique knowledge. That is, professional development designers should consider referring to the biology teachers' population as having both uniformity and diversity and encourage the meeting between the differences of biology teachers' PCK orientations in order to enable the evolution of each teacher's own professional knowledge. In addition, professional development designers should not neglect the missing links between CK and PCK which may further promote biology education.

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Appendices

Appendix 1

Outline of the daily professional development program of Path A and Path B teachers that ran for two academic years (during 2008–2012).

Semester	Periods in a day	Course title Path A - day 1	Course title Path A - day 2	Course title Path B
1	1-2	Selected issues in molecular biology	Laboratory activities for microbiology teaching	Laboratory activities for microbiology teaching
	3-4	Bioinformatics	Developing learning materials	Designing new teaching and learning materials in biology
	5-6	Neurophysiology	Seminar	Designing new teaching and learning materials in biology
	7-8	Seminar	Introduction to science education	Introduction to science education
2	1-2	Developmental biology	Experiencing contemporary research in the life sciences	Experiencing contemporary research in the life sciences
	3-4	Bioinformatics	Developing learning materials	Designing new teaching and learning materials in biology
	5-6	Cellular biology	Seminar	Designing new teaching and learning materials in biology
	7-8	Self-learning	Cognition, learning and instruction	Cognition learning and instruction
3	1-2	Biochemistry of proteins	Stem cell biology	Stem cell biology
	3-4	Designing new teaching and learning materials in biology	Assessment and measurement methods in science education research	Designing new teaching and learning materials in biology
	5-6	Designing new teaching and learning materials in biology	Interdisciplinary seminar	Designing new teaching and learning materials in biology
	7-8	Scientific writing	Learning and instruction in biology teaching	Selected topics in teaching and learning biology
4	1-2	Plant biology	Selected topics in ecology	Selected topics in ecology
	3-4	New teaching and learning materials - workshop	Journal club—science education articles	Designing new teaching and learning materials in biology
	5-6	Designing new teaching and learning materials in biology	Interdisciplinary seminar	Designing new teaching and learning materials in biology
	7-8	Seminar	Integration of learning technologies	Integration of learning technologies

Each period lasted approximately 45 minutes with two 15- to 30-minute breaks during the day.
White = biology courses, Gray = science education courses.

Appendix 2

Rozenszajn, R., & Yarden, A. (2011). Conceptualization of in-service biology teachers' pedagogical content knowledge (PCK) during a long term professional development program

In A. Yarden & G. S. Carvalho (Eds ,(.Authenticity in biology education: Benefits and Challenges: A selection of papers presented at the 8th Conference of European Researchers in Didactics of Biology (pp. 79-90). Braga, Portugal.

Abstract

A case study of four in-service biology teachers revealed the possible relationship between pedagogical content knowledge (PCK) and the professional development process during a long-term course. Here we suggest a potential assertion of PCK components which enabled us to characterize a significant one: teaching strategies. Teachers in this study paid major attention to their unique teaching strategies in both their practice and their initiative development. The teaching strategies conception was found to be consistent and resistant to change. The teachers expanded their conception of teaching strategies over the course of the professional development program and developed their initiatives accordingly. We recommend that professional development designers be aware of this PCK component and find means of expanding it for better performance.

Keywords: pedagogical content knowledge (PCK); professional development; teaching strategy; conception; initiative

1. Introduction

A new program aimed at expanding science teachers' knowledge and empower them to improve science education in Israel was established at the Science Teaching Department of the Weizmann Institute of Science during the 2008-09 academic year. The new long-term program provides resources and professional support for knowledge expansion in both science and science education. Its main outcomes are designing and implementing initiatives to improve the teaching of science in high schools in Israel. The rationale for the biological part of this program lies in designing initiatives that are based on teaching needs as stated by the biology teachers themselves. This program addresses biology teachers' will, experience and knowledge, based on the well-known fact that teachers are an important resource for the implementation of changes in schools (Magnusson et al., 1999; Parke & Coble, 1997; Tytler et al., 2009; Van Driel et al., 2001).

Experienced teachers bring with them a unique teaching knowledge, termed pedagogical content knowledge (PCK) (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran et al., 2008; Magnusson et al., 1999; Shulman, 1986). Many researchers have indicated that teachers' PCK guides their actions in teaching specific content in class (Lee & Luft, 2008; Magnusson et al., 1999; Van Driel et al., 2001; Van Driel, De Jong, & Verloop, 2002). However, little is known about the connection between biology teachers' PCK and the process of professional development in the course of developing initiatives in biology education—the focus of this study. As such, the study is based on the theoretical frameworks of PCK and professional development, which are briefly discussed in the following.

1.1 Teachers' knowledge base: PCK

Teachers and researchers agree that special knowledge is acquired by teachers during their teaching career. It was Shulman (1986) who first suggested referring to this knowledge as a special knowledge domain, the PCK. Researchers agree upon the nature of PCK as an integration of knowledge, skills and beliefs, acquired through teaching, and used in the context of teaching a specific content (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran et al., 2008; Magnusson et al., 1999).

In an effort to analyze the PCK concept, researchers have variously categorized it, resulting in eight major categories of conceptualization (Lee & Luft, 2008; Park & Oliver, 2008b; Van Driel et al., 1998): 1. *knowledge of subject matter*; 2. *knowledge of representations and instructional strategies*; 3. *knowledge of student learning and conceptions*; 4. *knowledge of general pedagogy*; 5. *knowledge of curriculum and media*; 6. *knowledge of context*; 7. *knowledge of purpose* (some researchers refer to this component as *orientation toward science teaching and learning*); 8. *knowledge of assessment*.

PCK relates to teachers' knowledge, i.e. their professional knowledge base. This knowledge base refers to two different kinds of information: *knowledge* and *beliefs*. Knowledge refers to information that is certain, solid, dependable, and supported by research. Beliefs are what we think we know or may be coming to know based on new information; they are supported by experience, and people are strongly committed to them (Loucks-Horsley et al., 2003).

Beliefs about the teaching practice are described in the literature in various ways (Van Driel et al., 2007). In the literature on teachers' PCK, the term *orientation* toward teaching science is related to teachers' ideas about which subject matter is important to teach, and thus influences the choices teachers make in their teaching (Cohen & Yarden, 2009; Gess-Newsome, 1999; Magnusson et al., 1999; Van Driel et al., 2007). Teaching beliefs, from a constructivist perspective, are regarded as *conceptions* about the nature of science, scientific concepts, and how to learn and teach them (Da-Silva et al., 2006). Experienced science teachers have teaching conceptions that have been consolidated by their own professional experience, and these are usually stable and resistant to change. Sometimes this is because they feel satisfied with their teaching conception, and there is coherence between their goals, their conceptions, their educational practice and their perception of their students (Da-Silva et al., 2006); other times this may be because the conception is associated with a positive mood or because it was critical to the individual's survival (Sinatra & Mason, 2008).

Teachers' knowledge and beliefs inform the choices they make in terms of professional development (Loucks-Horsley et al., 2003), and may inform the designers of professional development programs on factors that they have to take into account while designing the programs.

1.2 Professional development

Teachers are able to take what they have learned from a professional development course and incorporate it into an ongoing program in the subject covered by the course. This places teachers' professional learning at the very center of what can be gained from such programs (Tytler et al., 2009). On the other hand, most subject-matter courses in teacher education programs are viewed by teachers as having little bearing on the day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball et al., 2008). There are no guidelines for which designs are right in a particular situation.

It is assumed that teachers need knowledge and skills to enhance the effectiveness of professional development programs and their ability to adapt to possible changes in their teaching. The concept of change itself denotes a "disruption in the status quo". Individuals possess a natural tendency to remain in a steady state, so any changes that disrupt this are viewed with caution and are only accepted if the perceived outcomes add value to the individuals (Hanley et al., 2008). It has been suggested that effective professional development programs should engage the teachers' knowledge and experience in decision-making for new curriculum and instructional issues as they reflect the connection between theory and practice (Parke & Coble, 1997). The professional development program examined in this study shifts the focus from teacher-training workshops, aimed at implementing curricula developed by others and sometimes removed from the teachers' experience, knowledge and beliefs, to promotion of the teachers' professionalism as curriculum developers. Promoting teachers' professionalism with acquisition of academic knowledge and participation in collaborative workshops may empower them to become more thoughtful about their profession (Parke & Coble, 1997). However, the process is rather complex, one reason being the importance of teachers' PCK base and its relation to the professional development program. Thus, the process of teachers' empowerment within a long-term professional development program is not straightforward.

The professional development program examined in this study was designed to help in-service teachers expand their knowledge in biology and biology education through designing initiatives that could be incorporated in the biology classroom. The ability to design and implement various types of science teaching initiatives that will be aligned with teachers' different PCK and students' different cognitive abilities and learning styles is seen as an important component in professional development (Hofstein et al., 2003). Thus, this study's major objective was to characterize the possible changes in in-service biology teachers' PCK during the course of a long-term professional development program.

The specific research questions were:

1. What are the PCK components of the four biology teachers who participated in the program?
2. How do the various PCK components of these four teachers develop during the course of the program?
3. What are the relative proportions of PCK components related to teaching aspects in each of the four teachers?
4. How do the teaching strategy conceptions of each participating teacher develop over the course of the program?

2. Research design and methods

2.1 Research context

This research focused on four in-service biology teachers participating in a special professional development program established at the Weizmann Institute of Science. The main rationale of this program is to use the participating teachers' teaching knowledge, both scientific and educational, and experience to mutually design advances in the high-school biology program in Israel. The program's curriculum ran for eight hours weekly over the course of two academic years (Table 1). Each semester, the teachers participated in a different subject matter-oriented course in biology followed by a curriculum development course aimed at developing initiatives that might enhance biology teaching and learning in Israel. The course was named: "Initiatives development in biology". At the end of the day, the teachers participated in a basic science education course. The first author of this study was one of the instructors of the initiatives development course.

Periods	Course type
1-2	Biology course
3-6	Initiatives development course
7-8	Science education course

Table 1. Daily outline of the professional development program. Each period lasted approximately 45 minutes with two 15- to 30-minute breaks during the day.

2.2 Sample

Of 27 biology teachers who submitted applications, five were selected to join the program, based on academic achievements, excellence in the teaching realm and motivation to develop initiatives. One of the five teachers missed numerous lessons in the first year and chose not to participate in the second year. Thus, this study focused on four teachers who fully participated in the professional development program. All teachers had M.Sc. degrees in biology and their teaching experience ranged from 6 to 17 years at the beginning of the program.

2.3 Research design

This study addressed the process of the teachers' professional development and the possible relations with specific PCK components during the course of initiatives development. Data were collected from multiple sources:

1. recorded lessons from the initiatives development course
2. recorded conversations about designing the initiatives and the participating teachers' reflections
3. e-mail correspondence between the teachers and researchers
4. the participating teachers' written assignments which were handed in to the initiatives course instructors
5. recorded presentations of the initiatives to other teachers
6. interviews with the program participants at the end of each year.

The data from the various sources were analyzed chronologically, according to the four phases of the course.

Phase 1: Eliciting prior knowledge and background. Conversations about teachers' dreams, teaching goals and the first meeting with the chief supervisor of biology education in Israel, assignments and e-mail correspondence about the teachers' professional background, expectations from the program and general ideas about initiatives in biology (Aug-Nov 2008).

Phase 2: Planning the initiatives. Lessons, conversations, assignments, e-mail correspondence, and initial presentations of ideas for initiatives and of preliminary

parts of the initiatives to the group members, researchers in science education and the chief supervisor of biological education in Israel (Dec 2008-Feb 2009).
Phase 3: Assessing the initiatives. Lessons on initiatives assessment, reflective conversations about poster presentation of the initiatives, e-mail correspondence, questionnaires and interviews about the teachers' experiences after teaching and assessing a preliminary part of their initiative in class (Mar-Jul 2009).
Phase 4: *Writing and distributing the initiatives* to other teachers, researchers and science education students. Lessons on writing a teacher's guide, presentations of the initiatives, conversations, assignments, e-mail correspondence, and interviews with the participating teachers at the end of the program (Oct 2009-May 2010).

2.4 Data analysis

The groups' discussions, interviews, relevant e-mails, assignments, activities and lessons were fully transcribed. The data were divided into different episodes, which were classified according to their theme. We initially analyzed the PCK components according to the taxonomy suggested by Lee and Luft (2008), who summarized the main PCK categories appearing in the current literature, but we had difficulty aligning our data with a few of their categories. We therefore performed a qualitative analysis according to Shkedi (2003) and Chi (1997) and allowed categories of teachers' PCK to emerge from the data. The following steps were taken:
1. We read the transcripts several times and searched for recurrent categories and ideas as recommended by Shkedi (2003). Then the following four steps were taken: (i) forming primary categories from the collected data; segmenting the data into units, and categorizing every unit according to its content; (ii) developing more general domains; (iii) mapping all data according to the chosen domains; (iv) reorganizing the data according to the chosen domains. We then proposed assertions about the teachers' PCK components, and their possible relations with the teachers' professional development while designing the initiatives.
2. We attempted to capture the representations of the teachers' PCK as they were expressed in the data and to determine how those representations change with knowledge acquisition and actions, following Chi (1997). The verbal analysis added a quantitative dimension to our qualitative analysis.

Our assumption that the above methods would be successful in capturing the teachers' PCK components, although the data were not based on observations of the teachers' practice, is based on Van Der Valk and Broekman's (1999) "lesson preparation method" study. Those authors reported that this method is successful in the sense that teachers produce "rich" information about their PCK while reporting on their lesson design and teaching.

To validate the results, data were analyzed by the first author at two time points, six months apart. In addition, data were presented to five researchers in science education for peer validation twice during the data analysis. The first peer validation was used to examine the identity rate between the suggested PCK domains and their related components. The mean identity rate between the five researchers and the suggested classification of the three PCK domains and their related components was 92.3%. The identity rate of the "teachers' world" alone was 97.1%, the identity rate of the "students' world" alone was 83.3% and the identity rate of the "initiatives' world" alone was 96.6%.

The second peer validation examined the suggested analysis of the possible changes in the teachers' PCK along the program. Twenty-five episodes were given to three science education researchers who were asked to classify each episode according to the suggested PCK classification. The overall validation rate was 85.6%. Moreover, interviews were used for interpretive validity with the participants following the analysis of the teachers' PCK change. The relevant results on PCK dynamics were presented to each teacher, who were asked to express their opinions on the accuracy of the results. The validation rate was 94%.

3. Results

3.1 PCK components of the four teachers from the program

The teachers' PCK components were analyzed from the bottom up according to Shkedi (2003). Nineteen PCK components emerged in the course of this analysis, and were grouped into three main domains: teachers' world, students' world and initiatives' world (Figure 1). The components are numbered chronologically and described in detail below:

1. *Knowledge and beliefs about the teachers' world*, namely, about teaching science. This includes knowledge and beliefs about: i) difficulties in biology teaching; ii) the personnel that accompany the teaching (e.g. school principal or chief supervisor of biological education); iii) assessment of related contents; iv) teaching strategies; v) subject matter; vi) curriculum; vii) available teaching facilities.
2. *Knowledge and beliefs about the students' world*, namely, about students' learning processes. This includes knowledge and beliefs about: viii) students' prior knowledge; ix) students' thinking skills; x) students' motivation to learn science; xi) means to promote students' meaningful learning; xii) students' interest outside of the school context; xiii) the influence of science learning on students' future life.
3. *Knowledge and beliefs about the initiatives' world*, namely, about the process of development, assessment and distribution of initiatives. This includes knowledge and beliefs about: xiv) writing useful teachers' guide materials; xv) the process of initiative development; xvi) personal feelings during the development process; xvii) modes of assessing initiatives; xviii) means of distributing initiatives; xix) possible collaborations during initiative development.

Most of the above PCK components have strong correlations with the categories suggested in the literature. The initiatives' world contains components that are very specific to initiative development and thus may not be adequately correlated to the literature categories.

Figure 1. The three main domains of PCK emerging from this research.

3.2 Changes in the teachers' PCK components during the course of the program

To reveal possible changes in the four teachers' PCK during the course of the program, we examined the research data according to the four phases of the course. Initially, we asked the teachers, in various ways, to describe their work, in order to capture the teachers' PCK prior to their learning in the initiatives program. In the three subsequent phases, we looked for possible changes in the teachers' PCK during the program and during the development of their initiatives.

Verbal analysis of the data following Chi (1997) revealed the proportion of each PCK component among the participating teachers and its change (Figure 2). Close examination of the data revealed some mutual patterns of the teachers' PCK components along the four phases of the course.

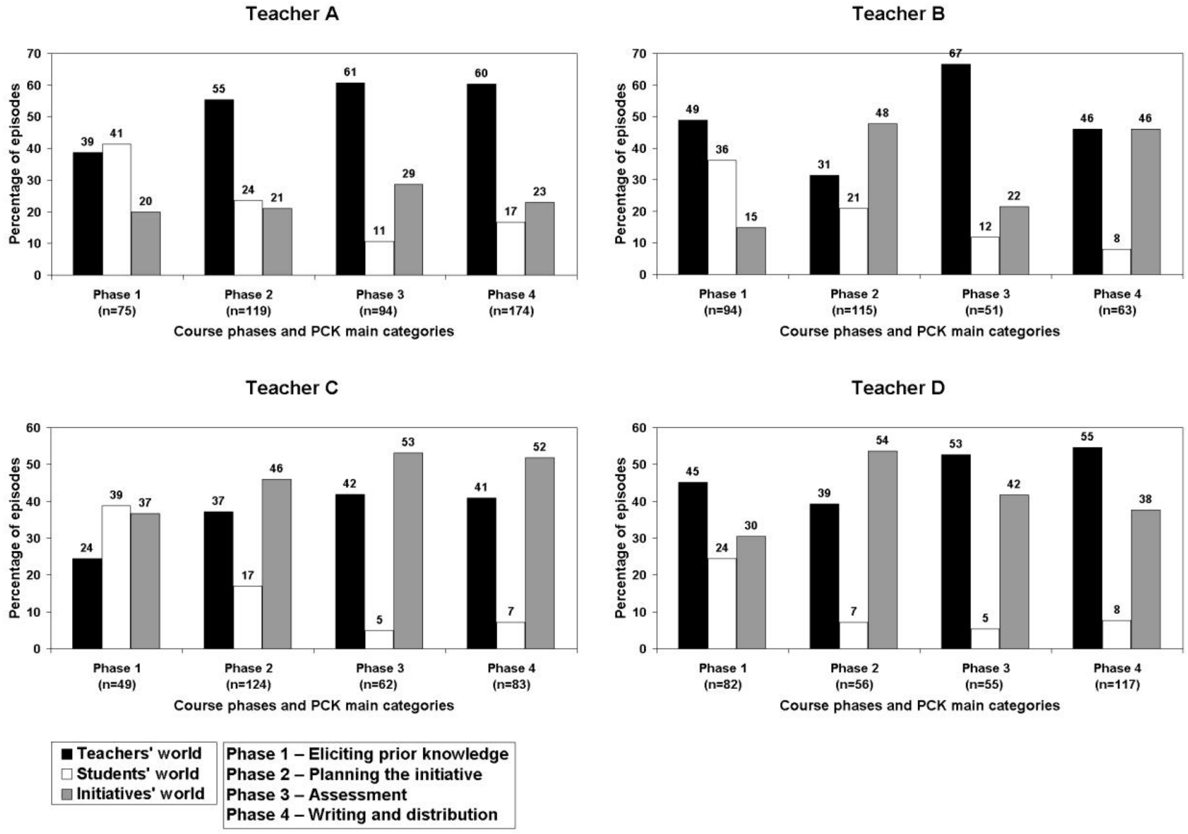

Figure 2. Distribution of the PCK domains for the four participating teachers through the four phases of the two-year program. Above each column, the percentage of each PCK domain is shown.

The relative proportion of the initiatives' world remained steady or grew during the course of the program (Figure 2). The increase was expected, due to the course's contents and goals. These teachers were offered to design initiatives for the first time in their career, and thus they concentrated on themes related to initiative design, implementation and distribution. In contrast, the relative proportion of the students' world component decreased dramatically during the course of the program, particularly during phases 2 and 3. Since the teachers related less to the students' world in the materials collected during the course of the study, the meaning of the students' world component for the teachers' PCK cannot be revealed, due to the absence of discourse about this world.

The most interesting finding was an increase in the relative proportion of teachers' world as the course progressed and the fact that it stayed relatively high during phases 2-4. Thus, the teachers' world held significant weight in the teachers' PCK during the initiatives program. These results led us to carefully examine the components of the teachers' world to understand which PCK component is more important to the teachers during the course.

3.3 The relative proportion of teachers' world components in the teachers' PCK

In this section, we focus on the findings regarding the teachers' world. Presented in Figure 3 are the relative proportions of components of the teachers' world from episodes during the four phases of the course.

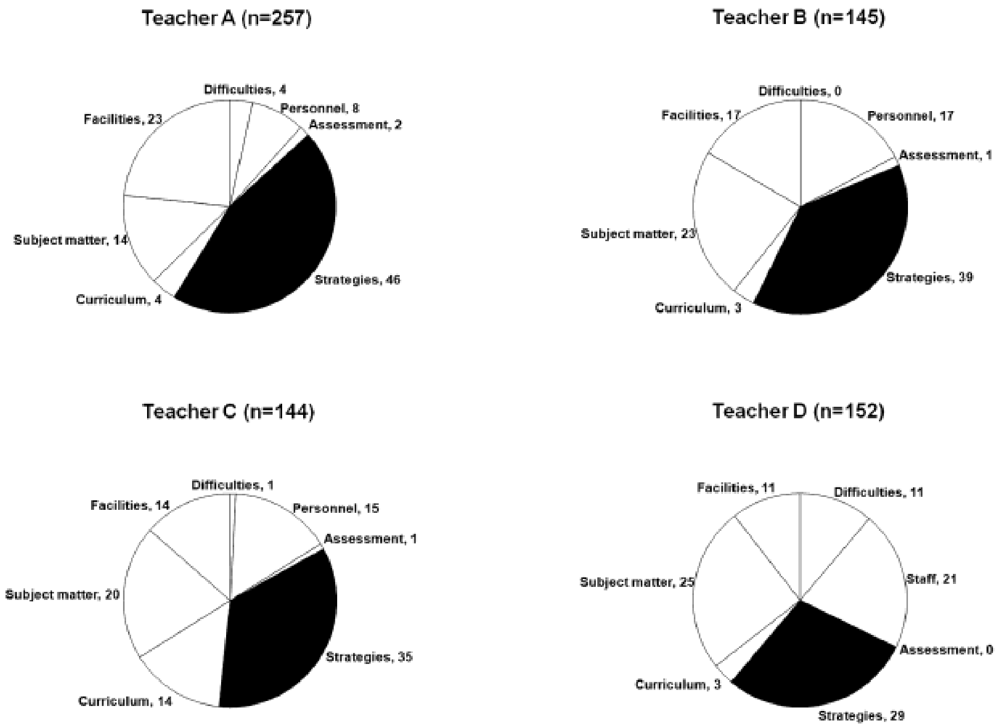

Figure 3. Percentage of teachers' world PCK components during the initiatives course

The most frequent teachers' world component for all four teachers was teaching strategies. All four teachers dedicated a third or more of their attention to this component. Although other patterns differed within the teachers' world data, the consistent dominance of the teaching strategies led us to focus on this component to reveal its significance to the teachers' professional development process.

3.4 Changes in the teaching strategies component for each teacher during the program

Teachers A, B and C each consistently related to a different, unique teaching strategy, which could be defined as the teachers' conceptions about teaching strategies due to their consistency and uniqueness. These teaching strategy conceptions expanded during the initiatives course, as described in detail below. Each teacher is described as a case study.

Teacher A increased her attention to the teachers' world during phases 2-4 of the study (Figure 2). In addition, Teacher A dedicated 45% of her attention to the teaching strategies component (Figure 3). At the beginning of the program, Teacher A concentrated on connecting the contents of several concepts and processes in biology as a leading teaching strategy concept aimed at helping students learn meaningfully. In phase 2, she developed an initiative that uses laboratory-based skills to strengthen biological knowledge that had been previously learned in class. In that way, Teacher A expanded her teaching strategy conception to a strategy that connects skills and content. Teacher A ended the program developing a different initiative that enables the student to use high-order thinking skills, such as inquiry-based laboratory skills, to learn new contents. Thus, Teacher A further expanded her teaching strategy conception to one that works to connect high-order thinking skills and knowledge construction, in order to scaffold meaningful learning.

Teacher B dedicated 39% of her attention during the program to the teaching strategies component (Figure 3). Her attention to the teachers' world showed a particular increase in phase 3 (Figure 2). Teacher B developed bioethical dilemmas together with Teacher C. Teacher B had a very strong conception about teaching using interesting stories from everyday life. In the first phase, she described her teaching strategy as random, connected to everyday life stories in order to motivate her students to learn. In her initiative design in phase 2, she concentrated on a story about a family with a genetic disease. She saw this story as the main scaffold of an initiative that might scaffold the students' knowledge. As the course continued, she began to understand the importance of teaching according to the teaching sequence of the syllabus and of planning the lesson in advance. This occurred in phase 3, when she assessed and reflected on her initiative after teaching it in her class, and she thus expanded her teaching strategy conception to be more ordinate and syllabus-related. Along with the improvement in her teaching strategy, Teacher B improved the contents of the initiative by bringing other stories that better explained the dilemmas in question. By the end of the program, she was still looking for "interesting stories" to teach and insert into her initiative design, and a relatively high percentage of her attention was still on the teachers' world (Figure 2).

Teacher C was Teacher B's partner in developing bioethical dilemmas. Teacher C's attention to the teachers' world increased during phases 2-4 (Figure 2); 35% of Teacher C's attention was given to the teaching strategies component. Teacher C had a very strong conception about teaching biology as a means of educating her students on human values. Her main focus was on collecting arguments for and against the dilemmas from various aspects: religious, economic, legal, moral and political. In the initial phase, she paid relatively little attention to the importance of scaffolding biological knowledge in her practice; she gave relatively less attention to the teachers' world (Figure 2). At the end of phase 3 and during phase 4, Teacher C began to seriously refer to the scaffolding of biological content knowledge in her initiative as well as in her practice. In phase 3, she reported that she had become more aware of meaningful learning and spent time establishing students' understanding while teaching: in addition to humanity education, she began asking questions, and thus establishing students' knowledge, evidencing an expansion of her teaching strategy conception.

Teacher D's data show that although about a third of her attention was focused on the teaching strategies component (Figure 3) and she increased her attention to the teachers' world in phase 3-4, unlike the other three teachers, she did not hold a central conception about teaching strategies. Most of the data show that during the meetings, Teacher D mainly asked the others about their teaching strategies. During phase 1, she did not speak about her teaching strategies at all, but instead spoke relatively more about her difficulties in teaching biology. Teacher D was the least experienced of the four, and it appears that she had not yet developed her unique teaching strategy conception. Along with difficulties in her practice, she experienced difficulties in developing her initiative, which consisted of adapted primary literature articles in ecology. As the program continued, Teacher D felt that she had had a good experience in teaching her initiative. She reported in phase 3 that her students had shown interest in the content of the article, even during a school trip to the desert. After asking many questions about the right way to teach articles in class, Teacher D decided to teach them using a strategy of students' knowledge construction via teacher's questions. Along with the progression in the initiatives development (phases 3 and 4), Teacher D stopped complaining about teaching difficulties and kept referring to the teachers' world (Figure 2) in trying to construct her teaching strategy conception.

These data show that the three experienced teachers of this program (A-C) had developed their unique teaching strategy conceptions during their long years of practice. The only teacher who did not have a clear teaching strategy conception tried to establish it during the professional development program. Nevertheless, all four teachers showed progress in their practice throughout the course of the program.

4. Discussion

For many teachers, professional development programs are an opportunity for professional renewal (Tytler et al., 2009), where they become students and thus engage their own existing knowledge in the acquisition of new knowledge. In our program, the teachers not only learned new scientific and science education knowledge, they also developed new initiatives on the basis of their knowledge, professional experience and needs. As such, the course requirements combined knowledge with practice, and it was therefore expected that the teachers would use their PCK as a basis for further professional development. Science teachers are regarded as having conceptions about the nature of science, about scientific concepts and about how to learn and teach them (Da-Silva et al., 2006). This study proposes that conception about teaching strategies is a significant component of in-service teachers' PCK.

The experienced teachers that took part in this research had unique conceptions of teaching strategies that were resistant to change. The high proportion of the teaching strategies component in the research data implies that this is a significant factor in the teachers' practice and professional development. Although conceptions are resistant to change, they are capable of expansion. The less experienced teacher in this study had not yet established her unique teaching strategy conception. However, she attempted to form one throughout our program.

Designers of professional development programs should be aware of the unique teaching strategy conceptions that each teacher may hold. They can then focus on expanding them for better performance or try to help a teacher who does not hold any such conceptions to establish one.

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Appendix 3

Rozenszajn, R., & Yarden, A. (2013). Characterizing the tacit relationships between biology teachers' content knowledge (CK) and pedagogical content knowledge (PCK)

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Abstract
Considerable effort has been made in the last three decades to construct a well-established conception of science teachers' professional knowledge. Both Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) are considered as critical professional development resources for science teachers. Recently, the interconnectedness between PCK and CK as an integral part of teachers' knowledge for practice has been raised. Exploring the relationships between CK and other professional knowledge components is not a straightforward process due to their internal tacit nature. In-service teachers who develop expertise in teaching possess tacit or intuitive knowledge which is difficult to reveal. The teachers who hold tacit knowledge about something will be unable to verbalize it and will often be unaware of it. Here we examine the possible relations between CK and other professional knowledge components of in-service biology teachers using the repertory grid technique which has been used to elicit experts' personal tacit knowledge. Data analysis revealed that CK is a very important component of teachers' knowledge and that it is by and large distinct from other professional knowledge components. We therefore believe professional development programs should strengthen the relationships between biology teachers' CK and other professional knowledge components instead of assuming that increasing CK will automatically lead to an improvement in teachers' professional knowledge .

Introduction

1. 1 Teachers' knowledge base

Teachers hold a unique teaching knowledge known as PCK. Shulman (1986) was the first to suggest referring to teachers' knowledge as a special knowledge domain, divided it into three categories: (a) subject matter CK—the amount and organization of knowledge per se in the teacher's mind; (b) PCK—the dimension of subject matter for teaching, namely the ways of presenting and formulating the subject to make it comprehensible to others, and (c) curricular knowledge—the knowledge of alternative curriculum materials for a given subject or topic within a grade (Shulman, 1986).

The possible interconnectedness between the PCK and CK as an integral part of teachers' knowledge for practice is still controversial. Some researchers suggest that CK may enhance teachers' quality of teaching, while limited CK has been shown to be detrimental to PCK, limiting the scope of its development (Baumert et al., 2010). Moreover, it has been suggested that the degree of cognitive connectedness between CK and PCK among secondary mathematics teachers is a function of their degree of mathematical expertise (Krauss *et al.*, 2008). In other words, it was suggested to be impossible to distinguish CK from PCK (Fernandez-Balboa and Stiehl, 1995; Marks, 1990). In contrast, other studies have indicated that science teachers' subject matter knowledge is not automatically transferred to classroom practice (Lederman and Gess-Newsome, 1992; Zeidler, 2002), implying that CK and PCK are different and distinct domains within the teacher's cognitive structures (Grossman, 1990; Magnusson *et al.*, 1999; Shulman, 1986). Examining the relationships between PCK and CK is not a straightforward undertaking because expert teachers hold tacit knowledge about the role of PCK in their practice (Bjorklund, 2008) which is not easily revealed.

1.2 Tacit knowledge and the personal construct psychology theory

Tacit knowledge is often acquired through repeated experiences with a certain domain. The person who holds tacit knowledge about something will be unable to verbalize it and will often be unaware of it (Polanyi, 1966). Tacit knowledge is contextual and situated. As one repeatedly goes through certain experiences, one becomes an expert in that field. Experts are often unable to verbalize their 'know how' (Bjorklund, 2008), meaning that they know more than they can say (Polanyi, 1966).

Experienced teachers are usually able to function automatically. Many of their activities in class, such as their interactions with students, are behavioral patterns that they can invoke and perform without any conscious effort. Experienced teachers seem to have organized their knowledge of students and classrooms in particularly effective patterns that can be retrieved unconsciously from their long-term memory via classroom cues (Johansson and Kroksmark, 2004).

The inability to verbalize tacit knowledge and the fact that teachers may not even know that it is there controlling their decisions and actions, led us to search for a suitable method to elicit teachers' tacit non-verbal knowledge. Such a method was suggested by the American psychologist, George Kelly, who formulated the Personal Construct Theory (Kelly, 1955).

The Personal Construct Theory argues that people have different views of events in the world. These views are organized uniquely within each person's cognitive structure. Kelly (1955) established a psychological theory, the Personal

Construct Theory, which argues that each person makes use of unique personal criteria, constructs to help him or her construe meaning from events. The Personal Construct Theory states that peoples' view of the objects and events with which they interact is made up of a collection of related similarity–difference dimensions, referred to as personal constructs (Kelly, 1955, 1969).

. Following the formulation of the Personal Construct Theory, Kelly designed a method to elicit personal constructs, namely tacit knowledge, which is known as the repertory grid technique (RGT).

1.3 The Repertory Grid Technique (RGT)

The RGT is designed to elicit and probe personal tacit knowledge. It is a phenomenological approach which is more closely aligned with grounded theory and interpretive research than with positivist, hypothesis-proving, approaches. The technique appeals to the person's concurrent tacit knowledge on a given topic and encourages that person to confront his or her intuitions, to make the tacit explicit (Jankowicz, 2001). Detailed explanation of the technique used in this study is described in the Manual for the repertory grid technique (Jankowicz, 2004). Every grid of the RGT consists of four components: *topic, elements, constructs* and *ratings*. These components are usually elicited in a four-step procedure between an interviewer and an interviewee. The four steps are detailed below (see methodology). The RGT argues that this technique is free of external influences (Jankowicz, 2004). It overcomes the difficulties inherent in the collection of data with "traditional" instruments of investigation, in which interviewees are supposed to perceive and interpret the researcher's questions to match the researcher's meaning.

The main goal of this study was to discover the tacit dimensions of in-service biology teachers' PCK and its possible relationships with CK by means of a repertory grid. Two questions address the main goal:

1. What is the biology teachers' teaching knowledge repertoire?
2. What are the relationships between biology teachers' CK and PCK?

2. Methodology

2.1 Research Context

The context of this study is a unique professional development program for outstanding high-school science teachers entitled "XXX program for excellence in science education" given at the XXX. The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science or mathematics and science education theories. The participants hold a Bachelor of Science (BSc) degree and are studying toward a Master's degree in science education without a thesis in the course of the program. The program's curriculum runs for eight hours a day, twice a week, over the course of four semesters. Each semester, the teachers participate in different science and science education courses.

The program includes a long-term "Designing New Teaching and Learning Materials" workshop, which served as the context for this research. The workshop is aimed at promoting the teachers' professional development through design activities. The workshop lasted three semesters and the product of this longitudinal course was the teachers' final projects of their Master's studies.

2.2 Research Population

The population of this study consisted of a total of 20 teachers participating in the above-described professional development program. The study's population included experienced in-service high-school biology teachers with 7-22 years of teaching experience from a variety of high schools: national (n = 11), religion-oriented (n = 7), boarding school (n = 1), and Bedouin (n = 1).

2.3 RGT

Tacit dimensions of PCK were analyzed according Kelly's Personal Construct Theory (Kelly, 1955) using the RGT. We followed the four above-described elicitation steps of the RGT at the termination of the professional development program. The four steps procedure takes about an hour and they are detailed in the following.

Step 1- Introducing the topic

Initially, we asked each group the same question: "What does a biology teacher need to know in order to be a good biology teacher?"

Step 2 – Choosing the elements

Each teacher was asked to write down, on 12 separate cards, the elements that a teacher should possess in order to be a good biology teacher.

Step 3 – Elicitation of personal constructs

Each teacher was asked to fold each element card so that he or she could not see what was written on it, place all 12 cards on the table and randomly pick three cards. After unfolding the three cards, each teacher was asked to write down the contained elements in a four-column table, each element in a separate column. Then the teacher was asked to choose the exceptional element of the three, circle it, and write down in the fourth column the reason that two of the elements were similar and the third exceptional. For example: Teacher A3 picked up the elements: 'ecology', 'the human body' and 'critical thinking'. She chose the element 'critical thinking' as an exceptional and wrote that the first two are content knowledge elements and the third describes a skill (see Fig. 3). The teachers were then asked to refold the cards, return them to the table, mix them and then again randomly choose three cards. This action was repeated 10 times with each interviewee.

Step 4 – rating

At this stage repeating explanations for choosing the exceptional elements were defined as constructs. Each teacher was then asked to write down the opposite of a given construct, meaning that he or she had to define the construct poles, in a new empty table. On the right-hand side, the teacher was asked to write the definition of each construct and on the left-hand side, the opposite of the construct's definition. Each teacher was also asked to write the elements, each as a header of a separate column. Then each teacher was asked to rate the correlation between each element and each construct on a five-point scale in which '1' means 'totally agree with the left pole of the construct' and '5' means 'totally agree with the right pole of the construct'. The full tables constructed by each teacher were handed to the researcher for computed data analysis.

2.4 Content analysis

For content analysis of the repertory grid data, all of the interviewees' elements were pooled and categorized according to the meanings they expressed. The categories were derived bottom-up from the elements themselves, by identifying the various themes they expressed (Jankowicz, 2004).

2.5 Cluster analysis

Once the constructs were elicited and rated, the cluster analysis calculations (using factor analysis calculation) were performed with REPGRID, version 5 software (http://gigi.cpsc.ucalgary.ca:2000/). This program provides a two-way cluster analysis grid in which there is the least variation between adjacent constructs and elements. The relationships between elements and constructs are visualized as tree diagrams arranging nearby the most similar rows and the most similar columns in the cluster. The tree diagram presents the elements at the bottom of the diagram (1, in Figure 3) and the coherence rate between the elements (the percentage of similarity between columns) at the top of the diagram using the coherence scale between elements which appears on the upper right side of the diagram (2, in Figure 3). The constructs are presented on the right and left (4, in Figure 3, opposite to each other), and their coherence rate (the percentage of similarity between lines) is presented on a scale on the right side of the diagram (5, in Figures 3).

Over 80% similarity is considered high coherence between the repertory grid's elements or constructs (Kelly, 1969). The meaning of the high coherence between elements or constructs allowed us to identify cognitive links between elements and between constructs, thus presenting an image of each teacher's personal mental model (Jankowicz, 2004). Subsequently, we searched for more than 80% coherence between CK elements and other professional knowledge elements, and more than 80% coherence between the CK constructs and other professional knowledge constructs, thus allowing us to identify the teachers' tacit knowledge about the relations between CK and teaching knowledge. Each teacher's data were analyzed individually and a repertory grid tree diagram (similar to the one presented in Figure 3) was drawn.

2.6 Validation of the RGT

We performed interviews for interpretive validity with five biology teachers. During each interview, the grid map of each teacher and our interpretations of it was presented to him or her. Each teacher was asked to express his or her view on the accuracy of the results referring themselves. The overall validation rate was 100%, meaning that each of the five teachers agreed with the RGT results and our interpretations.

3. Results

3.1 Biology teachers' teaching knowledge repertoire

Each teacher (n = 20) managed to elicit between 9 and 12 elements, for a total of 230 elements. 148 different elements, out of theses 230 elements, were different (mentioned by only one teacher), while the other 82 were repeated by 2 to 10 different teachers. For example: the element: 'knowing biology' was mentioned by 10 different teachers, while the element: volume was mentioned by one teacher (Teacher A3, see Fig.3). Thus, the teachers who participated in this study possessed a diverse repertoire of biology teaching elements. These elements were categorized according to their content. Six main groups of elements emerged in the course of the content analysis: (i) teaching skills; (ii) learning skills; (iii) relevance; (iv) CK; (v) teacher's personality; (vi) learner's personality.

A close examination of the data revealed that each teacher possesses a different repertoire of biology teaching knowledge elements within these categories.

Elements of the CK category were mentioned by all of the teachers, whereas the other elements from the other categories were mentioned only by several teachers (Figure 1). Examining the diversity of the elicited elements revealed that the CK category included the most diverse elements among the six groups of elements (Figure 2). In addition, the CK category seemed to be the most frequently mentioned category (33% of all of the elements), meaning that one out of each three elements that were elicited by all of the teachers was a CK element. We then focused on analyzing the coherence rate between elements from the CK category and other elements, to better understand their significance to the high-school biology teachers' practice.

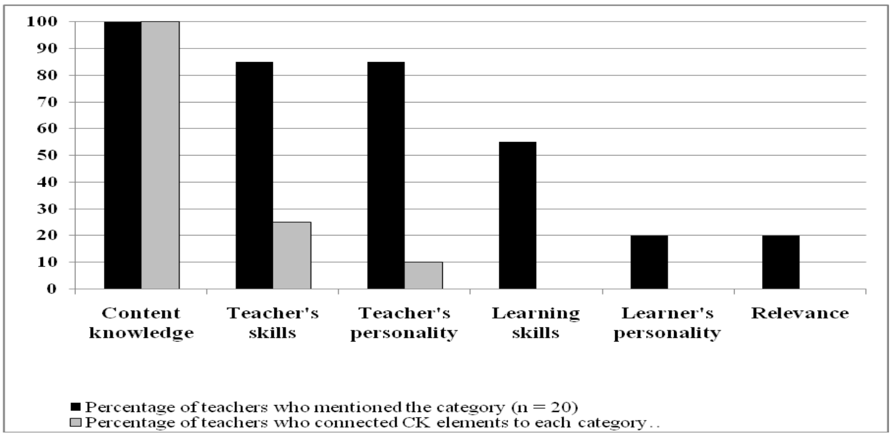

Figure 1: Percentage of teachers mentioning CK elements, and the percentage mentioning connections between CK elements and other elements

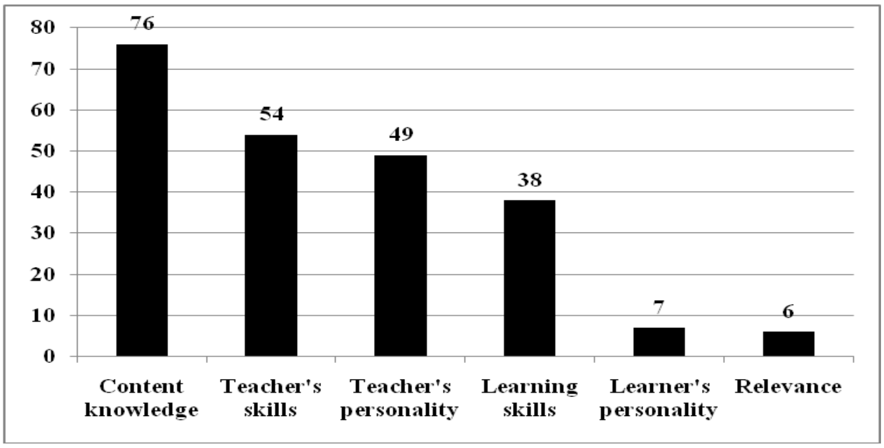

Figure 2: Diversity of elements of each category in the participating teachers' data

3.2 Analysis of elements

Teacher A3's cluster is shown here as a case study (Figure 3). Twelve elements that were elicited by Teacher A3 during step 2 of the RGT are slanted at the bottom of the diagram (1, in Figure 3). The rate of similarity (in percentage) between the different elements appears at the top of the diagram on the element coherence rate scale (2, in Figure 3). Teacher A3's elements: 'The human body', 'volume', 'cell', and 'ecology' (3, in Figure 3) are similar with 85% coherence (2, in Figure 3). This means that these four elements constitute a group of elements that are considered similar by Teacher A3 with respect to biology teaching.

Analysis of each teacher's tree diagram revealed that all 20 teachers connected the CK elements with high coherence (Figure 1) namely, the CK elements appeared to be a separate group of elements. In addition, 35% of the teachers demonstrated high coherence between elements from the CK category and elements from the other categories. Five teachers (25%) connected elements of CK to elements of teaching skills (Figure 1) such as the ability to demonstrate biological knowledge, to characterize students' understanding and to teach in an experiential way. Two teachers (10%) connected CK elements to those of teacher's personality (Figure 1) such as enthusiasm for the wonders of nature, curiosity and openness to students' questions and ideas, and personal interest in science.

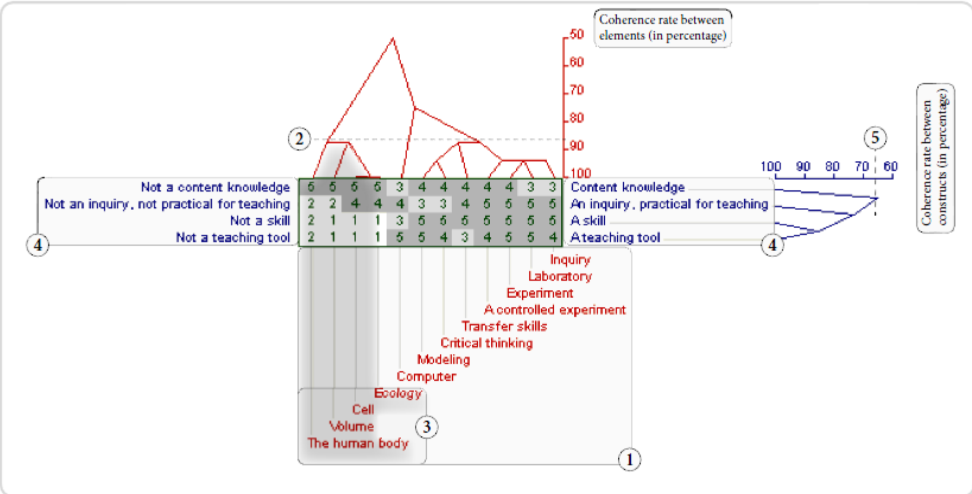

Figure 3. Analysis of Teacher A3's data using a repertory grid tree diagram

(1) Elements; (2) coherence scale and its use in defining a group of elements (3) with more than 80% coherence; (4) constructs; (5) coherence scale and its use in defining coherence rate of the construct 'content knowledge' and other constructs (lower than 80% coherence)

3.3 Analysis of constructs

A similar analysis was performed for the constructs formed by the teachers. The constructs that were defined in step 4 of the RGT are listed opposite each other (4, in Figure 3). The coherence rates between the constructs (in percentages) appear on the right side of the diagram (5, in Figure 3). The graph on the right shows the similarity rates between the constructs corresponding to the graph. For example, the construct 'content knowledge' is 65% similar to the other constructs (5, in Figure 3). This means that 'content knowledge' is a different and separate construct within Teacher A3's cognitive structure regarding biology teaching, since less than 80% similarity was identified between this construct and the others (following Kelly, 1969).

Similar analyses of the RGT data collected from each of the 20 teachers revealed that 15 of them (75%) elicited the CK construct during step 3 of the RGT (not shown, see Figures 3 for examples). Fourteen out of fifteen clusters that included CK constructs demonstrated CK as a separate construct with a low coherence rate (less than 80%) with the other constructs (for example 5 in Figure 3).

Taken together, the analysis of the elements elicited by each of the participating teachers and the analysis of the constructs suggest that by and large CK is a unique category of biology teachers' knowledge which is not integrated as part of their professional knowledge.

4. Discussion

Investigating the interrelationships between various professional knowledge components may shed light on the nature of teaching professional knowledge and its role in teachers' practice (Park and Chen, 2012). Understanding biology teachers' knowledge about teaching may be an important factor in professional development programs aimed at enhancing teachers' professionalism (Henze *et al.*, 2007). Here we examined the tacit dimensions of biology teachers’ knowledge by means of RGT and showed that CK is not integrated as part of their PCK. This finding indicates that CK should not be considered an integral part of biology teachers' PCK, but can be considered a separate entity, as suggested by Shulman (1986, 1987).

A group of 20 high-school biology teachers were asked to intuitively elicit knowledge elements that refer to biology teaching practice. Intuitive elicitation of elements is important because the elements come from the teacher's cognitive structure with minimal impact from the researcher (Fransella et al., 2004). The elements of biology teachers' knowledge that were intuitively elicited in the course of this research raise three major issues: (i) knowledge is personal (following Kelly, 1955) in the sense of biology teaching. Appealing to the biology teachers' tacit knowledge, we found that 65% of the elements that were elicited by the teachers were unique (148 different elements out of a total of 230 elements). Each teacher who participated in this research thus possesses a unique repertoire of knowledge elements, and these elements are uniquely distributed among the element categories in each teacher's cognitive structure. This result may imply that biology teachers are a heterogeneous group with respect to their knowledge of biology teaching. This emphasizes the importance of considering diverse teaching perspectives during planning professional development programs (Author, 2011); (ii) knowledge is socially distributed (following Collins *et al.*, 1989). Pooling together all of the elements that were elicited by the various teachers demonstrated the variety and large scope of knowledge within the area of biology teaching, thus emphasizing the importance of sharing knowledge between teachers during professional development programs; (iii) CK is an important factor of biology teachers' teaching knowledge. Of all of the elements that were elicited by the teachers, CK was the only element that all teachers mentioned. In addition, our analysis revealed that the CK category of elements was the most variable category of elements that was most frequently mentioned by the teachers. Although the cognitive structure of the teachers is variable, the relatively high frequency of elicitation of CK elements within all of the teachers' data suggests that CK is an important factor in these teachers' knowledge for practice (following Fernandez-Balboa and Stiehl, 1995; Marks, 1990), yet differs from other PCK components.

Analysis of the repertory grid data revealed that the biology teachers’ CK was in most cases a different component of knowledge, distinct from other professional knowledge components. The coherence rate of CK elements with other elements was low, less than 80% on average. Seven teachers connected CK elements to elements that describe teaching skills, laboratory skills and learning skills. This might imply that although CK forms a different knowledge group in the RGT, there are teachers who consider CK an important part of their PCK. Therefore, these teachers hold a model of knowledge in which content and pedagogy are integrated and transformed into practice (Gess-Newsome, 1999; Krauss *et al.*, 2008). It is possible that these teachers did integrate their CK with other professional knowledge components following their learning in academic biology courses and science education courses during the professional development program that they had participated in (Krauss *et al*., 2008), while the other teachers did not assimilate new CK into their existing professional knowledge . One possible explanation for the teachers not integrating CK with other professional knowledge components may lie in the fact that some teachers need to be encouraged to assimilate new CK into their existing knowledge. Another possible explanation may be that different teachers hold different teaching perspectives, some of which are not based on CK but rather on cognitive procedures (Author, 2011). This question remains open and is a subject for further research.

The analysis of CK constructs reinforced the conclusions of the analysis of CK elements. Teachers make sense of their practice through constructs regarding teaching. Seventy-five percent of the teachers who participated in this research used the CK constructs as an integral part of their cognitive structure about biology teaching, but the coherence of the CK constructs with other constructs was low. That is, CK is an important yet separate domain of knowledge in these teachers' cognitive structures. It is worth noting that all of the teachers who connected CK elements to teaching or learning strategy elements demonstrated a separate CK construct, except Teacher A2, who connected CK constructs with teaching and thinking skills constructs (data not shown). This teacher was unique since she views acquisition of biological content knowledge as a very important factor in her professional development and a very important factor in her teaching and her students' learning. However, characterizing this teacher's knowledge structure and the way she refers to CK as a part of PCK is a subject for future research.

As the main contribution of this research, the RGT clearly shows that CK is a separate domain in these biology teachers' cognitive structure regarding biology teaching. The theoretical frameworks related to professional knowledge usually exclude CK from PCK (Shulman, 1987). However, some practical studies of PCK within educational systems emphasize the importance of CK and include it as an integral construct of PCK (Fernandez-Balboa and Stiehl, 1995). The high coherence between the elicited CK elements and the separation of the CK constructs from the other constructs strengthen the notion that CK is indeed a very important, but separate domain of biology teachers' knowledge. Thus, professional development programs should promote the connection between biology teachers’ CK and other professional knowledge components instead of assuming that increasing CK will automatically improve teachers' professional knowledge.

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Appendix 4

Rozenszajn, R., & Yarden, A. (submitted). Expansion of biology teachers' pedagogical content knowledge (PCK) during a long-term professional development program

Abstract

Experienced teachers possess a unique teaching knowledge comprised of an itnter-related set of knowledge and beliefs that gives direction and justification to a teacher's actions. This study examined the expansion of two components of pedagogical content knowledge (PCK) of three in-service teachers in the course of a professional development program aimed at designing new teaching and learning materials suggested by the teachers themselves. The research presents an enlargement of previous PCK representations by focusing on a detailed representation of two main PCK domains: teaching and learning, including ten PCK components that emerged in the course of data analysis. This representation enabled to reveal the unique PCK held by each teacher and to characterize the expansion of the two components of the participating teachers' PCK during the long-term professional development program. Retention of major parts of the expanded PCK a year after termination of the program implies that designing and implementing new teaching and learning materials based on the teachers' experiences, needs and knowledge in a workshop format accompanied by biology and science education courses might provide a powerful means for PCK expansion. We recommend that designers of professional development programs be aware of the unique PCK held by each teacher in order to promote meaningful professional development of each teacher. Moreover, the PCK representation that were identified in the course of this study enabled to clarify the 'orientation toward teaching science' category of PCK which appears to be unclear in current literature.

Key words: Pedagogical Content Knowledge (PCK); Professional development; Long–term professional development program; Orientation

Rationale

Experienced teachers hold a unique teaching knowledge that enables teachers to operate effectively in the complex situation of the classroom (Ainley & Luntley, 2006). Shulman (1986) was the first to suggest referring to parts of this knowledge as a special amalgam of content and pedagogical knowledge. This knowledge is a unique and special form of professional knowledge and is entitled "pedagogical content knowledge" (PCK). Researchers agree on the nature of PCK as an integration of knowledge and beliefs, acquired through teaching and used in the context of teaching a specific content (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran et al., 2008; Magnusson et al., 1999). It is also agreed that an overarching component of PCK is teachers' conceptions of purposes and goals for teaching a particular subject matter, which together with a general way of viewing or conceptualizing science teaching, was termed orientations toward teaching science (Magnusson et al., 1999). It has been suggested that professional development programs that consider teachers' PCK may further improve this knowledge (Hofstein et al., 2003; Kind, 2009; Tytler, Symington, & Smith, 2011; Van Driel & Beijaard, 2003). Yet little attention has been paid to the PCK of experienced teachers during a long-term professional development program aimed at designing and implementing new teaching and learning materials for high-school science.

Here we focus on three experienced high-school biology teachers' PCK during a long-term professional development program entitled: "Entrepreneur Teachers—Design of New Teaching and Learning Materials". During the two years of the program, the participating teachers took various courses in science education and biology. In addition, they participated in a two-year workshop in which they designed new teaching and learning materials based on the new knowledge acquired during the course of the program and on their individual teaching knowledge and teaching experience.

The main goal of our study was to characterize these three biology teachers' PCK and to examine its possible expansion and retention during the long-term professional development program described above. We focused on two categories of teachers' PCK: teaching strategies and meaningful learning which helped us track the teachers' PCK expansion and retention. Interestingly, the orientations component of PCK emerged during data analysis as the most influential factor which shapes teachers' PCK, as previously suggested by Magnusson et al. (1999). Our study is based on two main theoretical frameworks: theories related to teachers' knowledge base and those related to effective professional development programs for teachers. Both frameworks are described in detail below.

Theoretical Framework

Teaching knowledge base

Teachers hold a unique teaching knowledge. Shulman (1986) first suggested referring to this knowledge as a special knowledge domain, and entitled it pedagogical content knowledge (PCK). It includes understanding how particular topics, problems or issues are organized, represented and adapted to learners' diverse interests and abilities, as well as how they are presented during instruction. Numerous science educators have discussed and revised Shulman's PCK model, suggesting more detailed representations. Grossman (1990) proposed a model that includes four components of PCK: conceptions of purposes for teaching a subject matter, knowledge of student understanding, curricular knowledge, and knowledge of instructional strategies. Magnusson et al. (1999) changed Grossman's use of the term 'purposes' to 'orientation', added beliefs to knowledge, and added an additional component—knowledge and beliefs about assessment. Thus, the five modified components of science teachers' PCK suggested by Magnusson et al. (1999) are: (i) orientation toward science teaching; (ii) knowledge and beliefs about science curriculum; (iii) knowledge and beliefs about students' understanding of specific science topics; (iv) knowledge and beliefs about instructional strategies for teaching science; (v) knowledge and beliefs about assessment in science. These five PCK components have served as the basis for analyzing science teachers' PCK in various contexts (Author, 2009; Friedrichsen et al., 2009; Friedrichsen et al., 2011; Henze, van Dreil et al., 2007; Lee & Luft, 2008; Park & Oliver, 2008a, 2008b).

Taken together, teachers' knowledge base is comprised of two different kinds of information: knowledge and beliefs. Knowledge refers to information that is certain, solid, dependable, verbalized by teachers and supported by research (Smith et al., 1993). Beliefs are what people think they know or may come to know based on their experience, and they are strongly committed to them (Loucks-Horsley et al., 2003). Thus, while knowledge may be constructed and modified when the learner meets new information or new ideas and as such it may change (Loucks-Horsley et al., 2003; Smith et al., 1993), beliefs are unique, individual, and are more resistant to change (Da-Silva et al., 2006; Pareja, 1992; Van Driel et al., 2007).

Researchers agree that PCK is used in the context of teaching a specific content (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran et al., 2008; Magnusson et al., 1999), but the resolution of the term "specific content" is a subject for debate. While some researchers refer to the term "content" of the construct PCK as the knowledge of teaching a specific subject matter (de Jong & Van Der Valk, 2007; Henze et al., 2008; Loughran et al., 2008; Van Driel et al., 1998), others refer to it as "the knowledge of teaching all the topics they teach" (Magnusson et al., 1999), or "discipline-specific knowledge as well as general science" (Abell, 2008). Berry et al. (2008), quote an interview with Lee Shulman that was conducted at the Annual Meeting of the American Educational Research Association (AERA), in Chicago, April 2007. In this interview Shulman refers to PCK as the knowledge of teaching the whole domain, giving an example of teaching biology: *"Well that's why the pedagogy of biology is an example of PCK. Because you've got to deeply understand what it is that makes evolutionary theory? Whether you think ecologically or cellularly*". In other words, teachers need to go beyond knowledge of facts or concepts of a domain to the explanation of the structure of the domain and the basic principles and the rules that determine the disciplinary domain. Here we follow Shulman's definition of PCK and refer to it as the pedagogical knowledge of teaching biology as a whole domain rather than the knowledge of teaching a specific subject matter in biology (e.g., genetics).

The term belief regarding PCK is more difficult to define (Friedrichsen et al., 2011). Magnusson et al. (1999) proposed the orientation toward teaching science component of PCK as a 'conceptual map' that guides instructional decisions about issues such as daily objectives, the content of student assignments, the use of text books and other curricular materials, and the evaluation of student learning" (p. 97). Namely, the orientation toward teaching science component encompasses the four other PCK components to describe the general notion of the pedagogical knowledge of teaching and learning science.

The orientation component of PCK was reported to be unclear (Friedrichsen et al., 2011) mainly because of the dual meaning of this component. According to Magnusson et al. (1999) this component includes both: "the purposes and goals of teaching science at a particular grade level" and "a general way of viewing or conceptualizing science teaching" (Magnusson et al., 1999). Moreover, Magnusson et al. (1999) proposed nine different orientations that seem to originate from different sources while their theoretical and empirical bases were previously claimed to be either weak or non existing (Friedrichsen et al., 2011). Friedrichsen et al. (2011) proposed defining science teaching orientation as: "an interrelated set of beliefs that teachers hold in regard to the goals and purposes of science teaching, about the nature of science, and about science teaching and learning", and suggested that there is a need for studies that focus on whether and how the development of PCK affects science teacher orientations.

Professional Development Programs Based on PCK

Most teachers view teacher education programs as having little bearing on the day-to-day realities of teaching and little effect on the improvement of teaching and learning (Ball et al., 2008). It is assumed that teachers need knowledge and skills to enhance the effectiveness of professional development programs and their abilities to adapt to possible changes in their teaching. The concept of change itself denotes a "disruption in the status quo" (Smith et al., 1993). Individuals possess a natural tendency to remain in a steady state, so any changes that disrupt this status quo are viewed with caution and are only accepted if the perceived outcomes add value to the individuals (Hanley et al., 2008). It has been suggested that effective professional development programs should engage the teachers' knowledge and experience in decision-making for new curriculum and instructional issues, as they reflect the connections between theory and practice (Parke & Coble, 1997). Therefore, to design an effective professional development program, it is recommended that the designers take into account both the teachers' PCK (Magnusson et al., 1999) and their teaching beliefs (Henze et al., 2008; Henze & Verloop, 2009).

Magnusson et al. (1999) argue that each component of PCK has a different influence on further development of that component due to differences in the amount of knowledge that each teacher holds in each component. Moreover, there are different routes or multiple pathways for PCK development. Magnusson et al. (1999) recommend using the teachers' PCK to examine their pre-existing knowledge and beliefs, address the relationship between subject matter knowledge and PCK, situate the learning experiences in meaningful contexts, and use the PCK components in helping teachers develop their PCK.

Although previous studies have examined teachers' PCK in the course of professional development programs (Author, 2009; Bybee et al., 2003; de Jong & Van Der Valk, 2007; Friedrichsen et al., 2009; Loughran et al., 2008; Schneider & Plasman, 2011; Van Dijk & Kattmann, 2007; Van Driel & Beijaard, 2003; Van Driel et al., 2001), little attention has been paid to the PCK of experienced teachers during a long-term professional development program aimed at designing and implementing new teaching and learning materials. It has been shown that in the course of a professional development program, teachers initially see themselves as competent professionals who nevertheless have room for growth in some aspects of their practice. They then learn new ideas, approaches and activities, and become more self-aware, they reconstruct aspects of their practice, and they develop a new sense of being a teacher of science within their collegial group (Bell & Gilbert, 1996; Hewson, 2007). Moreover, the ability to design and implement new teaching and learning materials that are aligned with the different teachers' PCK is seen as an important component in teachers' professional development (Hofstein et al., 2003), especially since the level of a teacher's PCK has been recently shown to be highly connected with the degree to which his or her instruction is reform-oriented (Park et al., 2011). Thus, teachers' learning can be further enhanced by interactions that encourage them to articulate their views, challenge those of others, and come to a better understanding as a community (Bransford et al., 1999).

The professional development program that served as the context for this research was built on the teachers' previous experience and knowledge with the aim of advancing teachers' understanding of their practice to higher levels (Schneider & Plasman, 2011). The design of this study was based on Park and Oliver (2008a) who reported that one of the salient effects on the development of in-service science teachers' PCK is making them more reflective and analytical about their own practices. Therefore, the teachers of this study first elicited their teaching knowledge through reflection on their practice and then examined them through the design, implementation and assessment of new teaching and learning materials suggested by the teachers themselves. In addition, the theoretical and practical foundations in science education that seemed compatible with the teachers' experiences were provided to the teachers in courses that they took. Our aim in the professional development program was to provide an accessible way of making teachers aware of teaching and learning procedures, thereby leading to their professional development (Parke & Coble, 1997) and thus helping them construct a relatively reliable and coherent model of their individual experiential worlds (Von Glasersfeld, 1989).

The main goal of this study was to characterize the possible expansion and retention of the PCK of three experienced high-school biology teachers who participated in a long-term professional development program entitled "Entrepreneur Teachers—Design of New Teaching and Learning Materials". The research questions addressing this goal were:

- What are the components of the participating biology teachers' PCK?
- What PCK components appear more frequently and did they expand in the course of the program?
- Was the expansion of the frequently mentioned PCK components retained following termination of the program?

Methodology

Research Context

The context of this study was a professional development program entitled "Entrepreneur Teachers—Design of New Teaching and Learning Materials" given at the XXX Institute over the course of two consecutive academic years (2008–2010). The aim of this program was to provide a learning environment that might enrich the participating teachers' knowledge in both contemporary topics in biology and science education theories. The program's curriculum ran for 8 hours once a week for four semesters. Each semester, the teachers participated in a different biology course followed by a long-term curriculum development workshop entitled: "Designing New Teaching and Learning Materials in Biology" or shortly "Initiatives design workshop". The workshop focused on designing and implementing new teaching and learning materials that were aimed to promote high-school biology education. In addition, the teachers participated in a different science and science education course each semester (for the topics learned in the workshop and the additional courses see Online Resource ESM1). During the curriculum development workshop, the teachers were encouraged to use the new knowledge acquired during the courses in the design of their new teaching and learning materials. The teachers implemented the new materials they had designed in their classes, giving them the opportunity to assess the feasibility of the new materials in their everyday practice.

The initiatives design workshop was divided into four stages of different lengths that were not necessarily aligned with the four semesters of the program (Online Resource ESM1):

Stage 1: *Eliciting prior knowledge*. During this stage, the teachers were asked to describe, in various ways, their teaching experiences, needs and goals. In addition, the teachers were asked to express their expectations from the program and to raise general ideas about teaching and learning materials in biology that may enhance biology education in Israel (Aug-Nov 2008).

Stage 2: *Planning the design of the preliminary part of the initiative.* During this stage, the teachers designed the general idea of their new teaching and learning materials and wrote the preliminary part of the teaching and learning materials. In addition, they presented their general design of the teaching and learning materials to other group members, to science education researchers and to the chief supervisor of biological education in Israel. At the end of this stage, the teachers implemented the preliminary part of their new learning and teaching materials in their classrooms (Dec 2008-Feb 2009).

Stage 3: *Assessing the preliminary part of the initiative*. During this stage, the teachers learned different means of assessment in science education which could be related directly to their design of teaching and learning materials. The teachers reflected on their and their colleagues' experiences in implementing the new materials in their classes and of assessing them (Mar-Jul 2009).

Stage 4: *Writing the whole initiative and distributing it to other teachers and researchers*. During this stage, the teachers learned the principles of distributing the new teaching and learning materials to other teachers: writing a teacher's guide, possible rejections to implementing new materials in other classes, and heterogeneity of teaching and learning styles (Oct 2009-May 2010).

In parallel to the "Initiatives design workshop" the teachers took courses in biology (a, c, e and g, in the Online Resource ESM1) and in science education (b, d, f and h, in the Online Resource ESM1).

Research Population

The population of this study consisted of three in-service high-school biology teachers participating in the above-described professional development program. These teachers were selected from 27 teachers who applied to join the program. The XXX advertised a call for experienced biology teachers, with a second or third degree in biology or in biology education, to join an "Entrepreneur Teachers" program at the institute. In the application, the teachers were asked to present their academic degrees and records, discuss their teaching experiences and possible educational initiatives with which they had been involved in the past. Out of 27 senior-high-school biology teachers who sent in applications, seven teachers with high academic achievements who had more than 7 years experience teaching biology in high school and who had previously been involved in implementing educational initiatives in their classes were invited for interviews. Following the interviews in which their motivation to design, implement, and distribute initiatives, and thus their potential to become teacher leaders, was assessed, five experienced in-service biology teachers were selected to participate in the program. Three out of these five teachers participated in the entire program and developed an entire new teaching and learning unite, while the two other teachers did not complete all the program's requirements and were therefore excluded from this study. The three teachers learned together throughout the entire program and served as the study population. All three teachers hold a M.Sc. degree in biology. Their professional background, teaching experience and the subjects of the new teaching and learning materials they developed are summarized in Table 1.

[Insert Table 1 about here]

Data Sources

The data sources of this study were collected as follows: (i) All group discussions were recorded using a digital tape recorder; (ii) All the lessons that included discussions about the initiatives' design, implementation and distribution were fully transcribed (a total of 21 lessons, about 2 hours each); (iii) Relevant parts of the teachers' e-mails and assignments were collected (a total of 64 e-mails and 28 assignments); (iv) Interviews with the teachers were transcribed. The interviews took place at three time points during the program: at the end of the first year of the program, at the end of the program, and a year after the termination of the program (a total of 9 interviews); (v) All the teachers' presentations of their new materials design to the other teachers, academic staff and policy makers were recorded, videotaped and transcribed.

Qualitative Data Analysis

Since the uniqueness and complexity of teaching and learning knowledge in general and specifically of PCK must be understood in context (Stake, 1995), we used the ‘grounded theory’ methodology which states that human behavior cannot be understood without reference to the meanings and purposes attached by human players to their activities (Lincoln & Guba, 1994). The grounded theory focuses on the attempt to derive the representativeness of concepts, not persons, as viewed by the participants in a study. This process involves multiple stages of data collection and the refinement and interrelationship of categories of information. The constant comparison of data with emerging categories and the theoretical sampling of different groups are aimed at maximizing the similarities and differences in the information (Corbin & Strauss, 1990). In addition, we used the mixed-methods approach, which involves gathering both numerical information and text information so that the final database represents both quantitative and qualitative information in which the results from one method help inform those of the other (Creswell, 2003). Accordingly, data were analyzed qualitatively Bottom-Up following Shkedi (2003) and then a quantitative dimension was added following Chi (1997), within the context of the professional development course.

Intentionally, we did not use available categorizations of PCK (i.e.,Magnusson et al., 1999) as we followed Friedrichsen et al. (2011) who called for investigating science teaching orientations from multiangel perspectives, instead of categorizing teachers into one of the categories of Magnusson et al. (1999) or any other list of categories. Initially, a qualitative data analysis was performed on all the data. Data were divided into episodes, which were classified according to the themes discussed. One episode consisted of a section in which a single teacher is talking or writing about one theme. If the same teacher spoke several times sequentially about the same theme, even though others interrupted, it was still considered one episode. For example, the next episode began when the subject of the discourse changed. The episode describes Teacher B's belief about means for meaningful learning:

Teacher B: "Through the stories they will remember biology."

Course moderator: "Do you mean that it elevates their motivation for learning?"

Teacher B: "I see that they remember emotional experiences. It is only when they go through an emotional experience that they remember."

Teacher A: "Do you have some spare time?"

Teacher B: "Although it seems like I am wasting time, I think that if the story causes an association in the students' minds they will remember it."

The next episode, which comes right after the previous episode, describes Teacher B's belief about the syllabus. It begins with the sentence:

Teacher B: "By the way, did you see how long and difficult the syllabus is?"

The following five steps were then taken: (i) primary categories were formed from the collected data; the data were segmented into episodes, and every episode was categorized according to its content (i.e., subject matter, Figure 1); (ii) more general domains were developed (i.e., Teaching domain, Learning domain, Initiatives domain, Figure 1); (iii) all the episodes were mapped according to the chosen domains; (iv) episodes were reorganized according to the chosen domains; (v) assertions were then proposed about the teachers' PCK components, and their possible relations with previously published PCK components have been examined. PCK components were distinguished in order to be further examined (marked in grey in Figure 1).

In order to determine which teachers' PCK components are significant for longitude examination we subsequently applied verbal analysis of the data following Chi (1997). It was assumed that the frequency of appearance of each component in the data may reflect its importance or its concern within the speaker's PCK. For example: a component which repeats more frequently was assumed to represent a more pronounced PCK component which may be of higher importance or concern to the specific teacher than other components. To reveal each teacher's main PCK components along the four stages of the course, the number of episodes in each component was counted and the proportion of the number of episodes of each component out of the total number of episodes regarding PCK were examined. Then, a qualitative examination of the main PCK components was performed again in order to examine whether they represent unique patterns and in order to examine their possible expansion.

We assumed that the above mixed-methods analysis could capture main aspects of teachers' PCK, although the data were not based on observations of the teachers' practice. This assumption is based on Van Der Valk and Broekman (1999) who claimed that teachers produce "rich" information about their PCK while reporting on their lesson design and teaching.

Validation of emerging PCK components

Part of the data was presented to science education researchers for peer validation, twice in the course of the data analysis. The first peer validation was aimed at validating the emerging domains and their related components (see the emerging domains in Figure 1). The mean identity rate between five science education researchers and the emerged classification of the main domains and their specific components was 92.3%. The second peer validation was aimed at validating the analysis of the teachers' PCK during the program. Twenty-five episodes were given to three science education researchers who were asked to classify each episode according to the suggested classification. The overall validation rate was 85.6%. In addition, interviews were used for interpretive validity with the participants. During an interview, the qualitative result of a teacher's PCK was presented to her and she was then asked to express her view of the accuracy of the results. The overall validation rate was 94%.

In order to validate the emerging categorization of this study a close examination of the correlation between the PCK representations suggested herein and various PCK representations suggested in the current literature was performed (see below).

Results

The Emerging PCK Representation

The discourses (oral and written) as well as transcripts of teachers' interviews were subjected to qualitative data analysis. Seventeen categories related to the biology teachers' professional knowledge about teaching and learning emerged in the course of the data analysis (Figure 1). Those seventeen categories were classified to three domains: t*eaching domain*, *learning domain* and *initiatives development domain*. Among the seventeen categories we distinguished ten PCK components that represent knowledge about the teaching and learning of biology (highlighted in grey in Figure 1). Those components include teachers' knowledge and beliefs about: (i) teaching strategies; (ii) assessment of related contents; (iii) curriculum; (iv) available teaching facilities; (v) students' meaningful learning; (vi) students' motivation to learn biology; (vii) the influence of biology learning on students' future lives; (viii) students' prior knowledge; (ix) students' thinking skills; (x) students' interest outside of the school context. Components i-iv are part of the teaching domain, while components v-x are part of the leaning domain (for detailed examples see Online Resource ESM2).

Within the teaching domain the categories subject matter content knowledge (CK) and the personnel that accompany the teaching (e.g., school principal or chief supervisor of biological education) were not included in the subsequent analysis. CK is a different component of teaching knowledge (Magnusson et al., 1999; Shulman, 1986) and the personnel that accompany the teaching is part of general teaching practice and not a specific PCK component. The domain: *"New Materials Design"*, namely, about the process of designing, assessing and distributing new teaching and learning materials was not included in the subsequent analysis because it is specific to the process of designing new teaching and learning materials, and therefore remote from most teachers' everyday practice and not a specific PCK component.

[Insert Figure 1 about here]

A close examination of the correlation between the PCK components suggested herein and various PCK components suggested in the current literature revealed that they are aligned. Although the components that emerged in the course of this study comprising the teaching and learning domains were in line with PCK components previously suggested in the literature, they were more detailed and specific. For example, the component *knowledge of student learning and conceptions*—knowledge of the conceptions and preconceptions that students of different ages and backgrounds bring with them to the lessons (Fernandez-Balboa & Stiehl, 1995; Loughran et al., 2001; Magnusson et al., 1999; Shulman, 1986; Tamir, 1988) is included in four PCK components in this study: 'students' prior knowledge', 'students' thinking skills', 'students' motivation to learn biology' and 'students' meaningful learning'. In addition, some PCK components of this study appear to be similar to PCK components previously suggested in the literature. For example, the component *knowledge of instructional strategies* (Magnusson et al., 1999; Shulman, 1986) is similar to the component 'knowledge about teaching strategies' that emerged in the course of this study. Aligning the PCK components according to previously published teaching and learning domains enabled us to validate the emerging categorization of this study. The detailed categorization that emerged here assisted in pinpointing specific PCK components and their expansion in the course of the teachers' professional development program (see below).

Frequencies of the PCK Components

The frequency of appearance of each teacher's PCK components from the teaching domain and the learning domain was examined (following Chi,1997). Some topics associated with certain PCK components appeared to be more frequently mentioned by the teachers during the course of designing of new teaching and learning materials (Figure 2). We assume that the frequency of appearence of topics in the teachers' episodes provided rich qualitative data and may reflect their relative importance and concern about teaching and learning for each teacher. We followed the appearance of the most frequent components along the four stages of the program. Monitoring the frequency of each teacher PCK components and repeating explanations relating to these components enabled us to identify patterns that are unique to each teacher's PCK (see below).

[Insert Figure 2 about here]

Within the teaching domain, all three teachers related most to the teaching strategies component (59%–65%, Figure 2), and to teaching facilities (16%–29%, Figure 2). The other components were mentioned less than 19% of the times in the teachers' episodes. Within the learning domain, all three teachers related most to meaningful learning (38%-64%, Figure 2), and to motivation to learn (18%-33%). The other components were mentioned less than 19% of the times in the teachers' episodes.

Assuming that the high frequency of these components may provide rich qualitative data and may imply of the teachers' importance or concern about teaching strategies and meaningful learning we performed an in-depth qualitative analysis of these two PCK components for each of the three teachers along the four stages of the course. Differences between the three teachers' PCK and the unique expansion of each teacher's PCK appeared to emerge during the course, as described in detail below. Each teacher is described individually as a case study.

The Expansion of Each Teacher's PCK (Three Case Studies)

Teacher A. Teacher A had 17 years of experience in teaching biology at the beginning of the program in one of the leading high schools in the center of the country. The school is well known for the high success rates of its students in the matriculation exams in general and in biology in particular. She repeatedly declared that she asks her students a lot of questions during her lessons in order to induce thinking procedures and in order to scaffold their learning.

During the course on designing new teaching and learning materials, Teacher A mostly referred to teaching strategies (59% out of all her episodes about the Teaching domain) and to meaningful learning (64% out of all her episodes about the Learning domain) (Figure 2). At the beginning of the program, during stage 1, Teacher A hardly mentioned teaching strategies but she expressed her belief that her students are not able to use high-order thinking skills for acquiring knowledge during her lessons. She believes that using high-order thinking skills requires a lot of teaching time, which she claimed she does not have (Table 2). At this stage Teacher A repeatedly elicited a teaching problem: constrains of time that should be devoted to high-order thinking skills and about her lack of confidence in her students' cognitive abilities to use high order thinking skills. Repeated reference to students' thinking skills implies that Teacher A's conception about teaching and learning is that meaningful learning occurs via cognitive procedures but it demands a lot of teaching time and high cognitive capabilities.

[Insert Table 2 about here]

During stage 2, the episodes of Teacher A about teaching strategies related to her ideas on means to promote meaningful learning. She began to express the idea that meaningful learning occurs when new knowledge is connected to existing knowledge (Table 2). She expressed the idea of knowledge construction via connections of existing knowledge to new knowledge after learning about cognitive procedures of learning in the "Introduction to science education" course (see Online Resource ESM2). During stage 2, Teacher A developed teaching and learning materials that make use of laboratory experiments aimed at strengthening biological knowledge that has been previously learned in class. At this stage, Teacher A tried to use a new teaching strategy: connecting existing knowledge to newly acquired knowledge using high-order thinking skills through laboratory experiments in order to enhance meaningful learning. It seemed that she kept holding her initial PCK about using high-order thinking skills for meaningful learning and tries to use the new teaching strategy in order to solve the teaching and learning problem she elicited in the first stage.

During stage 3, Teacher A made her first attempt to use her newly designed teaching and learning materials in her class and felt that the materials needed improvement. At that point, Teacher A experienced knowledge construction herself during the 'Experiencing contemporary research in the life sciences' course. In this course the teachers were encouraged to read scientific articles and then experience laboratory experiments in the biological laboratories of the XXX Institute. She reported that reading and understanding scientific articles and then experiencing contemporary research procedures were hard but rewarding since she enjoyed the success of acquiring new up-to-date knowledge using high order thinking skills activities. At this point she was also introduced, in the 'Introduction to science education' course, to adapted scientific articles (Author, 2009) that are part of an elective program for high-school biology students. During the third stage she decided to develop new materials, based on the conclusions that she reached from experiencing the new materials in her class and the knowledge she acquired in the various courses. She mainly concentrated on a reading comprehension activity using adapted article that related to previously learned content, but she was still unsatisfied.

During stage 4, Teacher A had developed different teaching and learning materials that were aimed at using laboratory experiments in order to facilitate new knowledge construction. The new materials are designed differently from her previous design. In the previous design laboratory activities were used to strengthen biological knowledge previously learned in class. The new teaching and learning materials were designed so that students would be required to use high-order thinking skills, in order to construct new knowledge, knowledge that was not previously learned in class (Table 2). At this stage, she decided to ask her students to use high order thinking skills, expressing her confidence in her students' ability to use skills such as inquiry skills during her lessons. She elaborated upon a strategy of scaffolding students' knowledge construction via inquiry, thus enabling her students to achieve meaningful learning (Table 2). This development in her confidence in her students' capability of using high-order thinking skills represents an expansion of her PCK.

At the workshop of designing new teaching and learning materials Teacher A gained the opportunity to self-examine her conception about teaching and learning. She began to learn in the program declaring that meaningful learning occurs via cognitive procedures such as high-order thinking skills that may secure knowledge, but that she is not able to teach that way and her students are not capable of using high-order cognitive procedures. In the course of the program she designed new teaching and learning materials using high-order thinking skills that scaffold new knowledge construction. She began declaring that she trust her students' capabilities to use high-order thinking, and that it is possible to teach that way despite the time constrains, thus demonstrating an expansion of her PCK.

Teacher B. Teacher B also had 17 years of experience in teaching high-school biology toward the national matriculation exams, at the beginning of the program. She teaches in a religious high school for boys, in which students devote most of their days to religious studies and learn science only during the afternoon hours. This led her to develop a teaching strategy using interesting stories from everyday life in order to induce an emotional effect that would capture her students' attention.

Teacher B's discussions related mostly to teaching strategies (65% out of all her episodes about the Teaching domain) and to meaningful learning (38% out of all her episodes about the Learning domain) during the course (Figure 2). She developed teaching and learning materials that focus on bioethical dilemmas, together with Teacher C. During the first and second stage of the course, her episodes about teaching strategies described her teaching strategy as a random one, not ordinate according to the syllabus but rather, as she declared, associative. She believed that using exciting stories in her lessons motivates her students to listen to her and that learning means remembering via emotional experiences which induces long-term memory (Table 3). In the teaching and learning materials that she designed during stage 2, a bioethical dilemma about 'whether the government should require genetics testing from a couple before the marriage?' she insisted on using a dramatic story about a family with a genetic disease. Her discourse about meaningful learning demonstrated her conception that dramatic stories should be the main issue of a teaching and learning program which is aimed at scaffolding students' knowledge through emotional experiences.

[Insert Table 3 about here]

As the course continued, she learned in the 'Introduction to science education' course about the importance of connecting prior knowledge to newly acquired knowledge. She began to understand the importance of teaching according to a teaching sequence and of planning the lessons in advance. That idea was reinforced after the implementation of the new materials she designed in her class. She then declared that she is busy ordering all her stories according to a 'rational sequence'. Still, at stage 3, her discourse mainly focused on her belief that using interesting, dramatic stories will lead to meaningful learning (Table 3).

The main evidence of the expansion of Teacher B's PCK appeared in stage 4, where she expressed her realization of the importance of sequential and coherent teaching. In parallel, her episodes about meaningful learning included concerns about students' misconceptions (Table 3). This realization occurred after reflecting on the assessment of her newly designed materials in her class. During stage 4 Teacher B presented her design and the results of the assessment of her design in her class to the other participating teachers and the course moderators. During the presentation she reflected on her conception about teaching and learning via interesting stories. In addition, her exposure in the 'Cognition, Learning and Instruction' course to misconceptions seemed to make a meaningful influence on her PCK. She began to speak about her concern that the stories she tells at class may induce misconceptions (Table 3). She also declared that she was very impressed of the teaching strategy of the lecturer in the 'Biology of Stem Cells' course. The lecturer of this course taught with the help of very interesting scientific articles (primary scientific literature) and combined interesting stories about the various studies and the scientists involved. Nevertheless, the lectures' contents were very ordinate and always referred to previous knowledge that was taught in the course. At this stage, Teacher B improved the contents of her teaching and learning materials by bringing stories that better demonstrated the biological dilemmas in question followed by questions that clarify whether misconceptions had occurred in her students' minds.

It seems that the program, including the design of new teaching and learning materials, provided the opportunity for Teacher B to self examine her conception about teaching and learning. By the end of the program, she was still looking for "interesting stories" to insert into her new materials, meaning that her PCK may have not change, but she began to prepare to her lessons, in advance in contrast to her initial random choice of stories for her teaching. In addition, she began to be cautious about misconceptions that might occur among her students while learning through interesting stories. Thus, Teacher B demonstrated an expansion of her PCK.

Teacher C. Teacher C had 12 years of experience in teaching high-school biology toward the national matriculation examinations, at the beginning of the program. She teaches in a rather small religious school for girls located in a remote village. Teacher C was Teacher B's partner in developing teaching and learning materials focused on bioethical dilemmas. During the course Teacher C repeatedly declared that she teaches biology as a means of educating her students about human values. Her main focus during the course was on collecting arguments for and against the dilemmas from various aspects: religious, economic, legal, moral and political.

Teacher C's episodes mostly referred to teaching strategies (64% out of all her episodes about the Teaching domain) and to meaningful learning (43% out of all her episodes about the Learning domain, Figure 2). During the first and second stages of the course, Teacher C's episodes emphasized her role in the class in promoting human values among her students via biology. She repeatedly declared that her main goal in class is to educate her students to be good citizens (Table 4, stage 1). During these stages, Teacher C's episodes referring to meaningful learning focused on the importance of the relevance of biological contents to everyday life as a means of promoting meaningful learning (Table 4).

[Insert Table 4 about here]

At the end of stage 3 and during stage 4, Teacher C began to refer to the scaffolding of biological content knowledge as an additional goal of her teaching and learning materials, as well as of her practice: her episodes about meaningful learning in stage 3 and in stage 4, focused on reporting that she was establishing students' understanding while teaching with the help of leading questions, in addition to promoting human values (Table 4, stage 3). During her interview, Teacher C pointed out that both the 'Cognition, Learning and Instruction' course, and listening to Teacher A while presenting the implementation of her newly designed materials, influenced her to broaden her teaching strategies.

During stage 4, Teacher C continued reporting on inserting questions related to biological contents into her teaching and learning materials, in order to establish students' knowledge, in addition to promoting human values. Following this expansion of her teaching strategy she added questions to her dilemma that may scaffold students' meaningful learning (Table 4).

The program of designing new teaching and learning materials provided the opportunity for Teacher C to self examine her PCK. By the end of the program, she was still emphasizing the importance of the relevance of biological contents to everyday life and human values as a means of promoting meaningful learning. Thus, her conception did not change, but she paid attention to inserting questions that may scaffold the addition of knowledge in biology demonstrating an expansion of her PCK.

Taken together, the data show that during the professional development program, the unique PCK of the three experienced biology teachers who participated in this program (A–C) expanded. Although all the teachers related mostly to the same categories, each teacher held a unique PCK towards teaching strategies and meaningful learning. Each teacher demonstrated a unique expansion of her PCK. This expansion occurred during different course stages and different lessons which influenced the expansion in a unique manner typical for each teacher.

Retention of PCK Expansion *One Year Later*

A year after the course had ended the teachers reported that they were continuing to use the teaching and learning materials they had developed during the course. They all noted that they were not using the teaching and learning materials that were developed by the other teachers, but they were using a few teaching strategies in their class that they had learned from their colleagues during the course. For example, Teacher B and Teacher C reported asking their students questions in order to facilitate high-order thinking skills as a means of knowledge construction. They reported having learned this strategy from Teacher A during the course. Teacher B reported that she had started to dedicate more time to human values in her teaching and that she had learned this approach from Teacher C during the course. Teacher A and Teacher C reported that they would sometimes tell interesting stories in order to motivate their students to learn, similarly to the strategy reported by Teacher B during the course. In addition, all three teachers reported applying contents and skills which they had learned in the various courses of the program. They all reported inserting updated biological contents into their lessons, which they learned in the biology courses during the two-year program. Moreover, they all noted that the science education courses had made them more aware of their teaching and their students' learning, and that they felt that as a result, they had become 'better teachers'.

The fact that these teachers did not use the other teachers' materials emphasizes the uniqueness of each teacher's PCK: each teacher developed the new teaching and learning materials from her unique PCK which made it difficult for the other teachers with different PCK to use them. However, all of the teachers did use other teachers' strategies and applied contents and skills that they learned from each other or from the program, implying expansion of their PCK.

Discussion

For many teachers, professional development programs are an opportunity for professional renewal (Tytler et al., 2009), whereby they become students themselves and thus engage their own existing knowledge in the course of acquiring new knowledge. The main means for professional development used in this study was the design of new teaching and learning materials. The rationale behind this approach was that by making use of the teachers' practical knowledge and concerns, supported by a commitment to their own suggestions for improving science education in schools, teachers' professional development is encouraged. The teachers who participated in this study gained new biological and science education knowledge in the program's courses while being engaged in designing new teaching and learning materials on the basis of their knowledge, professional experience and needs. As such, the new materials design course requirements combined newly acquired knowledge with the teachers' practice, and it was therefore expected that the teachers' PCK would further develop during the program.

In an effort to characterize the participating teachers' PCK and its possible expansion, a categorization of biology teaching professional knowledge emerged from the data collected during the program. Here we focused on two main PCK domains: teaching and learning, and their related categories. This detailed categorization revealed the complexity and expansion of the participating teachers' PCK during a longitudinal professional development program. A close examination of the correlation between the PCK components suggested herein and various PCK components suggested in the current literature showed that the two main PCK domains, namely teaching and learning, as well as most of their related components, are aligned with published PCK components but that they are more detailed and specific.

The teachers participating in this study were found to relate mainly to two PCK components: teaching strategies and students’ meaningful learning. This observation is similar to findings by Park et al. (2011), who stated that knowledge of students' understanding in science and knowledge of instructional strategies are positively related to the reform-oriented nature of instruction. Park et al. (2011) suggested providing teachers with opportunities to analyze students' understanding of a science concept and come up with teaching strategies to confront students' misconceptions and to meet their learning difficulties. Teachers' knowledge of students' understanding in science and of instructional strategies was suggested as critical in shaping the structure of teachers' PCK (Park & Chen, 2011).

The context of this study, namely the initiatives design course that offered teachers the opportunity to design new teaching and learning materials and assess them in their classes, provided a special opportunity to discuss various teaching strategies and confront students' learning difficulties. It is important to note that the new materials design course lessons did not focus on teaching strategies and meaningful learning. The main focus of the course was on designing new teaching and learning materials in biology. However the relatively high proportion of episodes in which the teachers related to teaching strategies and to meaningful learning imply that the initiatives design course served as a meaningful platform for the expansion of the participating teachers' PCK, which was mainly focused on teaching strategies and meaningful learning.

The expansion of each teacher's unique PCK during the new materials design course was driven by the need to examine different learning abilities and teaching strategies while designing the new teaching and learning materials. As a result, the teachers read materials developed by others and discussed the ideas with them with the help of the course moderators. This, in turn, led to exposure to other teachers' PCK, which might have facilitated the expansion of their own PCK. The teachers and moderators served as a community of practice in which points of view were formulated, defended, listened to and evaluated by others (Vygotsky, 1978). The expansion of the teachers' PCK probably took place within their zone of proximal development (Vygotsky, 1986), and assisted them in expanding their PCK. As a consequence of this PCK expansion, the teachers implemented new activities in their developed teaching and learning materials and incorporated them into their practice.

We were not able to identify any correlations between the topics discussed during the first three stages of the course and the frequency of appearance of the categories of teaching strategies and meaningful learning in the teachers' discussions. Therefore we cannot assume that the teachers chose to discuss their teaching strategies and means of achieving meaningful learning more frequently due to the topics chosen for each stage of the professional development program. Each teacher was influenced during different stages and by different activities during the first three stages of the course, while all three teachers experienced meaningful expansion of their PCK during the final stage (stage 4). In this last stage, the teachers finished analyzing the implementation of their new teaching and learning materials in their classes and were asked to think about ways of distributing their materials to other biology teachers who had not participated in the program. It seems that reflecting on the experience of designing, implementing and assessing their projects made a significant contribution to their PCK expansion. This was also the stage at which they became aware of the differences between their teaching strategies and their unique PCK and were asked to relate to different teaching strategies while explaining their teaching and learning materials to large and diverse teachers' groups in order to distribute them.

The unique PCK of each teacher that was characterized in this study might help better explain the orientation category, which is one of the five PCK categories suggested by Magnusson et al. (1999). Orientation toward teaching science was defined as: "the purpose and goals of teaching science at a particular grade level and a general way of viewing or conceptualizing science teaching" (Magnusson et al., 1999). This definition of PCK orientation was later reported to be unclear (Friedrichsen et al., 2011). After examining published studies using the term orientation when relating to PCK, Friedrichsen (2011) proposed defining science teaching orientation as: "an interrelated set of beliefs that teachers hold in regard to the goals and purposes of science teaching, about the nature of science, and about science teaching and learning". We suggest that orientation toward teaching science is the unique instructional way each teacher uses, according to his or her believes about the best strategy for promoting meaningful learning. For example, in this study Teacher A's orientation was dominated by a cognitive point of view which included knowledge and beliefs that served as a "conceptual map" guiding her to use high-order thinking skill questions in order to scaffold her students' knowledge construction. Friedrichsen (2011) suggests sorting through complex belief sets, and investigating orientations from multiangle points of view in order to allow comparisons that distinguish among different sets of teachers' beliefs. Here we describe how by tracking teachers' repeated explanations about teaching and learning, it is possible to determine each teacher's unique PCK orientation, thus clarifying and providing a practical meaning for the term orientation.

Following the analysis of the different PCK categories of the participating teachers, we noticed that these teachers hold orientations that may be characterized according to different teaching and learning theoretical frameworks. Specifically, Teacher A probably holds a cognitive (following Greeno et al., 1996) orientation towards teaching and learning. Her discourse implied that she uses high-order thinking skill to scaffold her students' knowledge construction. Her PCK orientation is that the best learning occurs when the students construct their knowledge with the help of their teacher's scaffolding questions. During the design course, Teacher A's cognitive PCK orientation became more sophisticated, leading her to add requirements for high-order thinking skills to her lessons as well as to the new teaching and learning materials she designed during the course.

Teacher B probably holds a behaviorist (following Greeno et al., 1996) orientation towards teaching and learning. This suggestion is based on Teacher B's use of interesting stories to elicit emotional feelings that might increase her students' motivation to listen to her and may lead them to long-term recall of the biological contents. Teacher B's PCK orientation is that the best learning occurs when the student is stimulated by interesting stories. During the initiatives course, Teacher B started to examine her students' cognitive structures, and tried to avoid the occurrence of misconceptions among her students during her lessons. Although she did not neglect her leading behaviorist orientation, a cognitive dimension was added to her practice.

Teacher C probably holds an a socio-cultural (following Greeno et al., 1996) orientation towards teaching and learning, one that emphasizes the connection between biological contents that have been learned in class and relevant social aspects from the students' everyday lives, such as legal, religious and ethical aspects. Her PCK orientation is that the best learning occurs when the students succeed in connecting the contents that are learned in class with everyday social life experiences. During the design course, Teacher C dedicated time to supporting her students' deep understanding of biological contents, adding high-order thinking skill questions, and thus added a cognitive dimension, to her sociocultural orientation. PCK orientations do not change over time but they are capable of expansion and may become more sophisticated. The term expansion stands in contrast to the term change to emphasize our understanding that the teachers' PCK orientation does not change but rather expands to a more sophisticated one.

Each teacher is unique and each teacher formulates his or her teaching style based on their unique PCK to be as effective an educator as possible (Heimlich & Norland, 2002). Thus, each teacher's unique PCK orientation is a significant component of in-service teachers' knowledge base. Designers of professional development programs should be aware of the unique PCK orientation held by each teacher (Lotter et al., 2007). During the course we were aware of the differences in the PCK and especially to each teacher's unique PCK orientation, and we therefore followed each teacher's PCK orientations and guided her accordingly. While discussing the design of the new teaching and learning materials, we emphasized points related to each teacher's PCK orientation in order to apply them to her cognitive structure. Thus, attempting to minimize the rejection of acquisition of new knowledge (Postholm, 2008b) that may appear when new knowledge does not correspond with the individual's existing construct (Von Glasersfeld, 1989). In addition, the teachers discussed the implementation in a group that included other teachers with different PCK orientations. The meeting of the heterogeneous group of teachers, each with her unique PCK orientation, allowed the construction of new knowledge within each teacher's unique cognitive structure. The exposure to other teachers' and researchers' PCK orientation enabled the teachers to improve their design of teaching and learning materials while further improving their teaching practice and subsequently expanding their unique PCK.

Retention of major parts of the expanded PCK a year after termination of the program implies that designing and implementing new teaching and learning materials accompanied by biology and science education courses might provide a powerful means for PCK expansion. It is recommended that program designers focus on expanding each teacher's own PCK for better performance. This is a subject for further research, which might provide a better understanding of the importance of professional development programs that focus on designing new teaching and learning materials suggested by the teachers themselves, thereby improving science education as well as teachers' PCK. In addition, an examination of the other PCK categories could potentially reveal additional important factors that might challenge teachers' current beliefs about teaching and learning science. This, in turn, could push them to explore ways to learn about, experiment with, reflect on, and share information on learning and teaching in the context of implementing new curriculum materials with colleagues (Bybee et al., 2003; Tytler et al., 2009).

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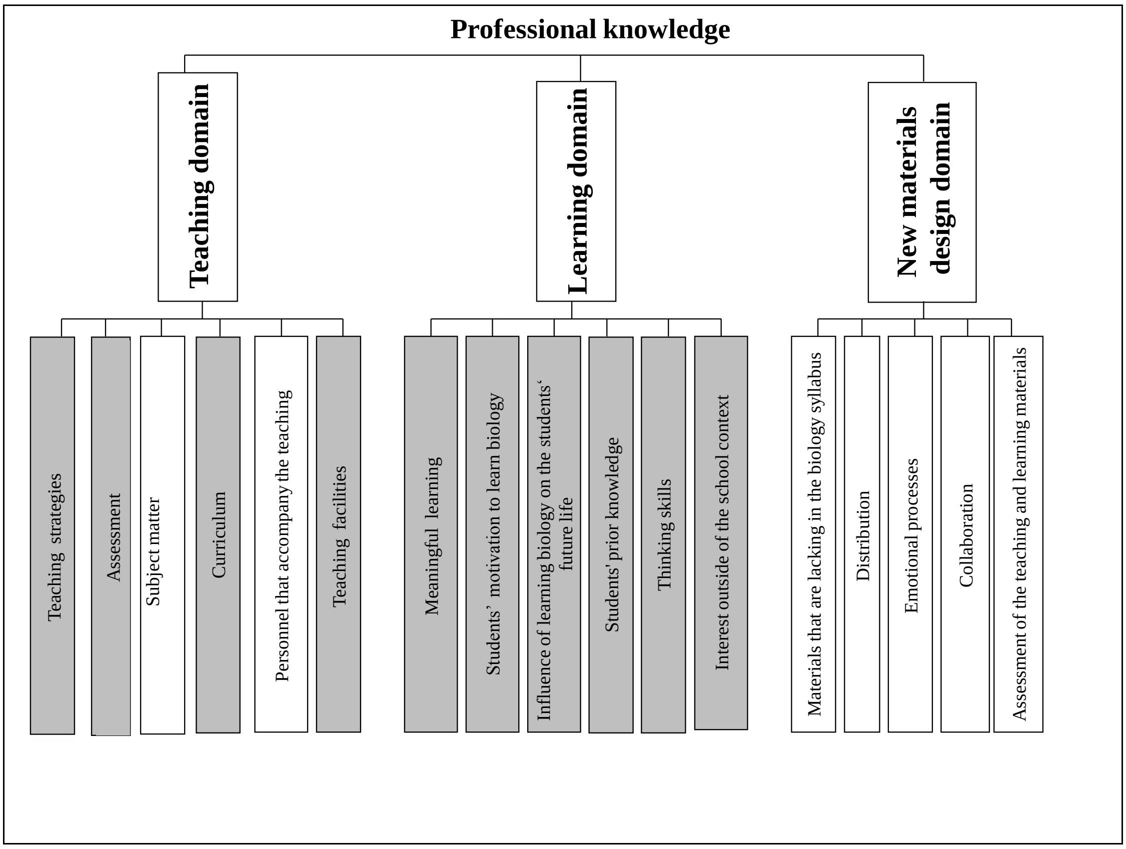

Figure 1: Biology teachers' professional knowledge. Data were classified to three domains: teaching, learning and initiatives design. Each domain includes several components. The PCK components, that were identified to be aligned with the current literature, are marked in grey.

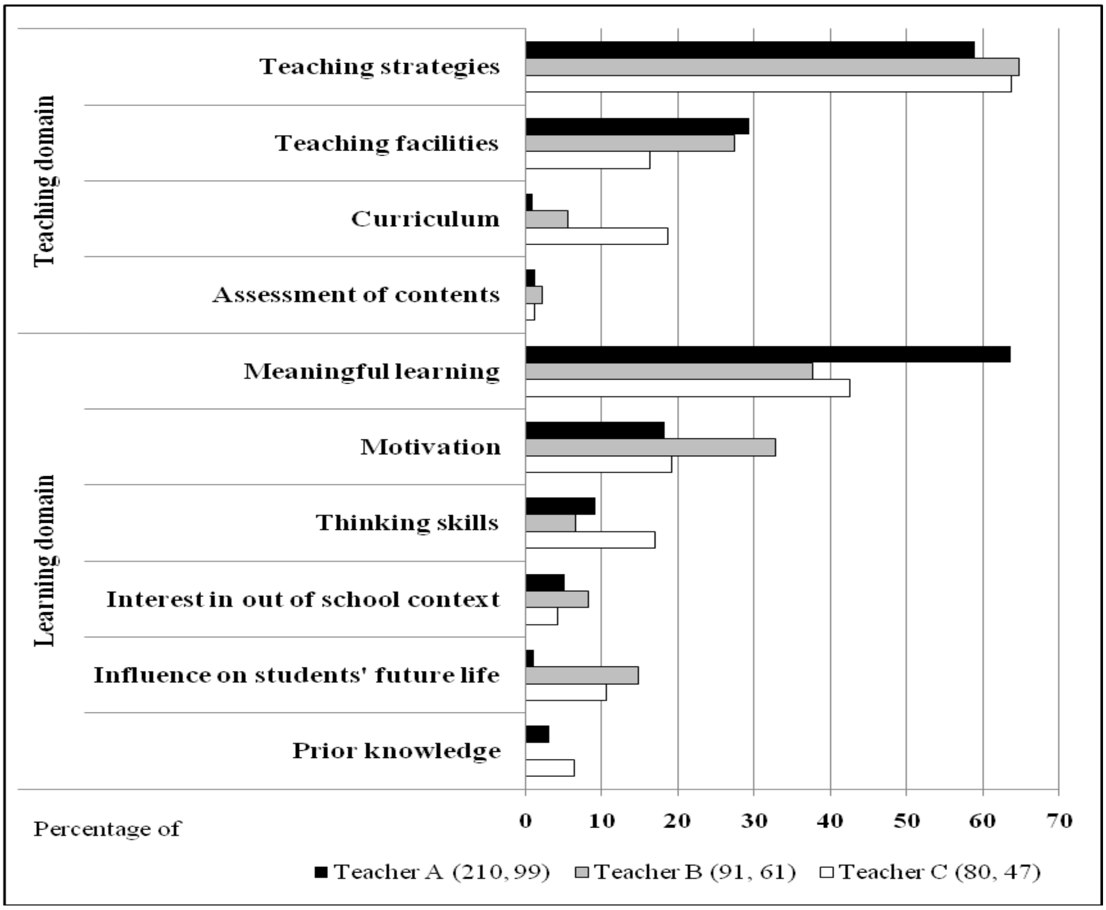

Figure 2: Distribution of the PCK components related to the Teaching domain and the Learning domain (in percentage, n1 = number of episodes in the Teaching domain, n2 = number of episodes in the Learning domain)

Table 1: The professional experience and the subject of teaching and learning materials of the three teachers that participated in this study

Teacher	Field of M.Sc. studies	Years of high-school teaching experience	Subject of the new teaching and learning materials
A	Nutritional sciences	17	The cell content through laboratory experiments
B	Immunology	17	Bioethical dilemmas
C	Ecology	12	Bioethical dilemmas

Table 2: *A summary of data analysis and quotations on teaching strategies and meaningful learning taken from Teacher A's episodes during the four course stages. n =numbers of episodes*

Stages in the course / PCK category	Stage 1	Stage 2	Stage 3	Stage 4
Teaching strategies (*n* = 137)		*"I would like to hand them [the students] an article that has four types of links: 1. connections to their knowledge; 2 connections to research data; 3 connections to laboratory instructions; 4. connections to an additional related article*."	*"This article is short. They read it in class and I think this is a good opportunity to exercise reading comprehension to be added to their knowledge expansion*."	"*In the new initiative I suggest using the laboratory lessons as sources for knowledge construction*."
Meaningful learning (*n* = 63)	*"I don't think that teaching the nature of science is important. Two preconditions are required before teaching it: a lot of content knowledge and basic thinking capability. But not everyone can reach it, and it requires a lot of time to teach high-order thinking skills. It is not intuitive. I don't have time."*	*"The connection between the knowledge acquired in class and the laboratory activities will make them understand that the things they learned are really done."*		*"I think that challenging a student's thinking when he watches a phenomenon in the laboratory and trying to find an explanation is motivating and a great science thinking practice. When learning becomes active it is remembered better…The student is experiencing the laboratory activity before learning the content in class. He uses the laboratory activity as a source of learning."*
Summary of data analysis	Teacher A believes that students have difficulties to use high-order thinking skills and that there are times constrains to teach through high high-order thinking skills.	Teacher A suggests connecting prior knowledge to newly acquired knowledge using high order thinking skills through laboratory experiments in order to enhance the establishment of previously learned contents.	Teacher A attempts to use high-order thinking skill as a teaching strategy for meaningful learning via reading comprehension.	Teacher A teaches using inquiry and expresses confidence in her students' ability to use high-order thinking skills aimed at knowledge construction.

Table 3: *A summary of data analysis and quotations on teaching strategies and meaningful learning taken from Teacher B's episodes during the four course stages and a summary of data analysis. n =numbers of episodes*

Stages in the course / PCK category	Stage 1	Stage 2:	Stage 3:	Stage 4:
Teaching strategies (n = 59)	*"I teach associatively. My strategy is to insert stories into my lessons that are not connected to the subject matter. That way my students think: 'Oh! This is not connected to learning; we should listen'."*	*"I teach them until six o'clock in the evening, so I 'feel' them. If something upsetting happened to them during the day, I immediately change my plans. I may tell a joke or some interesting story to 'wake them up'."*		*"I have two good nature movies…I also have leading questions that I prepared in advance. It is an excellent way to summarize the subject of relationships between organisms."*
Meaningful learning (n = 23)	*"Through the stories they will remember biology…I see that they remember emotional experiences. It is only if they go through an emotional experience that they remember…Although it seems like I am wasting time I think that if the story causes an association in the students' minds they will remember it."*	*"When learning, our students should have a 'wow!!!' feeling. Like the other day a student told me at the end of my lesson: 'wow! Today's lesson was worthwhile!'"*	*"At 5.00 pm there is no meaningful learning. They wish to sleep or play basketball. I need a dramatic story in order to make them listen to me and remember the lesson's content"*	*"I paid attention that sometimes students think that what I tell them, let's say about C-4 plants, is the norm. I tell a story and they think this is the norm, so we have to be very careful not to induce misconceptions."*
Summary of data analysis	Teacher B believes that students are not interested in learning biology therefore, she uses dramatic stories in order to enhance motivation to listen to her. She declares that dramatic stories may induce emotional feelings that may in turn lead students to long-term recall of the biological contents.			Teacher B speaks about the importance of teaching according to a teaching sequence. She prepares teaching activities in advance and is paying attention to students' misconceptions.

Table 4: *A summary of data analysis and quotations on teaching strategies and meaningful learning taken from Teacher C's episodes during the four course stages and a summary of data analysis. n =numbers of episodes*

Stages in the course / PCK category	Stage 1:	Stage 2:	Stage 3:	Stage 4:
Teaching strategies (*n* = 51)	*"My main goal in class is to educate my students to be a part of the community, part of the environment and the universe. I like biology and I insert examples from everyday life to exemplify the importance of human values through biology."*		*"Now, when a student answers me it doesn't satisfy me. I keep asking her to explain her answer in a more detailed way and I listen carefully to see if she really understands. I keep asking her until I am sure she understands. I am also more alert to misconceptions."*	*"We basically intended to design a dilemma for the core contents. Here we demonstrate how to summarize the 'human body' content. I ask my students:'If no insulin is secreted, how does it affect the body?' I use the dilemma as an additional tool for teaching biological contents."*
Meaningful learning (*n* = 20)	*"They need to understand the relevance of biological processes to everyday life."*	*"It broadens the students' horizons. The beauty is that they understand that there is no definite answer. There are no yes-or-no answers. We all know the same facts but decide differently. I think it is of very important educational value."*		*"Here we built a worksheet with questions that lead the students to understand the biological basis of the dilemma. Furthermore, it summarizes the homeostasis topic which is also an important issue for the discussion."*
Summary of data analysis	Teacher C declares that her role in the class is promoting human values among students via biology. She believes that emphasizing the relevance of biological contents is a valuable way for promoting meaningful learning.		Teacher C scaffolds biological content knowledge and establish students' understanding while teaching with the help of leading questions as an additional goal of her teaching.	

Online Resource ESM1: The professional development program course plan

Outline of the courses plans that ran for two academic years

Details of the "Initiatives Design workshop"				Additional courses and plans
Meeting no.	**Stage number**	**Stage focus**	**Special activity**	
1-3	1	Eliciting prior knowledge	What is your teaching dream?	Summer vacation
4			What is your idea about a teaching initiative?	
5			What are your expectations from this program?	Laboratory Activities for Microbiology Teaching Introduction to Science Education
6			What defines initiatives in high-school?	
7-10	2	Planning the design of the preliminary part of the initiative	Design your initiative's idea	
11			Prepare your initiative's idea presentation	
12			Presentation of the initiative's idea to other teachers and researchers	
13			Presentation of the initiative's idea to the chief inspector of biology education	
14			Presentation of the initiative's idea to different science teachers and science education researchers	
15			What did you learn from the presentations?	
End of semester			Teach your initiative in class and assess it	
1	3	Assessing the preliminary part of the initiative	What did you learn from teaching the activity?	Experiencing Contemporary Research in the Life Sciences Cognition, Learning and Instruction
2			What does science education know about APL?	
3-4			Evaluation of teaching programs	
5			Reflect on your assessment	
6			Rewrite your initiative's goals	
7			Assess your students' arguments	
8			What does science education suggest to do with argumentation?	
9			Design a poster that reflects your initiative and the initial's part assessment	
10			An alternative way of teaching APL	
11-13			Design a poster that reflects your initiative and the assessment of the initial's part	
14			Reflection on the first year initiatives' program	
End of First year			Written assignment about the initiatives' design implementation and assessment	
1	4	Writing the whole initiative and distributing it to other teachers and researchers	Meeting expectations: writing and distributing the whole initiative – time table plan	Biology of Stem Cells Selected Topics in Teaching and Learning Biology
2	4		What does science education tell us about written teachers' guides?	
3-4	4		Writing the whole initiative's activities	
5-7	4		Presentation of the new initiative to the course members	
8	4		Define your initiative's model	
9	4		Refining the initiative	
10	4		Planning of the presentation of the initiatives to the chief inspector of biology education	
11	4		Presentation of the initiatives to the chief inspector of biology education	
12	4		Professional development programs: how does it help teachers	
13	4		Why your initiative will not "work" in my class? Teachers reflect on each other's initiative	
14	4		Reshaping the initiatives in light of the teachers' reflections	
15	4		What is the DNA of your initiative?	
End of semester			Assignment: write your full initiative's plan	
1	4	Writing the whole initiative and distributing it to other teachers and researchers	What is the biology teachers' role and does the initiative meets it?	Selected Topics in Ecology Learning Technologies
2	4		Different professional development models	
3	4		What does science education tell us about professional development programs	
4-5	4		Design your distribution	
6-7	4		Presentation of the distribution plan to the initiatives' group members	
8-9	4		Presentation of initiatives to biology teachers and science education researches	

10	4		Reflection on the presentations	
11-12	4		Presentation of the initiatives to biology teachers and science education researches	
13	4		What did the distribution contribute to you personally and professionally?	
14	4		Reflection: evolution from a teacher to the initiatives' designers and back to class	
		End of program		

Online Resource ESM2: Examples of citations that were classified to teach the ten PCK components:

1. The teaching domain.

i) *Knowledge and beliefs about teaching strategies*: Knowledge and beliefs about the ways a teacher should teach. In other words: the teaching technique. For example Teacher B said at a lesson during the second stage: "My strategy is to insert in to my lesson stories that are not connected to the subject matter. That way my students think: 'Oh! This is not connected to learning, we better listen.'"

ii) *Knowledge and beliefs about assessment of related contents:* Knowledge and beliefs about the dimensions of scientific literacy that are important to be assessed and knowledge of the methods by which that learning can be assessed. For example, Teacher C wrote a question via email to the moderators regarding to developing an entrepreneurial in bioethics: "I don't know how we can assess students' argumentations."

iii) *Knowledge and beliefs about the curriculum:* Knowledge of the curriculum, including knowledge of the general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals. This category includes also the goals for teaching science at a particular grade level due to specific curricular demands. For example, Teacher B said while presenting her rationale for the development of her materials in bioethics to the other teachers: "It's a demand of the curriculum to teach bioethics, but teachers don't have materials."

iv) *Knowledge and beliefs about available teaching facilities*: knowledge and beliefs about the availability of appropriate resources for teaching. This category contains physical recourses like a projector, computers or teaching time and content knowledge recourses such as the need to be up-dated with new biological knowledge and the over load of new teaching programs. For example, Teacher A said during one of the first meetings of the workshop: "We will never have enough time to teach all this innovations in science."

2. The learning domain.

v) *Knowledge and beliefs about students' meaningful learning:* Knowledge and beliefs about the factors that promote meaningful learning in the students' mind. For example, Teacher C wrote in an assignment during stage three: "The adapted article helped the students establish their prior knowledge. They learned in the genetics lessons about PCR, now when reading the article they understand what is the use and implications of PCR in the real world".

vi) *Knowledge and beliefs about students' motivation to learn biology* Knowledge and beliefs about factors that influence student's motivation to learn specific themes or contents in biology. For example, while developing the bioethics materials Teacher B said to Teacher C: "I think that curiosity reinforces students' will to learn."

vii) *Knowledge and beliefs about the influence of biology learning on the students' future life:* Knowledge and beliefs about the influence of the topics learned in class on the students' future life. For example, Teacher A said to the other teachers and the researchers while presenting her materials design and implementation during the fourth stage: "I think that if we will elevate interest in biology the students will learn science in the university and may become researchers."

viii) *Knowledge and beliefs about students' prior knowledge:* Knowledge and beliefs about the knowledge and conceptions that students bring with them to the lessons. For example, Teacher C said during a workshop meeting in stage three: "That’s why we can teach bioethics only in high school, after the students learned genetics."

ix) *Knowledge and beliefs about students’ thinking skills*: Knowledge and beliefs about students' thinking skills while learning and their possible ability to use high order thinking skills. For example, in stage four, Teacher A wrote in the final assignment: "In laboratory lessons students often don't understand why they have to set the control category. Therefore, high order thinking skills should be taught."

x) *Knowledge and beliefs about students' interest outside of the school context*: Knowledge and beliefs about students' concerns, hobbies or activities during their after school hours that may affect learning. For example, Teacher A said during a workshop meeting in the first stage: "We forget that this is a new generation. They are very individualists. Each one is staying at home with his computer or MP3. They barley meet after school. Collaborative learning will be difficult."

Appendix 5

Rozenszajn, R., & Yarden, A. (submitted). Tacit relationships between biology teachers' content knowledge (CK) and their professional knowledge

Abstract
Considerable effort has been made in the last three decades to construct a well-established conception of science teachers' knowledge. There are several types of knowledge that are known to be required for teaching, including content knowledge (CK) and pedagogical content knowledge (PCK). Exploring the relationships between CK and PCK is not a straightforward process due to their internal tacit nature. Various methods for measuring CK and PCK have been developed to understand the role of CK and the connection between CK and PCK in teachers' practice and professional development programs. Here we examine the possible relationships between CK and in-service biology teachers' professional knowledge using the repertory grid technique (RGT), which has been used to elicit experts' personal tacit knowledge. The context of this study is a professional development program for outstanding science teachers aimed at enriching the teachers' knowledge in contemporary science and science education topics. Data collected from 20 in-service experienced high-school biology teachers revealed that CK is an important component of biology teachers' knowledge and that it may be by and large distinct from the biology teacher's professional knowledge, including their PCK. We therefore suggest that professional development programs consider strengthening the relationships between biology teachers' CK and PCK and not assume that increasing CK will automatically lead to an improvement in teachers' PCK.
Keywords: *Pedagogical content knowledge; Content knowledge; Tacit knowledge; Personal Construct Theory, Repertory grid techniqu*e

Tacit relationships between biology teachers' content knowledge (CK) and their professional knowledge

Rationale

Experienced teachers possess special knowledge, acquired during their teaching. Considerable effort has been made in the last three decades to construct a well-established conception of science teachers' knowledge. It was Shulman (1986) who first suggested that there are several types of knowledge that are required for teaching, including content knowledge (CK) and pedagogical content knowledge (PCK). Shulman defined CK as the amount and organization of subject matter knowledge per se in the teacher's mind, and PCK as a unique amalgam of content and pedagogical knowledge that reflects the ways in which the subject is presented and formulated to make it comprehensible to others (Shulman, 1986, 1987).

Both CK and PCK are considered critical professional development resources for teachers, each requiring special attention during teacher training and classroom teaching practice (Baumert et al., 2010). While many scholars agree with Shulman's (1986) categorization of science teachers' knowledge which distinguishes CK from PCK (Grossman, 1990; Krauss et al., 2008; Lederman & Gess-Newsome, 1992; Magnusson et al., 1999), others refer to CK as an integral part of PCK (Ball et al., 2008; Hill, 2008; Lee & Luft, 2008; Marks, 1990).

Various methods for measuring CK and PCK have been developed to understand the role of CK and the connection between CK and PCK in teachers' practice and professional development programs. These methods include meta-analysis (Zeidler, 2002), analysis of teachers' declarative explicit knowledge through interviews, knowledge tests such as multiple-choice and open-ended questions about teaching and learning situations (Baumert et al., 2010; Hill, 2008), and class observations (Author, 2011; Lee & Luft, 2008; Van Driel et al., 1998). Nevertheless, the debate over the distinction between CK and PCK within teachers' knowledge continues, especially since examining teachers' PCK is not a straightforward task due to its complex nature and its internal tacit construct (Loughran et al., 2001), as well as its dependence on context (Van Driel et al., 1998). Indeed, in-service teachers who develop expertise in teaching hold tacit or intuitive knowledge—the experts know what they should do while teaching, but cannot necessarily explain why it should be done (Bjorklund, 2008).

Here we examined the possible relationships between CK and in-service biology teachers' professional knowledge using the repertory grid technique (RGT) which has been previously used to elicit experts' personal tacit knowledge (Fransella et al., 2004; Jankowicz, 2001). This study focused on high-school biology teachers who were participating in a long-term professional development program that was especially designed for outstanding science teachers (see research context below). The main goal of this study was to expose the professional knowledge dimensions of in-service biology teachers and their possible tacit relationships with the teachers' CK.

Theoretical Framework

Teachers' Knowledge Base

Teachers hold a unique teaching knowledge known as PCK. Shulman (1986) was the first to suggest referring to professional teachers' knowledge as a special knowledge domain, divided it into three categories: (a) subject matter CK—the amount and organization of knowledge per se in the teacher's mind; (b) PCK—the dimension of subject matter for teaching, namely the ways of presenting and formulating the subject to make it comprehensible to others, and (c) curricular knowledge—the knowledge of alternative curriculum materials for a given subject or topic within a grade (Shulman, 1986).

Numerous science educators have discussed and revised Shulman's PCK model, suggesting more detailed representations. Grossman (1990) proposed a model that provides four categories of PCK: conceptions of purposes for teaching a subject matter, knowledge of student understanding, curricular knowledge, and knowledge of instructional strategies. Magnusson et al. (1999) changed Grossman's use of the term 'purposes' to 'orientation', added beliefs to knowledge, and added an additional category: knowledge and beliefs about assessment. Major effort has been invested in constructing a well-established conception for PCK and its related categories (e.g. (Author, 2011; Gess-Newsome, 1999; Lee & Luft, 2008; Park & Oliver, 2008b).

Researchers agree that PCK is used in the context of teaching a specific content (Ball et al., 2008; de Jong & Van Der Valk, 2007; Lee & Luft, 2008; Loughran et al., 2001; Loughran et al., 2008; Magnusson et al., 1999), but the resolution of the term "specific content" is a subject for debate. While some researchers refer to the term "content" of the construct PCK as the knowledge of teaching a specific subject matter (de Jong & Van Der Valk, 2007; Henze et al., 2008; Loughran et al., 2008; Van Driel et al., 1998), others refer to it as "the knowledge of teaching all the topics they teach" (Magnusson et al., 1999), or "discipline-specific knowledge as well as general science" (Abell, 2008). Berry et al. (2008), quote an interview with Lee Shulman that was conducted at the Annual Meeting of the American Educational Research Association (AERA), in Chicago, on April 2007. In this interview Shulman refers to PCK as the knowledge of teaching the whole domain, giving an example of teaching biology: "Well that's why the pedagogy of biology is an example of PCK. Because you've got to deeply understand what it is that makes evolutionary theory? whether you think ecologically or cellularly". In other words, teachers need to go beyond knowledge of facts or concepts of a domain to the explanation of the structure of the domain and the basic principles and the rules that determine the disciplinary domain. Therefore, PCK can be considered either as the knowledge of teaching a whole domain, or as the knowledge of teaching a specific subject matter within the domain. Here we follow Shulman's definition of PCK and refer to it as the pedagogical knowledge of teaching biology as a whole domain rather than the knowledge of teaching a specific subject matter in the biology domain (e.g., genetics). .

In addition to the need to understand PCK, the interconnectedness between PCK components and CK as an integral part of teachers' knowledge for practice has been raised. Some researchers suggest that CK may enhance teachers' quality of teaching. For example, in mathematics education, the breadth, depth, and flexibility of teachers' understanding of the mathematics they teach afford them a broader and more varied repertoire of teaching strategies (Ball et al., 2008; Baumert et al., 2010; Even, 2011; Krauss et al., 2008), while limited CK has been shown to be detrimental to PCK, limiting the scope of its development (Baumert et al., 2010). Moreover, it has been suggested that the degree of cognitive connectedness between CK and PCK among secondary mathematics teachers is a function of their degree of mathematical expertise (Krauss et al., 2008). In other words, it was suggested to be impossible to distinguish CK from PCK (Fernandez-Balboa & Stiehl, 1995; Marks, 1990). In contrast, other studies have indicated that science teachers' subject matter knowledge is not automatically transferred to classroom practice (Lederman & Gess-Newsome, 1992; Zeidler, 2002), implying that CK and

PCK are different and distinct domains within the teacher's cognitive structures (Grossman, 1990; Magnusson et al., 1999; Shulman, 1986). Examining the relationships between PCK and CK is not a straightforward undertaking because expert teachers hold tacit knowledge about the role of PCK in their practice (Bjorklund, 2008) which is not easily revealed.

Tacit Knowledge and the Personal Construct Theory

Tacit knowledge comprises a range of conceptual and sensory information and images that can be called upon when attempting to make sense of something. This kind of knowledge is often acquired through repeated experiences with a certain domain. The person who holds tacit knowledge about something will be unable to verbalize it and will often be unaware of it (Polanyi, 1966).

Tacit knowledge is contextual and situated. It is acquired through repeated experiences with a certain domain. That is, as one repeatedly goes through certain experiences, one becomes an expert in that field. Experts are usually able to recognize meaningful patterns faster than novices (Chi, 2006; Dreyfus, 2004). Experts facing an unfamiliar situation will intuitively identify what should be done: they seem to not even think about it. They just do what normally works and, of course, it usually works (Dreyfus, 2004). Experts are generally unable to verbalize their 'know how' (Bjorklund, 2008), meaning that they know more than they can say (Polanyi, 1966).

Polanyi (1966) argued that tacit knowledge involves functional relationships between an awareness of a phenomenon, which he defined as the 'proximal terms' of tacit knowledge and attending to its consequences, the 'distal terms'. The way in which one moves from the proximal terms to the distal terms, thus achieving an integration of particulars into a coherent entity, constitutes one's tacit knowledge. Since the particulars themselves are not being considered, one cannot identify them but may be aware of them in their bearing on the comprehensive entity they constitute. It may be said that it is not by looking at the particulars, but by dwelling on them, or in other words internalizing them, that their joint meaning can be understood, without being able to specify each of the components.

Moreover, individuals interpret their reality in an attempt to make sense of the external world through looking, listening, touching, feeling, perceiving and moving (Bezzi, 1999).Individuals store sensory information in their implicit memory as signal patterns together with a qualitative emotional assessment of the events (Chi, 2006; Dreyfus, 2004). This enables them to give meaning to a phenomenon by recognizing the sensory patterns they are experiencing from those stored in their implicit library of old experiences (Bjorklund, 2008).

Experienced teachers are usually able to function automatically. Many of their activities in class, such as their interactions with students, are behavioral patterns that they can invoke and perform without any conscious effort. Experienced teachers seem to have organized their knowledge of students and classrooms in particularly effective patterns that can be retrieved unconsciously from their long-term memory via classroom cues (Johansson & Kroksmark, 2004).

The inability to verbalize tacit knowledge, and the fact that teachers may not even know that it is there controlling their decisions and actions, led us to search for a suitable method to elicit teachers' tacit non-verbal knowledge. Such a method was suggested by the American psychologist, George Kelly, who formulated the Personal Construct Theory (Kelly, 1955). Eliciting tacit knowledge in the area of science education has been previously used for probing students' system thinking skills (Ben-Zvi Assaraf & Orion, 2005), exploring the perceptions held by a university geology instructor and his students (Bezzi, 1999), exploring possible relationships between teachers' conceptions about science and the types of inquiry activities in which they engage students (Bencze, Bowen, & Alspo, 2006), and investigating the change in teachers' reflections on the nature of science while teaching a new syllabus (Henze, Van Driel et al., 2007). Here we used this method to expose the professional knowledge dimensions of in-service biology teachers and their possible tacit relationships with the teachers' CK.

Kelly (1955) argued that people have different views of events in the world. These views are organized uniquely within each person's cognitive structure. Kelly (1955) established a psychological theory, the Personal Construct Theory, which argues that each person makes use of unique personal criteria, constructs to help him or her construe meaning from events. The Personal Construct Theory states that peoples' view of the objects and events with which they interact is made up of a collection of related similarity–difference dimensions, referred to as personal constructs (Kelly, 1955, 1969).

Kelly drew explicit parallels between the processes that guide scientific research and those involved in everyday activities (Bezzi, 1996; Bradshaw et al., 1993). Like scientists, people tend to predict and control the course of events in their environment by controlling mental models of the world. These mental models enable individuals to formulate testable hypotheses about future events, and then test them against their experience and revise them (Ben-Zvi Assaraf & Damri, 2009; Duit & Glynn, 1996; Duit & Treagust, 2003). Such acts or judgments of events are often experienced as intuition or gut feelings (Jankowicz, 2001) because of their tacit nature.

Following the formulation of the Personal Construct Theory, Kelly designed a method to elicit personal constructs, namely tacit knowledge, which is known as the repertory grid technique (RGT). The RGT has been used in clinical psychology for over 50 years but has recently found new use in a variety of research areas. The findings from experimental psychology and cognitive science on implicit learning and knowledge, the ideas of dual cognitive systems and the interest in tacit knowledge have given rise to new expectations for the use of this method (Bjorklund, 2008).

The Repertory Grid Technique (RGT)

The RGT is designed to elicit and probe personal tacit knowledge. It is a phenomenological approach which is more closely aligned with grounded theory and interpretive research than with positivist, hypothesis-testing, approaches. The focus is on understanding, before developing theories that can be subsequently proved or disproved (Edwards et al., 2009). The technique appeals to the person's concurrent tacit knowledge on a given topic and encourages that person to confront his or her intuitions, to make the tacit explicit (Jankowicz, 2001).

To further clarify the RGT, here we describe its general principles. The details of the method used in this study are described in the methods section. Every grid of the RGT consists of four components: *topic, elements, constructs* and *rating*. These components are usually elicited in a four-step procedure between an interviewer and an interviewee; (1) Introducing the topic; (2) Choosing the elements; (3) Elicitation of personal constructs; (4) Rating. Elicitation of *elements* (alternative events, states, or entities within a particular topic) and *constructs* (dimensions of similarity and differences between elements which each person uses to explain his or her choice of the exceptional element in a triad and the similarity of the two other elements) are central to knowledge representation in the repertory grids. The RGT allows identifying what a person means when she or he uses elements and constructs and a picture of what a person wishes to say about the topic in question. (For detailed description of the four steps see the 'Repertory Grid Technique' in the Methodology section).

In recent years, some researchers using repertory grids have deviated from Kelly's underpinning assumption that each individual constructs his or her world model personally. This has led to the emergence of three types of grids: (i) *full repertory grid*, where the individual identifies both the elements and constructs; (ii) *partial repertory grid*, where the individual is supplied with the elements and then identifies his or her personal constructs; (iii) *fixed grid*, where the individual is supplied with both the elements and the constructs (Edwards et al., 2009).

Kelly (1969) assumed that the meaning we attach to events or objects defines our subjective reality, and thus the way in which we interact with our environment. Kelly's own characterization of his theory was to see it as an expression of "constructive alternativism": that is, there is never a single "correct" way of seeing things. Existence and our understanding of it is something we have to negotiate within ourselves, whether we call ourselves scientists or ordinary people, managers or workers, seeking to make sense of what is going on. There are no absolutes, no right or wrong answers. The theory is best used when participants have practical experience with the studied domain because they must be able to identify representative elements and compare them through a set of their own criteria (constructs).

Researchers choosing to use the repertory grid argue that this technique is free of external influences (Bezzi, 1999; Fransella et al., 2004; Henze, Van Driel et al., 2007; Jankowicz, 2004). The repertory grid overcomes the difficulties inherent in the collection of data with "traditional" instruments of investigation, in which interviewees are supposed to perceive and interpret the researcher's questions to match the researcher's meaning. Problems of interpretation also exist in the clarification of observations or questionnaires, because these may force responders into predetermined channels dependent upon cultural assumptions and purposes designed by researchers (Bezzi, 1999). The RGT allows expression of their view by means of their own constructs. It allows the investigator to identify what the other person means when she or he uses the terms suggested as an element and a construct. Each element is rated on each construct, to provide a picture of his or her personal mental model—a statement of the way in which the individual thinks of, gives meaning to, *constructs* the topic in question (Jankowicz, 2004).

The main goal of this study was to expose the professional knowledge dimensions of in-service biology teachers and their possible tacit relationships with the teachers' CK by means of a full repertory grid. Two questions addressed the main goal:

3. What is the biology teachers' professional knowledge repertoire?
4. What are the relationships between biology teachers' professional knowledge and their CK?

Methodology

Research Context

The context of this study is a unique professional development program for outstanding high-school science teachers entitled "XXX" given at the XXX Institute. The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science or mathematics and science education theories. This unique program is divided into two paths, A and B.

Path A is specially designed for outstanding high-school science teachers who hold a Bachelor of Science (BSc) degree and are studying toward a Master's degree in science education without a thesis in the course of the program. The program's curriculum runs for eight hours a day, twice a week, over the course of four semesters. Each semester, the teachers participate in different science and science education courses.

Path B is designed for outstanding high-school science teachers who hold a graduate degree (MSc or PhD). The aim of this program is to provide a learning environment that may enrich the participating teachers' knowledge in both contemporary topics in science and in science education theories. The program's curriculum runs for eight hours a day, once a week, over the course of two years (four semesters). Each semester, the teachers participate in different courses in science.

The program for biology teachers in Path A and Path B includes a long-term "Designing New Teaching and Learning Materials" workshop, which served as the context for this research. The workshop is aimed at promoting the teachers' professional development through design activities. The workshop lasted three semesters for Path A and the product of this longitudinal course was the teachers' final projects of their Master's studies. The workshop lasted throughout the duration of the program for Path B and the products of this longitudinal course were the teachers' final projects of the program (Authors, submitted). The first author of this report was one of the lecturers in both long-term workshops. A detailed description of the professional development program courses in both Path A and Path B appears in Appendix 1.

Research Population

The population of this study consisted of a total of 20 teachers participating in the above-described professional development program. The study population included experienced in-service high-school biology teachers from Path A and Path B with 4–22 years of teaching experience at the beginning of the program. The participating teachers were from a variety of high schools: national (n = 11), religion-oriented (n = 7), boarding school (n = 1), and Bedouin (n = 1). The number of years of teaching experience and the type of school at which the teachers taught during this research are summarized in Appendix 2.

At the time of the study, the first Path A group, termed Class AI, consisted of four teachers (teachers A1–A4). The second group, Class AII, consisted of 12 teachers (A5–A16). The Path B group, Class BI, consisted of four teachers (B1–B4).

During the curriculum development workshop, the teachers were encouraged to use the new knowledge acquired during the program's courses in the design of their new teaching and learning materials. The teachers implemented their newly designed materials in their classes, giving them the opportunity to assess the feasibility of the new materials in their everyday practice. The products of this longitudinal workshop were the biology teachers' final projects of their studies.

Repertory Grid Technique (RGT)

The tacit dimensions of teachers' professional knowledge were analyzed according Kelly's Personal Construct Theory (Kelly, 1955) using the RGT, in which every grid consists of four components: topic, elements, constructs and ratings. We followed the four above-described elicitation steps of the full RGT with each group of teachers separately, at the termination of the professional development program. The four steps that were taken are detailed in the following.

Step 1—Introducing the topic: The topic of this research was teachers' knowledge. As such, our interest in teachers' knowledge was first declared to each group of teachers. We then briefly introduced the main rationale of the Personal Construct Theory (Kelly, 1955, 1969) and the idea that experts hold tacit knowledge (Polanyi, 1966) using a PowerPoint presentation that was specially designed for this introduction. The presentation included slides that presented the term PCK and the idea of 'teachers' professional knowledge' that combines knowledge and beliefs about teaching and learning following Shulman's (1986) theory and some examples of PCK. Then the notion of experts' tacit knowledge (Polanyi, 1966) was explained as well as Kelly's Personal Construct Psychology theory (1955). At the end of the presentation, we emphasized that there are no 'right' or 'wrong' answers and that we are interested in the teachers' unique professional knowledge. After the termination of the presentation, which lasted approximately half an hour, we asked each group of teachers the same question: "What does a biology teacher need to know in order to be a good biology teacher?" emphasizing that we are interested in the unique knowledge that each teacher holds.

Step 2—Choosing the elements: From this step on, each teacher filled in the repertory grid individually but teachers from each group stayed in the same room. Each teacher was asked to write down, on 12 separate cards, the elements that a teacher should possess in order to be a good biology teacher. (for an example of elements elicited by one of the teachers, see Table 1).

Step 3—Elicitation of personal constructs: The constructs in this research were elicited following Kelly's method of triads (Kelly, 1955). Each teacher was asked to fold each element card so that he or she could not see what was written on it, place all 12 cards on the table and randomly pick three cards. Then, each teacher was asked to write down the contained elements in a four-column table, each element in a separate column, and to choose the exceptional element of the three, circle it, and write down in the fourth column the reason that two of the elements were similar and the third exceptional. The teachers were then asked to refold the cards, return them to the table, mix them and then again randomly choose three cards. This action was repeated 10 times with each interviewee.

Step 4—Rating: At this stage each teacher was briefly interviewed individually in order to define his or her constructs. Repeated explanations for choosing the exceptional elements were defined as constructs, which is why there are only a few constructs (usually between 4 and 6) in each cluster. Each teacher was then asked to write down the opposite of a given construct, meaning that he or she had to define the construct poles (for an example of construct definitions and their opposites see the right and left columns in Table 1). Then the teacher was handed an empty table (similar to the one presented in Table 1) and asked to write the poles of each construct at opposite ends of each row. On the right-hand side, the teacher was asked to write the definition of each construct and on the left-hand side, the opposite of the construct's definition. Each teacher was also asked to write his or her 12 elements, each as a header of a separate column. Then each teacher was asked to rate the correlation between each element and each construct on a five-point scale in which '1' means 'totally agree with the left pole of the construct' and '5' means 'totally agree with the right pole of the construct' (for an example of a full table see Table 1). The full tables constructed by each teacher were handed to the researcher for computed data analysis. The analysis is described in detail in the cluster analysis section below.

[Insert Table 1 about here]

Content Analysis

For content analysis of the repertory grid data, all of the interviewees' elements were pooled and categorized according to the meanings they expressed. The categories were derived bottom-up from the elements themselves, by identifying the various themes they expressed (Jankowicz, 2004). The content analysis enabled characterization of the teachers' repertoire of knowledge elements as a community of high-school biology teaching experts.

Cluster Analysis

Once the constructs were elicited and rated, the cluster analysis calculations were performed with REPGRID version 5 software (http://gigi.cpsc.ucalgary.ca:2000/). This program provides a two-way cluster analysis that reorders the teacher's original table (Table 1, for example). The rows of constructs and the columns of elements are rearranged to produce a grid in which there is the least variation between adjacent constructs and elements. The relationships between elements and constructs are visualized as tree diagrams arranging, in close proximity, the most similar rows and the most similar columns in the cluster. The tree diagram presents the elements at the bottom of the diagram (1, in Figure 1) and the coherence rate between the elements (the percentage of similarity between columns) at the top of the diagram using the coherence scale between elements which appears on the upper right side of the diagram (2, in Figure 1). The constructs are presented on the right and left (4, in Figure 1, opposite to each other), and their coherence rate (the percentage of similarity between lines) is presented on a scale on the right side of the diagram (5, in Figure 1).

Over 80% similarity is considered high coherence between the repertory grid's elements or constructs (Kelly, 1969). The distance between elements or between constructs is considered a 'safe' measure for examining the association among elements or constructs (Fransella et al., 2004). The meaning of the high coherence between elements or constructs allowed us to identify cognitive links between elements and between constructs, thus presenting an image of each teacher's personal mental model—a precise statement of the way in which the teacher thinks of or gives meaning to the topic in question (Jankowicz, 2004). Subsequently, we searched for more than 80% coherence between CK elements and other elements, and more than 80% coherence between the CK constructs and other constructs, thus allowing us to identify the teachers' tacit knowledge about the relationships between CK and teaching knowledge. Each teacher's data were analyzed individually and a repertory grid tree diagram (similar to those presented in Figures 1 and 2) was drawn. Each repertory grid tree diagram that was formed for each teacher was called a cluster, and it was formed using the cluster analysis between elements and constructs.

Validation of the RGT

According to Kelly (1969), validity of the RGT is equated with usefulness. Thus many studies are performed using the Personal Construct Theory and the RGT as a way of exploring whether or not the grids are of value for them. Fransella et al. (2004) presented a massive assortment of studies performed since 1977 which found the RGT useful in clinical settings, education, language acquisition, forensic work, market research, politics, and organization and business applications. We also performed interviews for interpretive validity with five biology teachers. During the interviews, the grid map and our interpretations of it were presented to the teachers, and they were asked to express their views on the accuracy of the results. The overall validation rate was 100%, meaning that each of the five teachers agreed with the RGT results and our interpretations.

Results

Biology Teachers' Teaching Knowledge Repertoire

Initially we examined in-service biology teachers' knowledge of teaching. The biology teachers who participated in this research were asked to name 12 knowledge components that they believed a good biology teacher should possess (steps 1 and 2 in the RGT). These components served as the repertory grid's elements in the subsequent analysis, but they were first used for content analysis to examine the teachers' repertoire of knowledge components regarding high-school biology teaching.

Each teacher (n = 20) managed to elicit between 9 and 12 elements, for a total of 230 elements. The 230 elements included 148 different elements, i.e. 82 of the elements were mentioned by 2 to 10 different teachers. Examples of the different elements that different teachers elicited appear in Figures 1 and 2. Each teacher elicited different elements in the CK category. Thus, the teachers who participated in this study possessed a diverse repertoire of biology teaching elements.

The elements were categorized according to their content. Six main groups of elements emerged in the course of the content analysis: (i) CK namely, knowledge of science contents. (i.e., 'biological knowledge', 'knowledge about levels of organization' and 'deep knowledge in science') (ii) teaching skills namely, knowledge and beliefs about the ways a teacher should teach (i.e., 'clear explanations', 'the ability to simplify complex processes' and 'the ability to guide inquiry'); (iii) teacher's personality namely, knowledge and beliefs about personal characteristics of the teacher that may influence teaching (i.e., 'creative', 'moral personality' and 'loves people'); (iv) learning skills namely, knowledge and beliefs about the factors that influence meaningful learning (i.e., 'students' misconceptions', difficulties in comprehending a specific idea' and 'motivation to learn science'); (v) learner's personality namely, knowledge and beliefs about personal characteristics of students that may influence learning(i.e., 'understands students' personality') (vi) relevance namely, knowledge and beliefs about the connection between contents taught in class and the students' everyday world (i.e., 'updated in the students' world and respects it' and 'uses concepts of the students' everyday life'). Three of these categories were aligned with PCK categories that had been previously suggested in the literature: (i) teaching skills was aligned with the category 'knowledge and beliefs about instructional strategies for teaching science' (Magnusson et al., 1999); (ii) learning skills was aligned with the category 'knowledge and beliefs about students' understanding of specific science topics' (Magnusson et al., 1999); (iii) relevance was aligned with the category 'knowledge and beliefs about science curriculum' (Magnusson et al., 1999). The first category that emerged in the context of this study was CK. As already noted, CK is a controversial category. Some researchers refer to it as part of PCK, while others consider it a separate category. The two categories: teacher's personality and student's personality were not aligned with previously suggested PCK categories. They are more likely to be professional knowledge which might influence PCK rather than PCK.

A close examination of the data revealed that each teacher possesses a different repertoire of biology teaching knowledge elements within these categories. Elements of the CK category were mentioned by all of the teachers, whereas the other elements from the other categories were mentioned only by several teachers. Examining the diversity of the elicited elements revealed that most were from four categories: CK (28%), teaching skills (24%), teacher's personality (21%) and learning skills (20%); in other words, the CK category included the most diverse elements among the six groups of elements (Table 2). In addition, the CK category seemed to be the most frequently mentioned category (33% of all of the elements), meaning that one out of each three elements that were elicited by all of the teachers was a CK element (Table 2). The second most frequently mentioned category was teaching skills (23%) followed by teacher's personality (21%) and then learning skills (17%), learner's personality (3%) and relevance (3%) (Table 2). We then focused on analyzing the coherence rate between elements from the CK category and other elements, to better understand their significance to the high-school biology teacher's practice.

[Insert Table 2 about here]

Analysis of Elements

During step 3 of the RGT, the teachers were asked to select the exceptional element among three randomly selected ones, explain their selection and repeat this step 10 times. Constructs were then defined based on repeated explanations of the exceptional element. In step 4, each teacher was asked to fill out a table with ratings of each element relative to each construct (similar to Table 1). The computed outcome of the ratings given by each teacher was a two-dimensional tree diagram—a cluster—which represents similarities between rating patterns of the elements and similarities between rating patterns of the constructs (for examples see Figures 1 and 2).

Teacher A3's cluster is shown here as a case study (Figure 1). Twelve elements that were elicited by Teacher A3 during step 2 of the RGT are slanted at the bottom of the diagram (1, in Figure 1). The rate of similarity (in percentage) between the different elements appears at the top of the diagram on the element coherence rate scale (2, in Figure 1). The graph to the left of the element coherence rate scale shows the similarity rate between the elements that are attached to each line (2, in Figure 1). For example, the elements: 'The human body', 'volume', 'cell', and 'ecology' (3, in Figure 1) are similar with 85% coherence (2, in Figure 1). This means that these four elements constitute a group of elements that are considered similar by Teacher A3 with respect to biology teaching.

[Insert Figure 1 about here]

To examine the significance of CK for high-school biology teachers, we looked at the CK elements and searched for high coherence (more than 80%) between these and other elements mentioned by the teachers. Analysis of each teacher's tree diagram revealed that all 20 teachers participating in this study mentioned CK elements as elements that they believed that a high-school biology teacher should possess (Table 2). All of the teachers connected between different CK elements (Table 2) with high coherence (more than 80%) but not with other elements' categories, namely, the CK elements appeared to be a separate group of elements. In addition, 7 out of the 20 teachers demonstrated high coherence between elements from the CK category and elements from the other categories. Five teachers connected elements of CK to elements of teaching skills (Table 2), such as the ability to demonstrate biological knowledge, to characterize students' understanding and to teach in an experiential way. Two teachers connected CK elements to those of teacher's personality (Table 2), such as enthusiasm for the wonders of nature, curiosity and openness to students' questions and ideas, and personal interest in science.

An exceptional example of a repertory grid tree diagram the repertory grid tree diagram of Teacher A2, is shown in Figure 2. This tree diagram demonstrates high coherence between the CK elements and elements from other categories. Specifically, CK elements 'knowledge beyond the curriculum' and 'knowledge update' (3, in Figure 2) are connected to elements from the personality category: 'creativity', 'enthusiasm for the wonders of nature', 'curiosity', 'openness to new ideas and questioning' and one element from the learning skills category: 'scientific literacy' (2, in Figure 2). As mentioned above, connecting CK elements with other category's elements was rather rare. Most of the teachers did not connect CK elements with other category's elements. These results suggest that CK might form a separate group of elements within most of this research's biology teachers' knowledge structure.

Analysis of Constructs

A similar analysis was performed for the constructs formed by the teachers. The constructs that were defined in step 4 of the RGT are listed opposite each other (4, in Figure 1). The coherence rates between the constructs (in percentages) appear on the right side of the diagram (5, in Figure 1). The graph on the right shows the similarity rates between the constructs corresponding to the graph. For example, the construct 'content knowledge' is 65% similar to the other constructs (5, in Figure 1). This means that 'content knowledge' is a different and separate construct within Teacher A3's cognitive structure regarding biology teaching, since less than 80%

similarity was identified between this construct and the others (following Kelly, 1969).

Similar analyses of the RGT data collected from each of the 20 teachers revealed that 15 of them (75%) elicited the CK construct during step 3 of the RGT (not shown, see Figures 1 and 2 for examples). Five teachers did not use the CK construct (step 4 in the RGT). Fourteen out of fifteen clusters that included CK constructs demonstrated CK as a separate construct with a low coherence rate (less than 80%) with the other constructs (for example 5 in Figure 1).

Only one teacher connected the construct 'content knowledge' and the constructs: 'a subject of the teacher's Toolbox' and 'A thinking skill' with over 90% coherence (5 and 6 in Figure 2). It is worth noting that most of this teacher's elements are CK elements and that they appear in two groups (3, in Figure 2): the first group with 100% coherence between CK elements (correlation between structure and function; content knowledge; ratio between surface and volume; uniformity and differences) and the second group with more than 80% coherence between two elements of CK: ‘knowledge beyond the curriculum’ and ‘knowledge update’, and two elements from the personality category: ‘enthusiasm for the wonders of nature’ and ‘creativity’ (2, in Figure 2). Since the first author of the present report was a lecturer for all biology teachers participating in this research throughout the program and a tutor for the final projects, she was very familiar with the participating teachers and could therefore conclude that this teacher is unique in her approach to CK. This teacher designed a teaching program that included a lot of detail on protein structure. She holds the unique teaching conception that acquiring up-to-date biological CK is very important and very interesting and that it may motivate students to learn biology.

Taken together, the analysis of the elements elicited by each of the participating teachers and the analysis of the constructs suggest that by and large, CK is a unique category of biology teachers' knowledge which is not integrated as part of their PCK or as part of their professional knowledge.

[Insert Figure 2 about here]

Discussion

Biology Teachers' Teaching Knowledge Repertoire

Investigating the interrelationships between various teaching knowledge components may shed light on the nature of PCK and its role in teachers' practice (Abell, 2008; Friedrichsen et al., 2011; Park & Chen, 2012). Park and Chen (2012), who examined the declarative dimensions of PCK, showed that biology teachers tend to connect knowledge of students' understanding and knowledge of instructional strategies and representation, and that these two PCK components might be a target area for PCK improvement. Here we examined the possible tacit relationships between CK and other professional knowledge components of biology teachers by means of full RGT and showed that CK is not integrated as part of their professional knowledge. This finding indicates that CK should not be considered an integral part of biology teachers' PCK, as suggested by Lee and Luft (2008) and others (Ball et al., 2008; Hill, 2008), but can be considered a separate entity, as suggested by Shulman (1986, 1987). Moreover, understanding biology teachers' knowledge about teaching may be an important factor in professional development programs aimed at enhancing teachers' professionalism (Henze, van Dreil et al., 2007).

A group of 20 high-school biology teachers were asked to intuitively elicit knowledge elements that refer to biology teaching practice. Intuitive elicitation of elements is important because the elements come from the teacher's cognitive structure with minimal impact from the researcher (Bezzi, 1999; Fransella et al., 2004; Henze, Van Driel et al., 2007; Jankowicz, 2004). The elements of biology teachers' knowledge that were intuitively elicited in the course of this research raise three major issues: (i) knowledge is personal (following Kelly, 1955) in the sense of biology teaching. Appealing to the biology teachers' tacit knowledge, we found that 65% of the elements that were elicited by the teachers were unique. Each teacher who participated in this research thus possesses a unique repertoire of knowledge elements, and these elements are uniquely distributed among the element categories in each teacher's cognitive structure. This result may imply that biology teachers are a heterogeneous group with respect to their knowledge of biology teaching. This emphasizes the importance of considering diverse teaching perspectives during planning professional development programs (Author, 2011) ; (ii) knowledge is socially distributed (following Collins et al., 1989). Pooling together all of the elements that were elicited by the various teachers demonstrated the variety and large scope of knowledge within the area of biology teaching, thus emphasizing the importance of sharing knowledge between teachers during professional development programs; (iii) CK is an important factor of biology teachers' teaching knowledge. Of all of the elements that were elicited by the teachers, CK was the only element that all teachers mentioned. In addition, our analysis revealed that the CK category of elements was the most variable category of elements that was most frequently mentioned by the teachers. Although the cognitive structure of the teachers is variable, the relatively high frequency of elicitation of CK elements within all of the teachers' data suggests that CK is an important factor in these teachers' knowledge for practice (following Fernandez-Balboa & Stiehl, 1995; Marks, 1990), yet differs from other PCK components.

Biology Teachers' Views about the Relationships between CK and professional knowledge

The RGT is aimed at eliciting experts' tacit knowledge. We believe that examining this knowledge using a technique that minimizes the researcher's own interpretation and impact enabled us to reveal new and previously unknown dimensions of teachers' knowledge.

The fact that all of the teachers chose to elicit CK elements and 75% of the teachers sorted the elements using a 'CK' construct reinforces the idea that CK is an important factor in biology teachers' practice. But is CK an integral part of teachers' PCK or is it an independent knowledge type? This question has been much discussed in the literature (Fernandez-Balboa & Stiehl, 1995; Grossman, 1990; Krauss et al., 2008; Lederman & Gess-Newsome, 1992; Loughran et al., 2008; Magnusson et al., 1999; Marks, 1990; Shulman, 1987) and the debate continues. Analysis of the repertory grid data revealed that the biology teachers’ CK was in most cases a different component of knowledge, distinct from other professional knowledge components of these teachers, including their PCK. The coherence rate of CK elements with other elements was low, less than 80% on average. Seven teachers connected CK elements to elements that describe teaching skills, laboratory skills and learning skills. This might imply that although CK forms a different knowledge group in the RGT, there are teachers who consider CK an important part of their PCK. Therefore, these teachers hold a model of knowledge in which content and pedagogy are integrated and transformed into practice (Gess-Newsome, 1999; Krauss et al., 2008). It is possible that these teachers did integrate their CK with PCK following their learning in academic biology courses and science education courses during the professional development program that they had participated in (Krauss et al., 2008), while the other teachers did not assimilate new CK into their existing PCK. One possible explanation for the teachers not integrating CK with PCK may lie in the fact that some teachers need to be encouraged to assimilate new CK into their existing PCK. Another possible explanation may be that different teachers hold different teaching perspectives. Some teachers believe that teaching and learning biology should be mainly based on subject matter content knowledge, while others believe that teaching and learning biology should depend on cognitive procedures such as encouraging high order thinking skills (Author, 2011) . It is possible that we did not reveal additional tacit relations while using the RGT. However, it is worth noting that all the participating teachers except one chose not to insert new CK acquired in the professional development program into the learning materials they designed in the course of the program. The only teacher that did insert newly acquired CK into the learning materials she designed was Teacher A2, who elicited numerous CK elements, connected them to other professional knowledge elements and was the only one who connected CK constructs to other professional knowledge constructs in the RGT. The question why some teachers integrate CK into their professional knowledge while others do not remains open and is a subject for further research.

The analysis of CK constructs reinforced the conclusions of the analysis of CK elements. Teachers make sense of their practice through constructs regarding teaching. Constructs are frequently expressions of intuition, "gut feelings" and perceptions that the individual uses as a guide to action (Bjorklund, 2008). Seventy-five percent of the teachers who participated in this research used the CK constructs as an integral part of their cognitive structure about biology teaching, but the coherence of the CK constructs with other constructs was low. That is, CK is an important yet separate domain of knowledge in these teachers' cognitive structures. It is worth noting that all of the teachers who connected CK elements to teaching or learning strategy elements demonstrated a separate CK construct, except Teacher A2, who connected CK constructs with teaching and thinking skills constructs. This teacher was unique since repertory grid analysis of her data revealed that she elicited eight CK elements (of the 12 requested) and connected them with two teaching skills elements with high coherence. This teacher views acquisition of biological content knowledge as a very important factor in her professional development and a very important factor in her teaching and her students' learning. However, characterizing this teacher's knowledge structure and the way she refers to CK as a part of professional knowledge for biology teaching is a subject for future research.

We realize that although our results may imply that by and large the participating teachers do not connect CK to other professional knowledge dimensions, including PCK, it is possible to assume that the RGT fails to reveal some hidden links in the teachers' cognitive structure. Therefore, further research which will employ various methods and a bigger teachers' population should be conducted in order to answer the subject in question which subsequently may help design effective professional development programs.

As the main contribution of this research, the RGT may imply that CK is a separate domain in these biology teachers' cognitive structure regarding biology teaching. The theoretical frameworks related to PCK usually exclude CK from PCK (Grossman, 1990; Magnusson et al., 1999; Shulman, 1987; Tamir, 1988). However, some practical studies of PCK within educational systems emphasize the importance of CK and include it as an integral construct of PCK (Fernandez-Balboa & Stiehl, 1995; Marks, 1990). The high coherence between the elicited CK elements and the separation of the CK constructs from the other constructs strengthen the notion that CK is indeed a very important, but separate domain of biology teachers' knowledge. Thus, professional development programs should consider promoting the connection between biology teachers’ CK and PCK instead of assuming that increasing CK will automatically improve PCK. Moreover, it is likely that even if teachers do link between CK and PCK to some degree in their practice it is important to bring to mind the ability to recognize this link and articulate it during professional development programs. Making the tacit link explicit may further promote teachers' professional development.

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Figures:

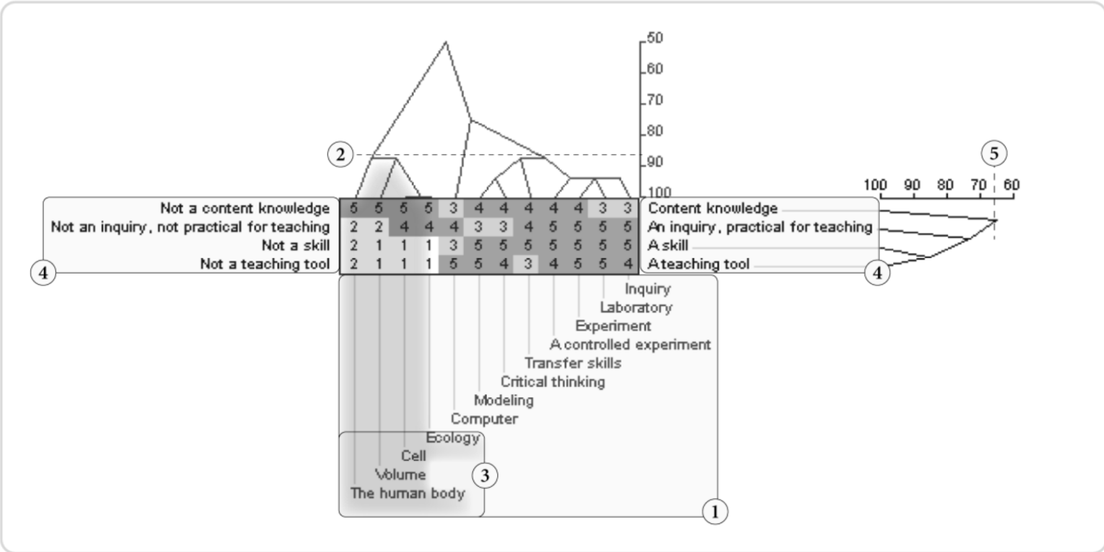


Figure 1. Analysis of Teacher A3's data using a repertory grid tree diagram

(1) Elements; (2) coherence scale and its use in defining a group of elements (3) with more than 80% coherence; (4) constructs; (5) coherence scale and its use in defining coherence rate of the construct 'content knowledge' and other constructs (lower than 80% coherence)

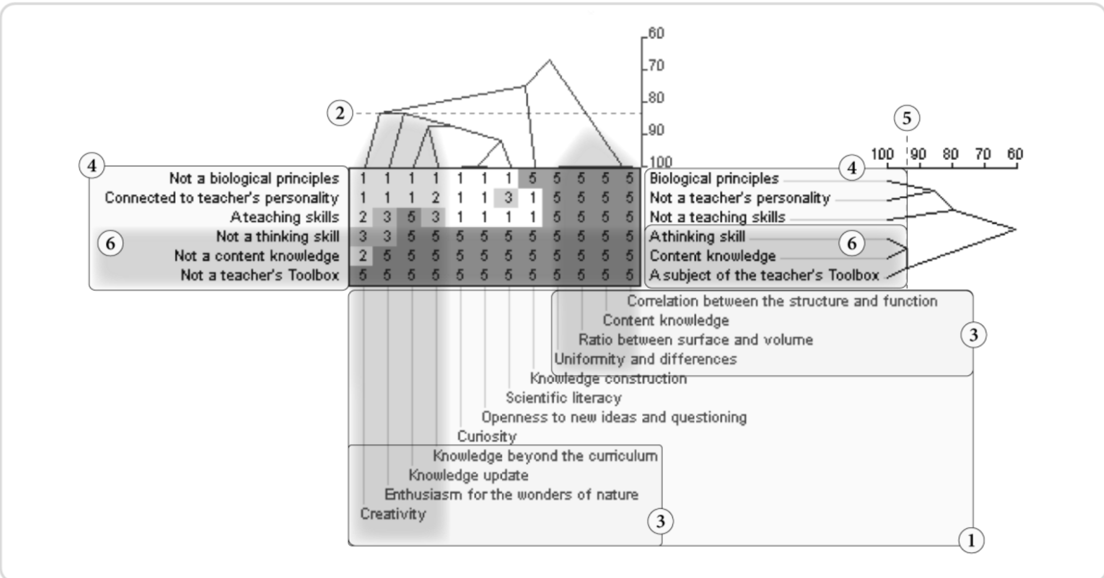


Figure 2. Analysis of Teacher A2's repertory grid tree diagram

(1) Elements; (2) coherence scale; (3) two groups of elements relating to CK with more than 80% coherence; (4) constructs; (5) coherence scale and (6) its use in defining more than 90% coherence between CK and other constructs

Table 1. Teacher A3's table of elements and constructs assembled at the end of the RGT

Element [a] / Construct [b]	Cell	Inquiry	Computer	Modeling	The human body	Volume	Transfer skills	Critical thinking	A controlled experiment	Experiment	Laboratory	Ecology	Element [a] / Construct [b]
Not a content knowledge	5	3	3	4	5	5	4	4	5	4	4	5	~~Content knowledge~~
Not an inquiry, practical for teaching	4	5	4	3	2	2	4	3	5	5	5	4	Inquiry, practical for teaching
Not a skill	1	5	3	5	2	1	5	5	5	5	5	1	A skill
Not a teaching tool	1	4	5	5	2	1	3	4	4	4	5	1	A teaching tool

The numbers represent the correlation between elements and the related construct; '1' means 'totally agree with the left pole of the construct'; '5' means 'totally agree with the right pole of the construct'. A teacher can choose any number between 1 and 5 which expresses the rate of correlation between constructs and elements.

c. Element: component of teaching knowledge

d. Construct*:* dimension of similarity or difference between elements

Table 2. Diversity of elements and the connection of each category to CK elements in the participating teachers' data

Element category	Number of teachers who mentioned the category (n = 20)	Number and percentage of different elements in each category (n = 148 different elements)	Number of times elements were mentioned (n = 230 elements in total)	Number and percentage of teachers who connected CK elements to each category with high coherence (more than 80%)
Content knowledge	20	42 (28%)	76 (33%)	20 (100%)
Teaching skills	17	36 (24%)	54 (23%)	5 (25%)
Teacher's personality	17	32 (21%)	49 (21%)	2 (10%)
Learning skills	11	30 (20%)	38 (17%)	0
Learner's personality	4	4 (3%)	7 (3%)	0
Relevance	4	5 (3%)	6 (3%)	0

Appendix 1:

Outline of the daily professional development program of Path A and Path B teachers that ran for two academic years (during 2008–2012).

Semester	Periods in a day	Course title Path A - day 1	Course title Path A - day 2	Course title Path B
1	1-2	Selected issues in molecular biology	Laboratory activities for microbiology teaching	Laboratory activities for microbiology teaching
	3-4	Bioinformatics	Developing learning materials	Designing new teaching and learning materials in biology
	5-6	Neurophysiology	Seminar	Designing new teaching and learning materials in biology
	7-8	Seminar	Introduction to science education	Introduction to science education
2	1-2	Developmental biology	Experiencing contemporary research in the life sciences	Experiencing contemporary research in the life sciences
	3-4	Bioinformatics	Developing learning materials	Designing new teaching and learning materials in biology
	5-6	Cellular biology	Seminar	Designing new teaching and learning materials in biology
	7-8	Self-learning	Cognition, learning and instruction	Cognition learning and instruction
3	1-2	Biochemistry of proteins	Stem cell biology	Stem cell biology
	3-4	Designing new teaching and learning materials in biology	Assessment and measurement methods in science education research	Designing new teaching and learning materials in biology
	5-6	Designing new teaching and learning materials in biology	Interdisciplinary seminar	Designing new teaching and learning materials in biology
	7-8	Scientific writing	Learning and instruction in biology teaching	Selected topics in teaching and learning biology
4	1-2	Plant biology	Selected topics in ecology	Selected topics in ecology
	3-4	New teaching and learning materials - workshop	Journal club—science education articles	Designing new teaching and learning materials in biology
	5-6	Designing new teaching and learning materials in biology	Interdisciplinary seminar	Designing new teaching and learning materials in biology
	7-8	Seminar	Integration of learning technologies	Integration of learning technologies

Each period lasted approximately 45 minutes with two 15- to 30-minute breaks during the day.

White = biology courses, Gray = science education courses.

Appendix 2:

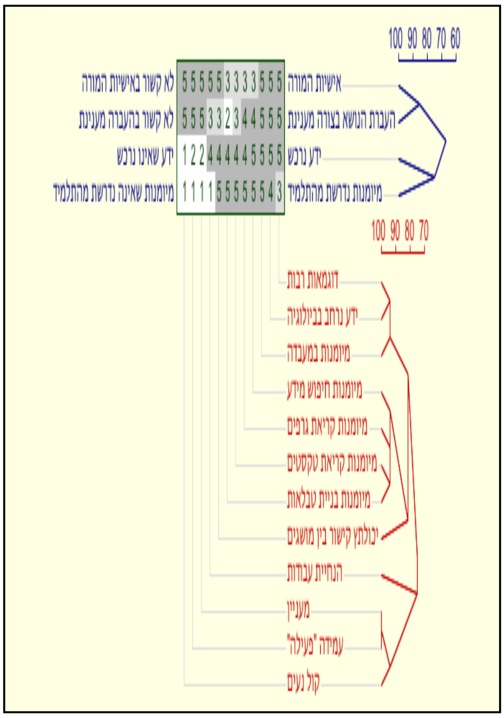
The professional experience and types of schools in which the teachers who participated in this study teach

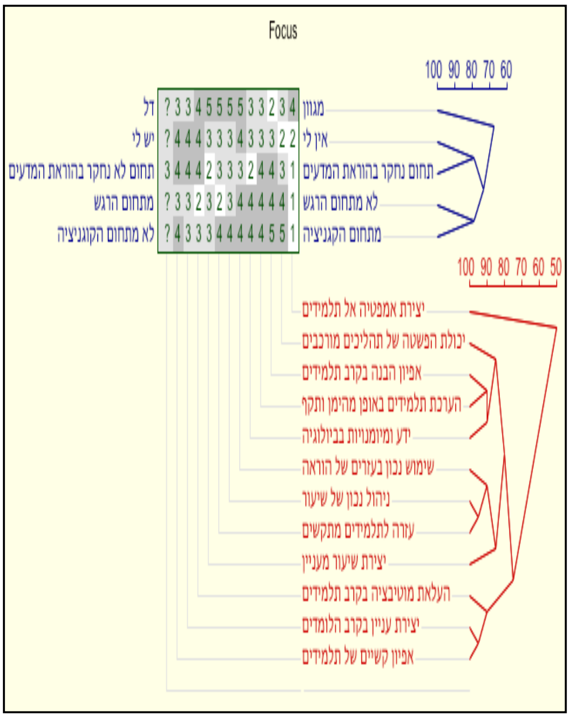
Teacher's no. (symbol)	Class in the professional development (PD) program	Years of high-school teaching experience at the beginning of the PD program	Type of school
1 (A1)	AI	11	National high school
2 (A2)	AI	14	National high school
3 (A3)	AI	7	Religion-oriented high school
4 (A4)	AI	9	Religion-oriented high school
5 (B1)	BI	17	National high school
6 (B2)	BI	17	Religion-oriented high school
7 (B3)	BI	12	Religion-oriented high school
8 (B4)	BI	6	National high school
9 (A5)	AII	22	National high school
10 (A6)	AII	8	Religion-oriented high school
11 (A7)	AII	18	Religion-oriented high school
12 (A8)	AII	4	Bedouin high school
13 (A9)	AII	22	National high school
14 (A10)	AII		Boarding high school
15 (A11)	AII	5	Religion-oriented high school
16 (A12)	AII	17	National high school
17 (A13)	AII	17	National high school
18 (A14)	AII	4	National high school
19 (A15)	AII	5	National high school
20 (A16)	AII	22	National high school

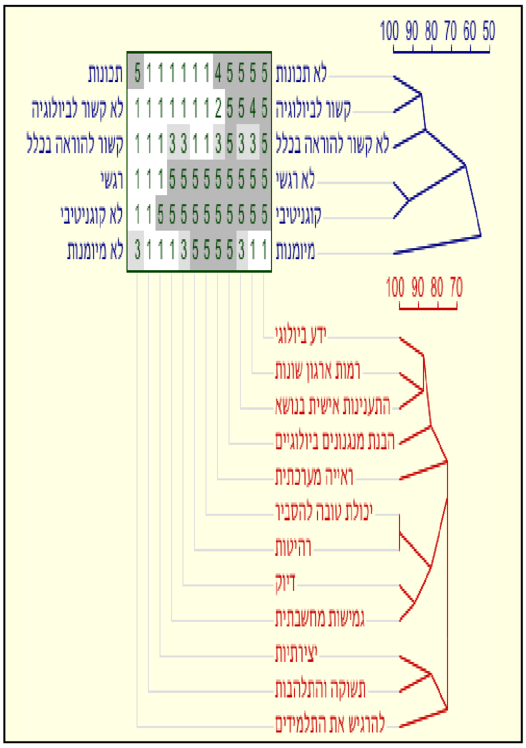
Appendix 6

Science and mathematics teachers' Repertory Grids

Biology teachers' repertory grids







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רגשי
לא רגשי
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רמות ארגון שונות
התעניינות אישית בנושא
הבנת מנגנונים ביולוגיים
ראייה מערכתית
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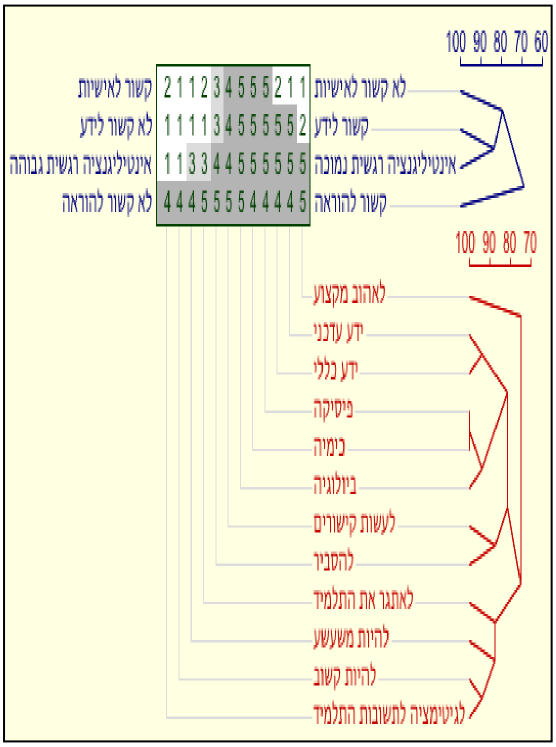

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לא קשור להוראה
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ידע עדכני
ידע כללי
פיסיקה
כימיה
ביולוגיה
לעשות קישורים
להסביר
לאתגר את התלמיד
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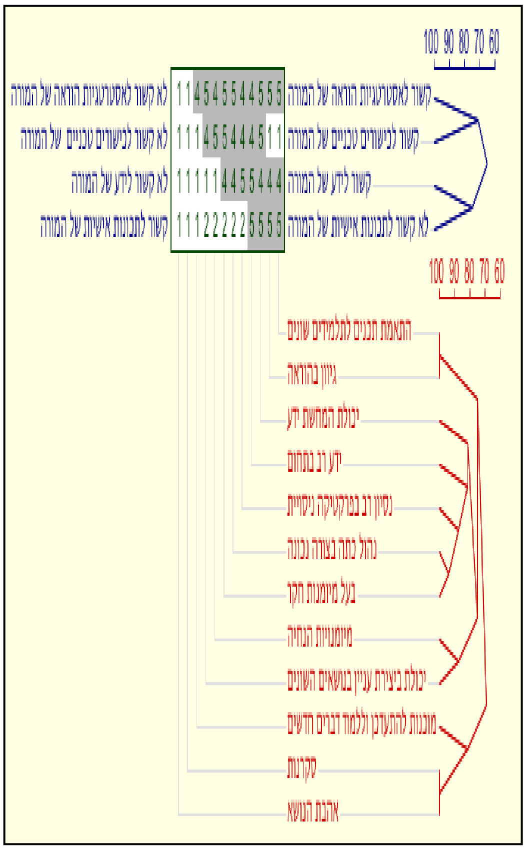

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לא קשור לכישורים טכניים של המורה
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ידע רב בתחום
נסיון רב בפרקטיקה ניסויית
נהול כתה בצורה נכונה
בעל מיומנות חקר
מיומנויות הנחיה
יכולת ביצירת עניין בנושאים השונים
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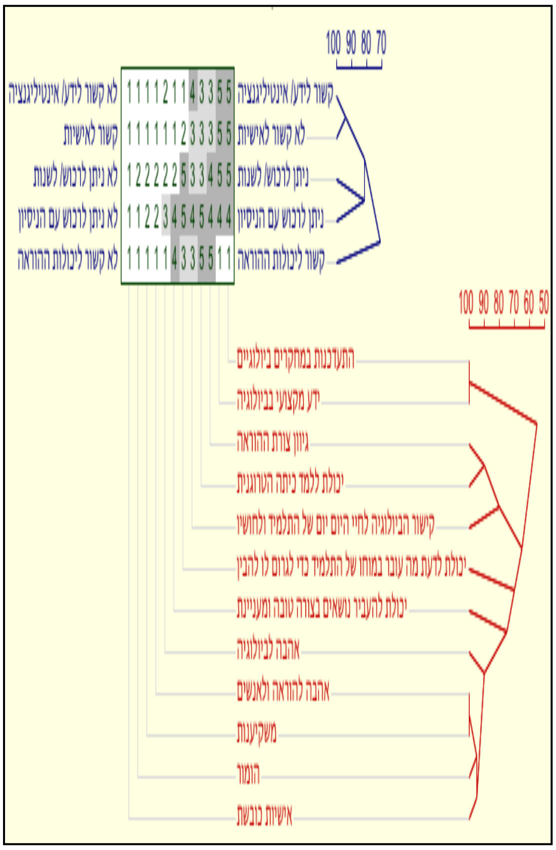

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לא ניתן לרכוש/ לשנות
ניתן לרכוש/ לשנות
לא ניתן לרכוש עם הניסיון
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לא קשור ליכולות ההוראה
קשור ליכולות ההוראה
התעדכנות במחקרים ביולוגיים
ידע מקצועי בביולוגיה
גיוון צורת ההוראה
יכולת ללמד כיתה הטרוגנית
קישור הביולוגיה לחיי היום יום של התלמיד ולחושיו
יכולת לדעת מה עובר במוחו של התלמיד כדי לגרום לו להבין
יכולת להעביר נושאים בצורה טובה ומעניינת
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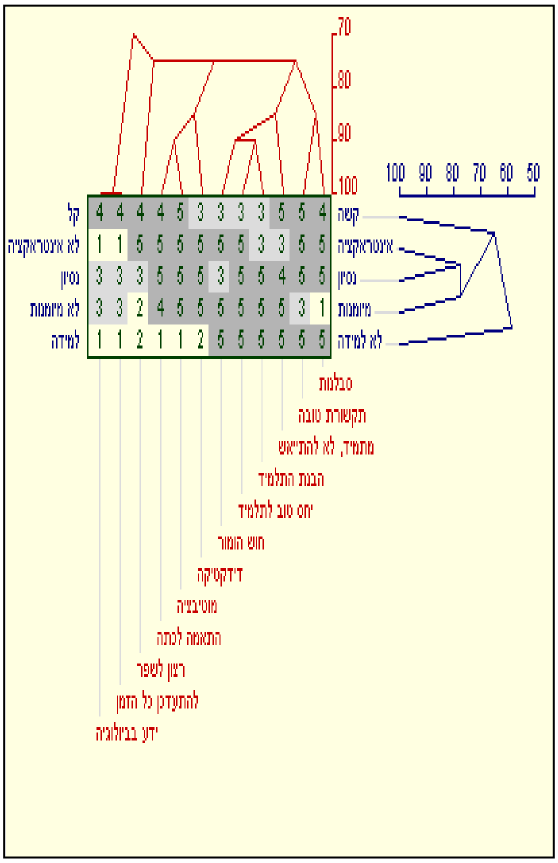

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דידקטיקה
מוטיבציה
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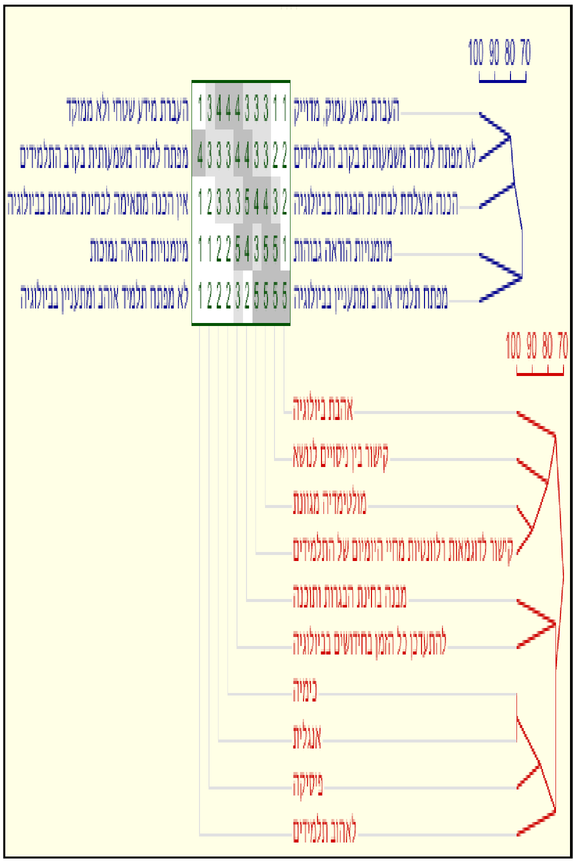

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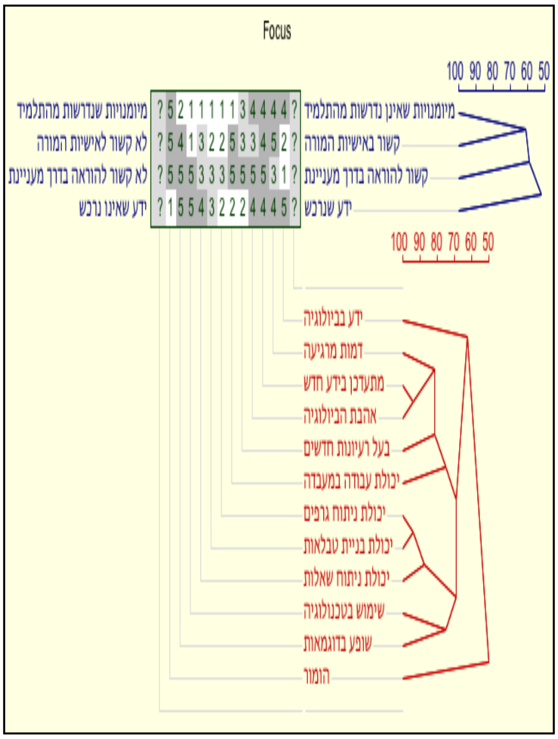
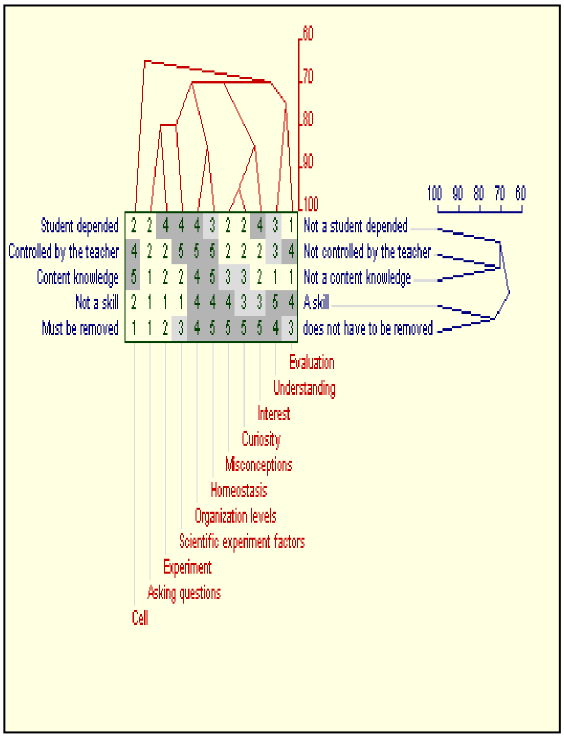
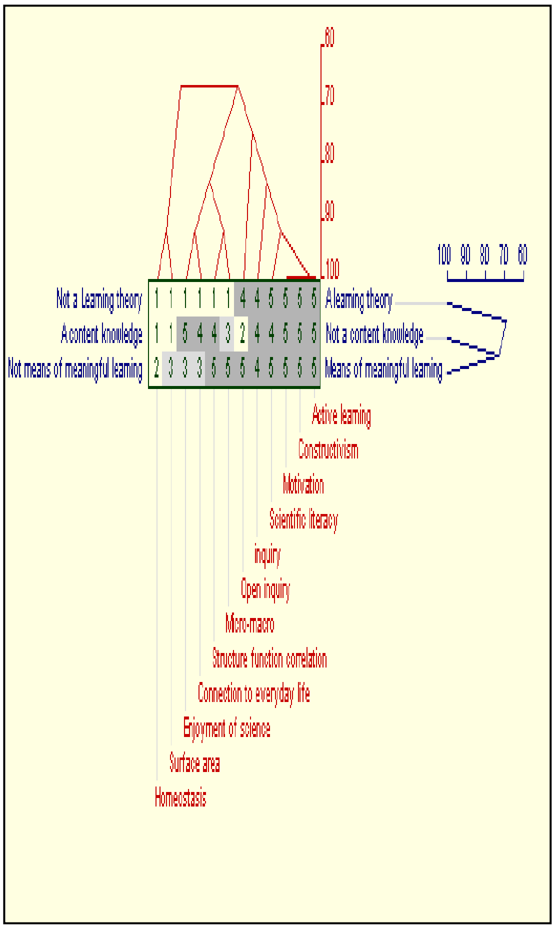
מפתח למידה משמעותית בקרב התלמידים 4 3 3 3 4 4 3 3 2 2 לא מפתח למידה משמעותית בקרב התלמידים
אין הכנה מתאימה לבחינת הבגרות בביולוגיה 1 2 3 3 3 5 4 4 3 2 הכנה מוצלחת לבחינת הבגרות בביולוגיה
מיומנויות הוראה נמוכות 1 1 2 2 5 4 3 5 5 1 מיומנויות הוראה גבוהות
לא מפתח תלמיד אוהב ומתעניין בביולוגיה 1 2 2 2 3 2 5 5 5 5 מפתח תלמיד אוהב ומתעניין בביולוגיה
אהבת ביולוגיה
קשר בין ניסויים לנושא
מולטימדיה מגוונת
קשר לדוגמאות רלוונטיות מחיי היומיום של התלמידים
מבנה בחינת הבגרות ותכנה
להתעדכן כל הזמן בחידושים בביולוגיה
כימיה
אנגלית
פיזיקה
לאהוב תלמידים

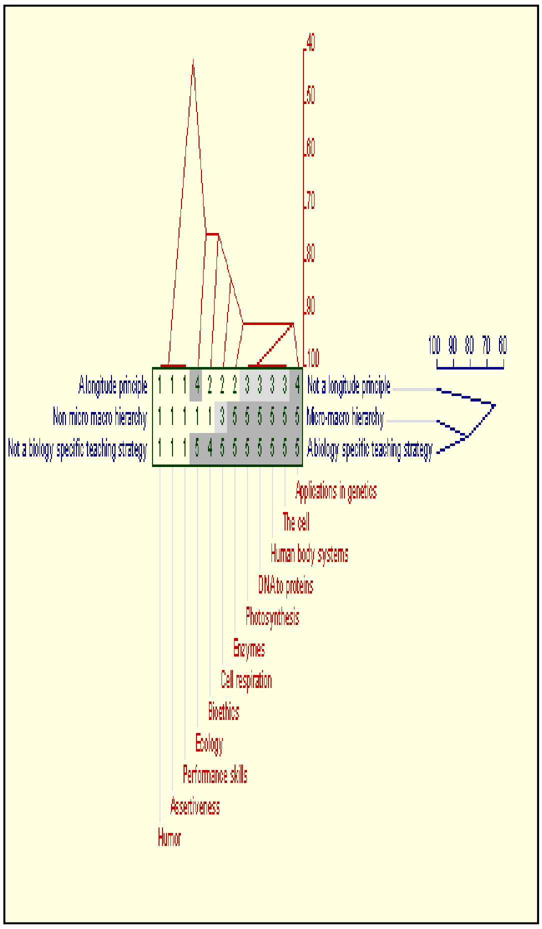


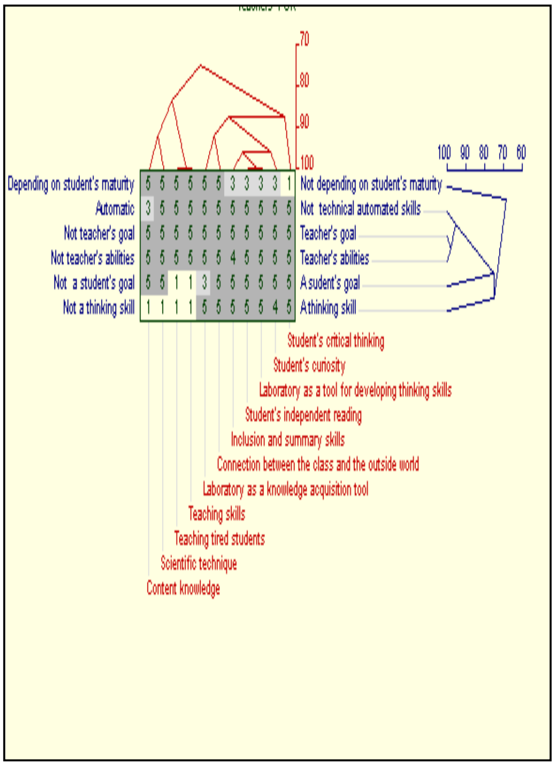
Focus
מיומנויות שנדרשות מהתלמיד ? 5 2 1 1 1 1 1 3 4 4 4 4 ? מיומנויות שאינן נדרשות מהתלמיד
לא קשור לאישיות המורה ? 5 4 1 3 2 2 5 3 3 4 5 2 ? קשור באישיות המורה
לא קשור להוראה בדרך מעניינת ? 5 5 5 3 3 3 5 5 5 5 3 1 ? קשור להוראה בדרך מעניינת
ידע שאינו נרכש ? 1 5 5 4 3 2 2 2 4 4 4 5 ? ידע שנרכש
ידע בביולוגיה
דמות מרגיעה
מתעדכן בידע חדש
אהבת הביולוגיה
בעל רעיונות חדשים
יכולת עבודה במעבדה
יכולת ניתוח גרפים
יכולת בניית טבלאות
יכולת ניתוח שאלות
שימוש בטכנולוגיה
שופע בדוגמאות
הומור

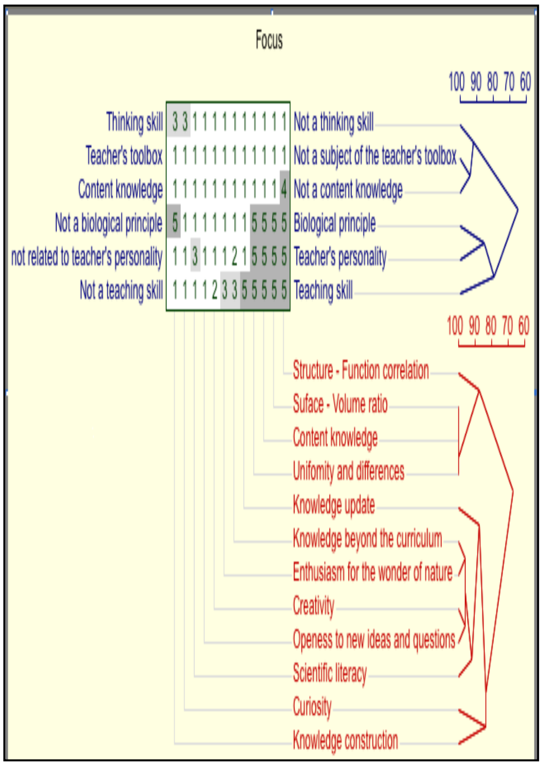


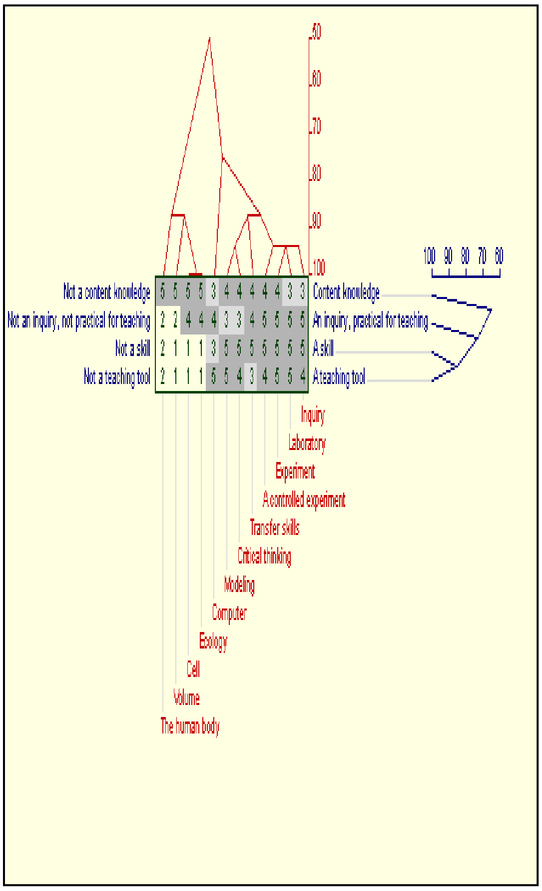
Student depended 2 2 4 4 4 3 2 2 4 3 1 Not a student depended
Controlled by the teacher 4 2 2 5 5 5 2 2 2 3 4 Not controlled by the teacher
Content knowledge 5 1 2 2 4 5 3 3 2 1 1 Not a content knowledge
Not a skill 2 1 1 1 4 4 4 3 3 5 4 A skill
Must be removed 1 1 2 3 4 5 5 5 5 4 3 does not have to be removed
Evaluation
Understanding
Interest
Curiosity
Misconceptions
Homeostasis
Organization levels
Scientific experiment factors
Experiment
Asking questions
Cell

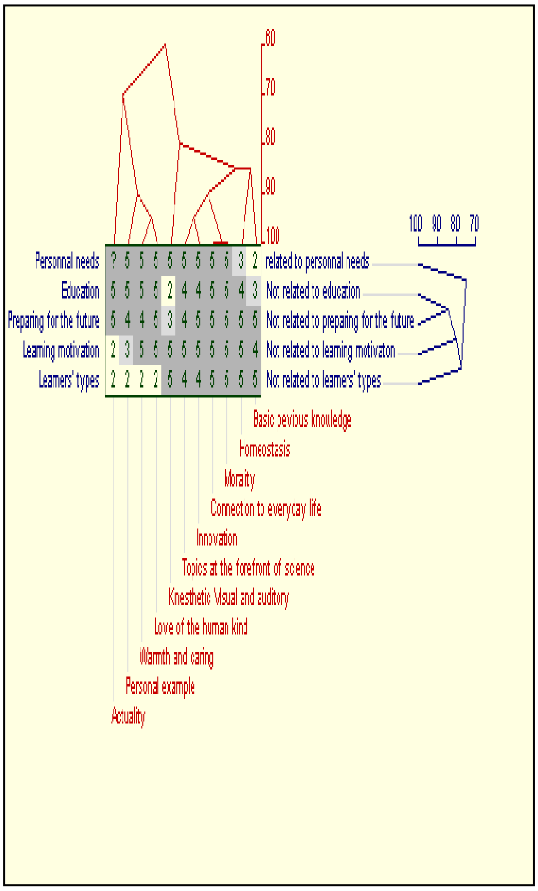

60
70
80
90
100
100 90 80 70 60
Not a Learning theory 1 1 1 1 1 1 4 4 5 5 5 5 A learning theory
A content knowledge 1 1 5 4 4 3 2 4 4 5 5 5 Not a content knowledge
Not means of meaningful learning 2 3 3 3 5 5 5 4 5 5 5 5 Means of meaningful learning
Active learning
Constructivism
Motivation
Scientific literacy
inquiry
Open inquiry
Micro-macro
Structure function correlation
Connection to everyday life
Enjoyment of science
Surface area
Homeostasis

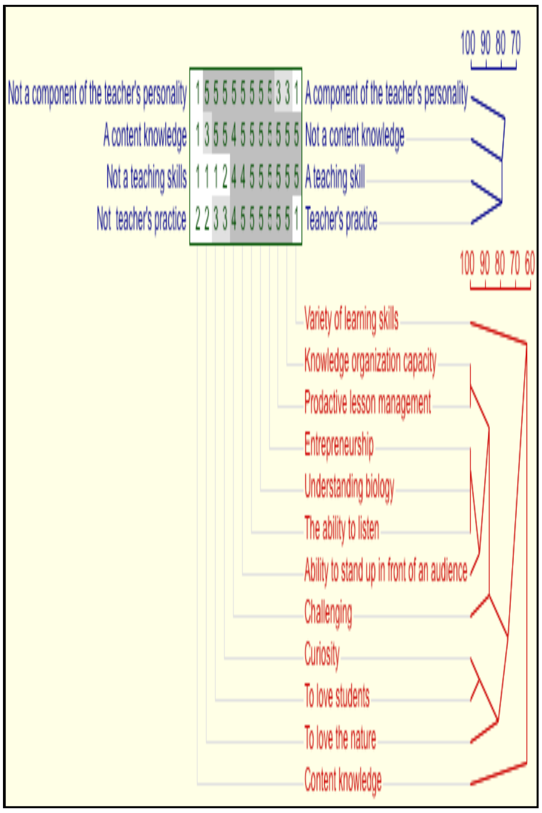

40
50
60
70
80
90
100
100 90 80 70 60
A longitude principle 1 1 1 4 2 2 2 3 3 3 3 4 Not a longitude principle
Non micro macro hierarchy 1 1 1 1 1 3 5 5 5 5 5 5 Micro-macro hierarchy
Not a biology specific teaching strategy 1 1 1 5 4 5 5 5 5 5 5 5 A biology specific teaching strategy
Applications in genetics
The cell
Human body systems
DNA to proteins
Photosynthesis
Enzymes
Cell respiration
Bioethics
Ecology
Performance skills
Assertiveness
Humor

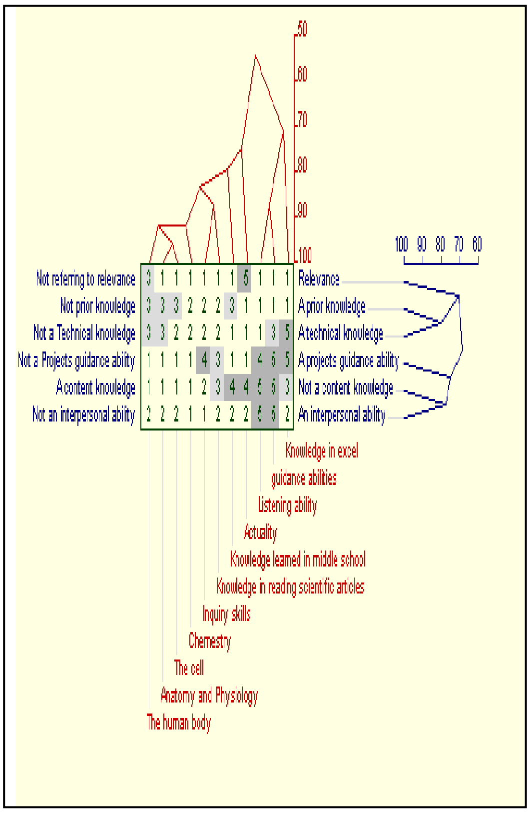

70
80
90
100
100 90 80 70 60
Depending on student's maturity 5 5 5 5 5 5 3 3 3 3 1 Not depending on student's maturity
Automatic 3 5 5 5 5 5 5 5 5 5 5 Not technical automated skills
Not teacher's goal 5 5 5 5 5 5 5 5 5 5 5 Teacher's goal
Not teacher's abilities 5 5 5 5 5 5 4 5 5 5 5 Teacher's abilities
Not a student's goal 5 5 1 1 3 5 5 5 5 5 5 A sudent's goal
Not a thinking skill 1 1 1 1 5 5 5 5 5 4 5 A thinking skill
Student's critical thinking
Student's curiosity
Laboratory as a tool for developing thinking skills
Student's independent reading
Inclusion and summary skills
Connection between the class and the outside world
Laboratory as a knowledge acquisition tool
Teaching skills
Teaching tired students
Scientific technique
Content knowledge


Focus
100 90 80 70 60
Thinking skill 3 3 1 1 1 1 1 1 1 1 1 1 Not a thinking skill
Teacher's toolbox 1 1 1 1 1 1 1 1 1 1 1 1 Not a subject of the teacher's toolbox
Content knowledge 1 1 1 1 1 1 1 1 1 1 1 4 Not a content knowledge
Not a biological principle 5 1 1 1 1 1 1 1 5 5 5 5 Biological principle
not related to teacher's personality 1 1 3 1 1 1 2 1 5 5 5 5 Teacher's personality
Not a teaching skill 1 1 1 1 2 3 3 5 5 5 5 5 Teaching skill
100 90 80 70 60
Structure - Function correlation
Suface - Volume ratio
Content knowledge
Unifomity and differences
Knowledge update
Knowledge beyond the curriculum
Enthusiasm for the wonder of nature
Creativity
Openess to new ideas and questions
Scientific literacy
Curiosity
Knowledge construction

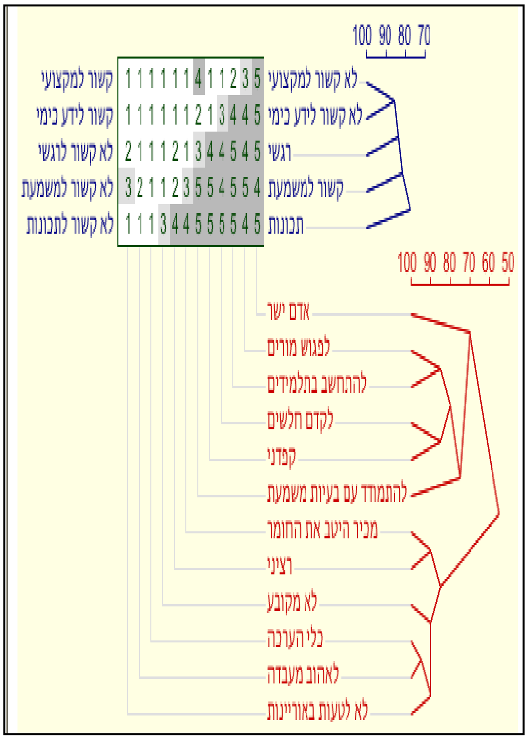

Not a content knowledge
Not an inquiry, not practical for teaching
Not a skill
Not a teaching tool
Content knowledge
An inquiry, practical for teaching
A skill
A teaching tool
Inquiry
Laboratory
Experiment
A controlled experiment
Transfer skills
Critical thinking
Modeling
Computer
Ecology
Cell
Volume
The human body

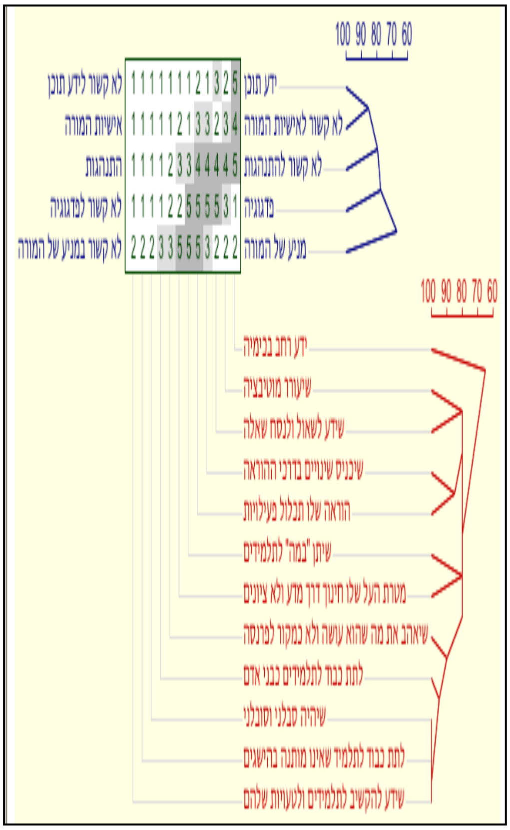

Personnal needs
Education
Preparing for the future
Learning motivation
Learners' types
related to personnal needs
Not related to education
Not related to preparing for the future
Not related to learning motivaton
Not related to learners' types
Basic pevious knowledge
Homeostasis
Morality
Connection to everyday life
Innovation
Topics at the forefront of science
Kinesthetic Visual and auditory
Love of the human kind
Warmth and caring
Personal example
Actuality


Not a component of the teacher's personality
A content knowledge
Not a teaching skills
Not teacher's practice
A component of the teacher's personality
Not a content knowledge
A teaching skill
Teacher's practice
Variety of learning skills
Knowledge organization capacity
Prodactive lesson management
Entrepreneurship
Understanding biology
The ability to listen
Ability to stand up in front of an audience
Challenging
Curiosity
To love students
To love the nature
Content knowledge


Not referring to relevance
Not prior knowledge
Not a Technical knowledge
Not a Projects guidance ability
A content knowledge
Not an interpersonal ability
Relevance
A prior knowledge
A technical knowledge
A projects guidance ability
Not a content knowledge
An interpersonal ability
Knowledge in excel
guidance abilities
Listening ability
Actuality
Knowledge learned in middle school
Knowledge in reading scientific articles
Inquiry skills
Chemistry
The cell
Anatomy and Physiology
The human body

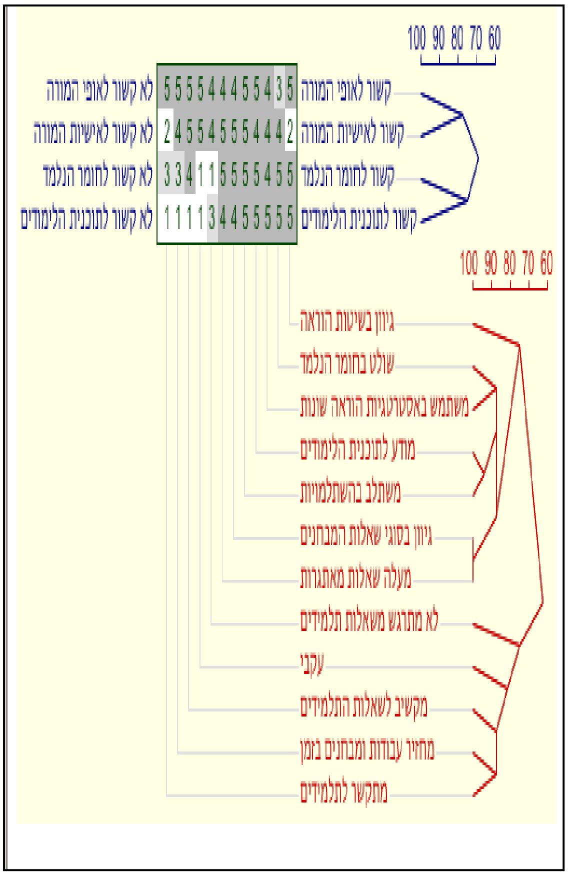

100 90 80 70
לא קשור להפעלת תלמידים 1 2 2 3 2 2 2 4 3 3 5 קשור להפעלת תלמידים
לא קשור לפדגוגיה 1 3 3 2 3 2 2 3 4 4 5 קשור לפדגוגיה
הרחבת הידע של המורה 2 1 1 2 3 3 3 3 2 4 5 הרחבת הידע של התלמיד
לא קשור לכימיה 5 1 1 3 3 4 5 3 4 5 3 קשור לכימיה
לא דורש הכנה 5 2 2 2 3 4 3 4 4 5 5 דורש הכנה
לא תלוי במורה 5 5 3 3 3 3 4 4 4 5 5 תלוי במורה
תלוי בתלמידות 5 4 3 2 2 1 3 3 3 2 5 לא תלוי בתלמידות
100 90 80 70 60 50
להשתמש במס. רב של דרכי הוראה
קישור הכימיה לחיים
לגרום לתלמידים לחשוב בבמה מישורים
לדעת לשאול שאלות
קישור מיקרו מקרו
לחשוב על שאלות לתלמידים
לעורר סקרנות בקרב התלמידים
לגרום לתלמידים לשאול שאלות
מכשלון להצלחה
נתינת חוזקות לתלמידים
קריאת נושאים מדעיים עדכניים

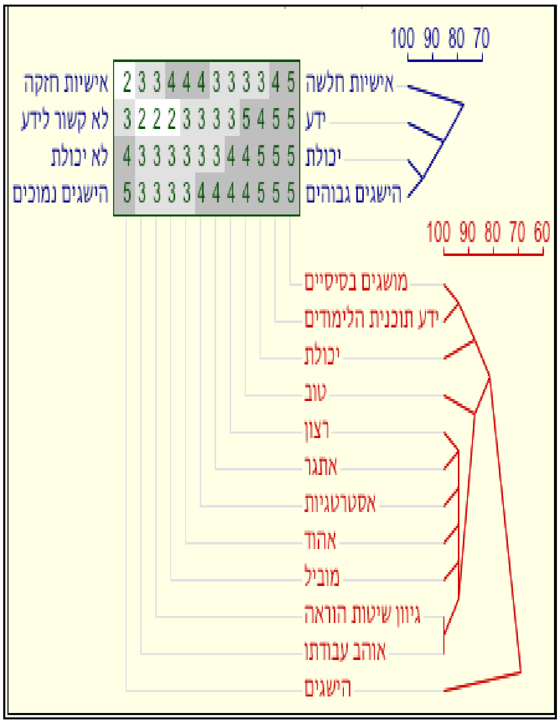

100 90 80 70
קשור למקצועי 1 1 1 1 1 1 4 1 1 2 3 5 לא קשור למקצועי
קשור לידע כימי 1 1 1 1 1 1 2 1 3 4 4 5 לא קשור לידע כימי
לא קשור לרגשי 2 1 1 1 2 1 3 4 4 5 4 5 רגשי
לא קשור למשמעת 3 2 1 1 2 3 5 5 4 5 5 4 קשור למשמעת
לא קשור לתבונות 1 1 1 3 4 4 5 5 5 5 4 5 תבונות
100 90 80 70 60 50
אדם ישר
לפגוש מורים
להתחשב בתלמידים
לקדם חלשים
קפדני
להתמודד עם בעיות משמעת
מכיר היטב את החומר
רציני
לא מקובע
כלי הערכה
לאהוב מעבדה
לא לטעות באוריינות

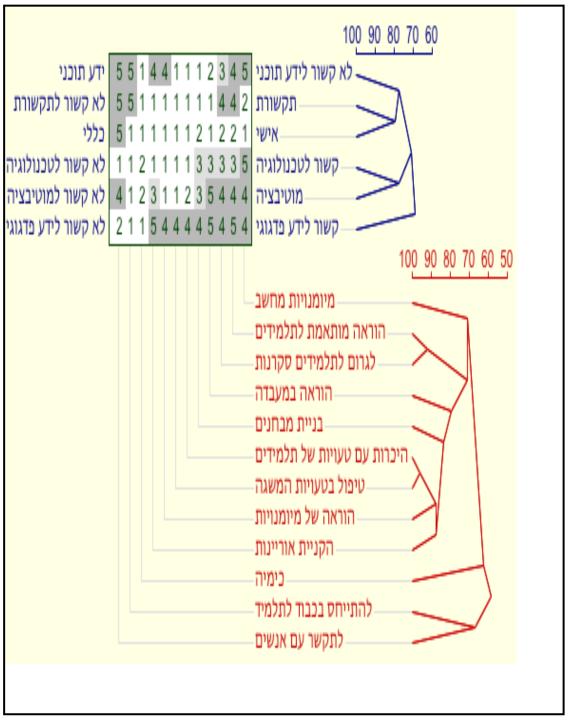

100 90 80 70 60
לא קשור לידע תוכן 1 1 1 1 1 1 1 2 1 3 2 5 ידע תוכן
אישיות המורה 1 1 1 1 1 2 1 3 3 2 3 4 לא קשור לאישיות המורה
התנהגות 1 1 1 1 2 3 3 4 4 4 4 5 לא קשור להתנהגות
לא קשור לפדגוגיה 1 1 1 1 2 2 5 5 5 5 3 1 פדגוגיה
לא קשור במניע של המורה 2 2 2 3 3 5 5 5 3 2 2 2 מניע של המורה
100 90 80 70 60
ידע רחב בכימיה
שיעורר מוטיבציה
שידע לשאול ולנסח שאלה
שיכניס שינויים בדרכי ההוראה
הוראה שלו תכלול פעילויות
שיתן "במה" לתלמידים
מטרת העל שלו חינוך דרך מדע ולא ציונים
שיאהב את מה שהוא עושה ולא כמקור לפרנסה
לתת כבוד לתלמידים כבני אדם
שיהיה סבלני וסובלני
לתת כבוד לתלמיד שאינו מותנה בהישגים
שידע להקשיב לתלמידים ולטעויות שלהם

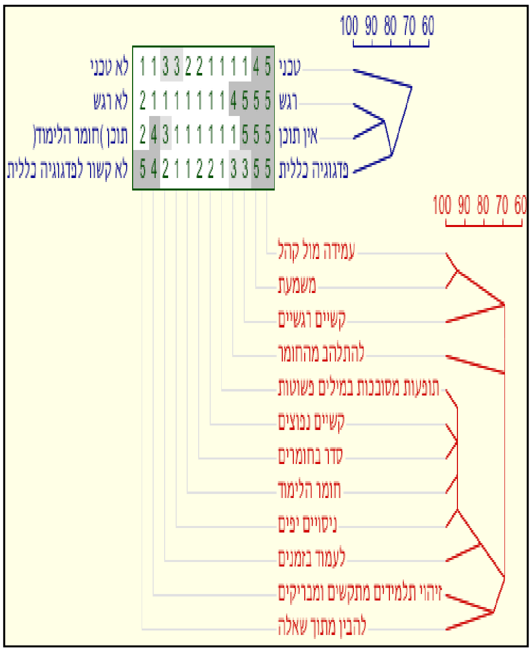

100 90 80 70
אסטתיקה 2 1 4 5 5 5 5 5 5 4 2 2 לא קשור לאסטתיקה
לא קשור לידע מתקדם 1 1 2 3 5 5 5 5 5 5 5 5 ידע מתקדם
לא קשור לידע עכשוי 1 1 2 3 5 5 5 5 5 5 5 5 ידע עכשוי
לא מקצועי 3 4 4 4 4 5 5 5 5 5 5 5 מקצועי
לא קשור לאישיות 5 5 5 4 3 4 4 4 4 5 5 4 אישיות
100 90 80 70
דוגמא לאיש מקצועי
להעלות התענינות
להפיק דברים מחומרים פשוטים
לדעת את החומר הנלמד
ללמוד דברים חדשים
שליטה בחומר
לפתור בעיות לא צפויות
לא מפחד מתוכנית חדשה
אהבה למקצוע כימיה
אהבה לתלמיד
להראות טוב
להיות חברתי


100 90 80 70
הוראה טובה
3 3 4 3 5 5 5 5 4 4 4 4
הוראה לא טובה
הכרת החומר
1 1 2 3 3 3 5 5 4 4 3 3
לא קשור להכרת החומר
עזרה לתלמידים
1 1 2 3 4 4 5 5 5 4 4 4
לא עוזר לתלמידים
המחשת החומר הנלמד
1 1 2 3 3 3 3 5 5 5 5 5
לא קשור להמחשת החומר הנלמד
100 90 80 70
משתמש בטכנולוגיות מחשבים ואינטרנט
מקשר את החומר לחיי היום יום
עושה ניסויים
עוזר לתלמידים מתקשים
יכולת הפנמת הידע שלו
יכולת העברה של החומר בצורה טובה
מערב את התלמידים ע"י שאילת שאלות
נותן לתלמידים לשאול שאלות
אכפת לו מהתלמידים, דואג להם
אנושי
לא נעדר מבית הספר
מערב את תלמידיו בחברה

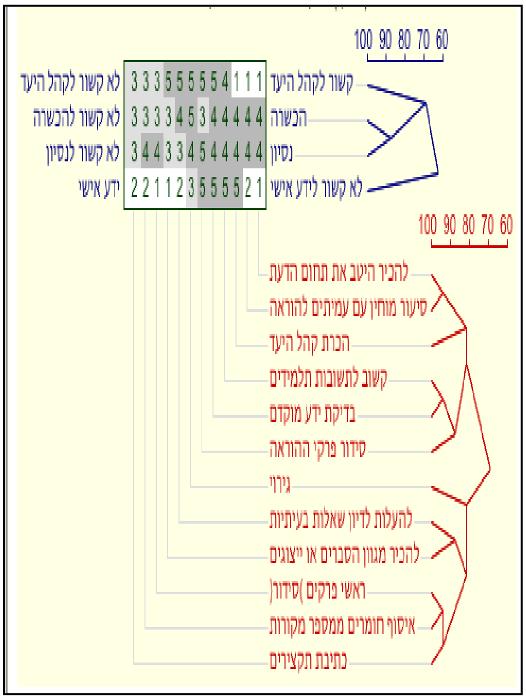

100 90 80 70 60
קשור לאופי המורה
5 5 5 5 4 4 4 5 5 4 3 5
לא קשור לאופי המורה
קשור לאישיות המורה
2 4 5 5 4 5 5 5 4 4 4 2
לא קשור לאישיות המורה
קשור לחומר הנלמד
3 3 4 1 1 5 5 5 5 4 5 5
לא קשור לחומר הנלמד
קשור לתוכנית הלימודים
1 1 1 1 3 4 4 5 5 5 5 5
לא קשור לתוכנית הלימודים
100 90 80 70 60
גיוון בשיטות הוראה
שולט בחומר הנלמד
משתמש באסטרטגיות הוראה שונות
מודע לתוכנית הלימודים
משתלב בהשתלמויות
גיוון בסוגי שאלות המבחנים
מעלה שאלות מאתגרות
לא מתרגש משאלות תלמידים
עקבי
מקשיב לשאלות התלמידים
מחזיר עבודות ומבחנים בזמן
מתקשר לתלמידים


100 90 80 70
אישיות חלשה
2 3 3 4 4 4 3 3 3 3 4 5
אישיות חזקה
ידע
3 2 2 2 3 3 3 3 5 4 5 5
לא קשור לידע
יכולת
4 3 3 3 3 3 3 4 4 5 5 5
לא יכולת
הישגים גבוהים
5 3 3 3 3 4 4 4 4 5 5 5
הישגים נמוכים
100 90 80 70 60
מושגים בסיסיים
ידע תוכנית הלימודים
יכולת
טוב
רצון
אתגר
אסטרטגיות
אהוד
מוביל
גיוון שיטות הוראה
אוהב עבודתו
הישגים


100 90 80 70 60
לא קשור לידע תוכני
5 5 1 4 4 1 1 1 2 3 4 5
ידע תוכני
תקשורת
5 5 1 1 1 1 1 1 1 4 4 2
לא קשור לתקשורת
אישי
5 1 1 1 1 1 1 2 1 2 2 1
כללי
קשור לטכנולוגיה
1 1 2 1 1 1 1 3 3 3 3 5
לא קשור לטכנולוגיה
מוטיבציה
4 1 2 3 1 1 2 3 5 4 4 4
לא קשור למוטיבציה
קשור לידע פדגוגי
2 1 1 5 4 4 4 4 5 4 5 4
לא קשור לידע פדגוגי
100 90 80 70 60 50
מיומנויות מחשב
הוראה מותאמת לתלמידים
לגרום לתלמידים סקרנות
הוראה במעבדה
בניית מבחנים
היכרות עם טעויות של תלמידים
טיפול בטעויות המשגה
הוראה של מיומנויות
הקניית אוריינות
כימיה
להתייחס בכבוד לתלמיד
לתקשר עם אנשים


100 90 80 70 60
טכני 1 1 3 3 2 2 1 1 1 1 4 5 לא טכני
רגש 2 1 1 1 1 1 1 1 4 5 5 5 לא רגש
אין תוכן 2 4 3 1 1 1 1 1 1 5 5 5 תוכן)חומר הלימוד(
פדגוגיה כללית 5 4 2 1 1 2 2 1 3 3 5 5 לא קשור לפדגוגיה כללית
100 90 80 70 60
עמידה מול קהל
משמעת
קשיים רגשיים
להתלהב מהחומר
תופעות מסובכות במילים פשוטות
קשיים נפוצים
סדר בחומרים
חומר הלימוד
ניסויים יפים
לעמוד בזמנים
זיהוי תלמידים מתקשים ומבריקים
להבין מתוך שאלה


100 90 80
התנהגותי, נוכחות המורה 5 5 5 3 4 5 4 4 4 4 4 3 לא התנהגותי
אישיות המורה 5 5 5 4 5 5 5 5 5 5 4 5 לא קשור לאישיות המורה
קשר ישיר עם התלמיד 5 4 3 4 4 5 5 5 5 5 5 5 אין קשר ישיר עם התלמיד
לימודי, הקנייה 4 4 4 4 5 5 5 5 5 5 5 5 לא לימודי
ידע תוכן 3 3 4 5 5 5 5 5 5 5 5 5 לא קשור לידע
100 90 80 70
יודע לומר לא יודע בודק ומחזיר תשובה
לבצע בחנים
גישה לתלמידים
מורה שיודע מעבר למה שמלמד
נגישות לתלמיד
לפשט מושגים
מורה המקנה כלים ללמידה עצמאית
ידע
לדעת לבדוק מבחן
נוכחות המורה בכתה
לנטרל בעיות משמעת
אישיות טובה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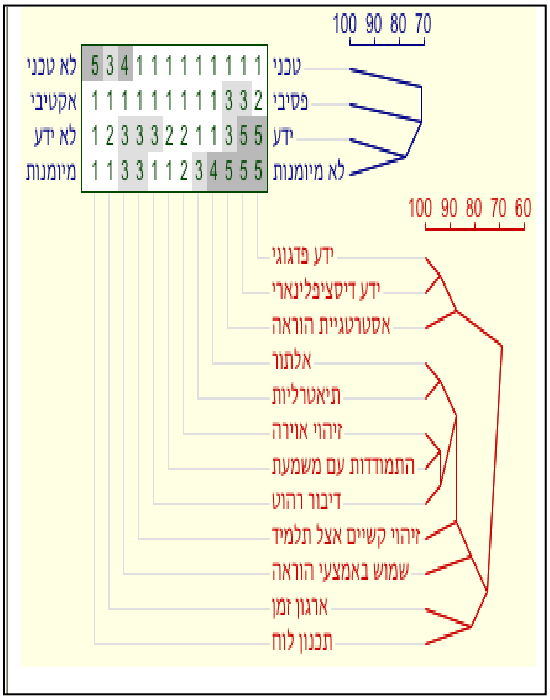
קשור לקהל היעד 3 3 3 5 5 5 5 5 4 1 1 1 לא קשור לקהל היעד
הכשרה 3 3 3 3 4 5 3 4 4 4 4 4 לא קשור להכשרה
נסיון 3 4 4 3 3 4 5 4 4 4 4 4 לא קשור לנסיון
לא קשור לידע אישי 2 2 1 1 2 3 5 5 5 5 2 1 ידע אישי
100 90 80 70 60
להכיר היטב את תחום הדעת
סיעור מוחין עם עמיתים להוראה
הכרת קהל היעד
קשוב לתשובות תלמידים
בדיקת ידע מוקדם
סידור פרקי ההוראה
גירוי
להעלות לדיון שאלות בעיתיות
להכיר מגוון הסברים או ייצוגים
ראשי פרקים)סידור(
איסוף חומרים ממספר מקורות
כתיבת תקצירים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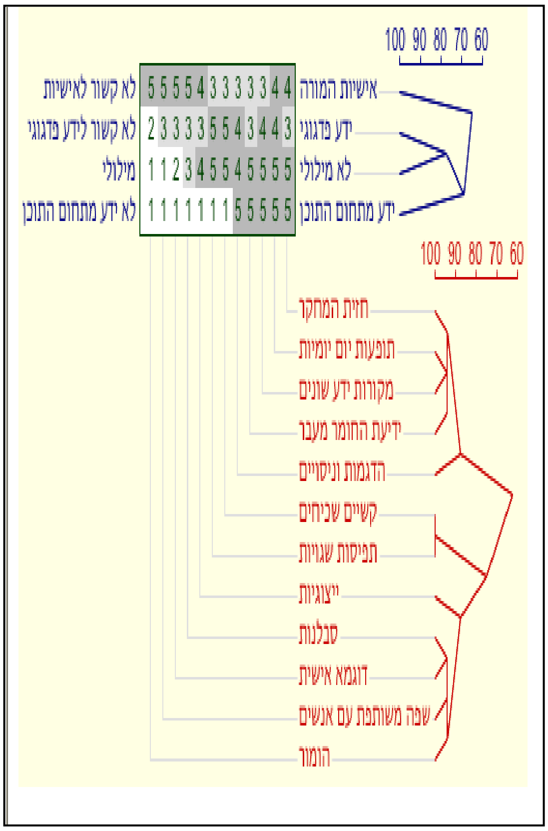
טכני 5 3 4 1 1 1 1 1 1 1 1 1 לא טכני
פסיבי 1 1 1 1 1 1 1 1 1 3 3 2 אקטיבי
ידע 1 2 3 3 3 2 2 1 1 3 5 5 לא ידע
לא מיומנות 1 1 3 3 1 1 2 3 4 5 5 5 מיומנות
100 90 80 70 60
ידע פדגוגי
ידע דיסציפלינארי
אסטרטגיית הוראה
אלתור
תיאטרליות
זיהוי אוירה
התמודדות עם משמעת
דיבור רהוט
זיהוי קשיים אצל תלמיד
שמוש באמצעי הוראה
ארגון זמן
תכנון לוח



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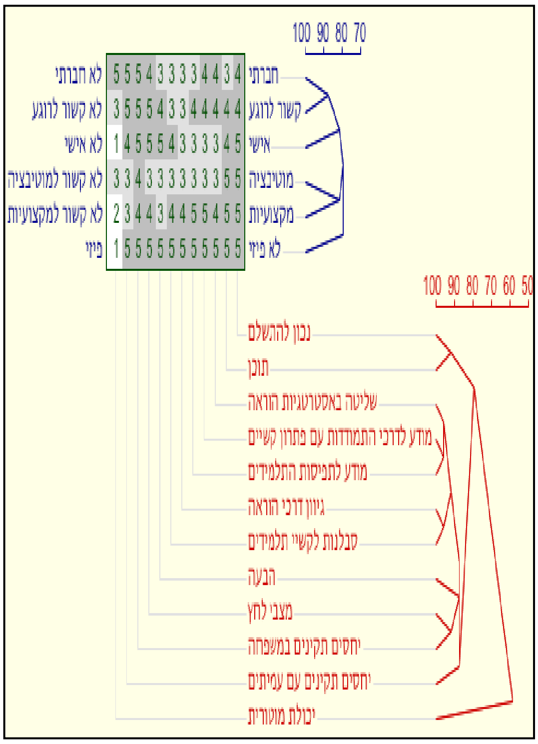
לא קשור לאישיות 5 5 5 5 4 3 3 3 3 3 4 4 אישיות המורה
לא קשור לידע פדגוגי 2 3 3 3 3 5 5 4 3 4 4 3 ידע פדגוגי
מילולי 1 1 2 3 4 5 5 4 5 5 5 5 לא מילולי
לא ידע מתחום התוכן 1 1 1 1 1 1 1 5 5 5 5 5 ידע מתחום התוכן
100 90 80 70 60
חזית המחקר
תופעות יום יומיות
מקורות ידע שונים
ידיעת החומר מעבר
הדגמות וניסויים
קשיים שכיחים
תפיסות שגויות
ייצוגיות
סבלנות
דוגמא אישית
שפה משותפת עם אנשים
הומור

100 90 80 70
לא קשור לאופן הוראה 1 1 1 2 5 5 5 5 4 3 3 2 אופן הוראה
ידע תוכן 1 1 1 1 3 3 2 5 5 5 4 4 לא ידע תוכן
לא קשור לקשר בין אישי 1 1 1 1 2 3 3 4 5 5 5 5 קשר בין אישי
100 90 80 70 60 50
יכולת לתת מוטיבציה לתלמידים
סבלנות
גשר לתלמיד
יכולת יצירת דיון
יכולת ליצור קשב אצל התלמידים
יכולת לשלב רעיונות שיעניינו את התלמידים
יכולת לעניין את התלמידים
יכולת שילוב טכנולוגיות בהוראה
יכולת הבנה מופשטת
יכולות מתמטיות גבוהות
יכולת הבנה של שאלות
הבנה עמוקה של חומר הלימוד



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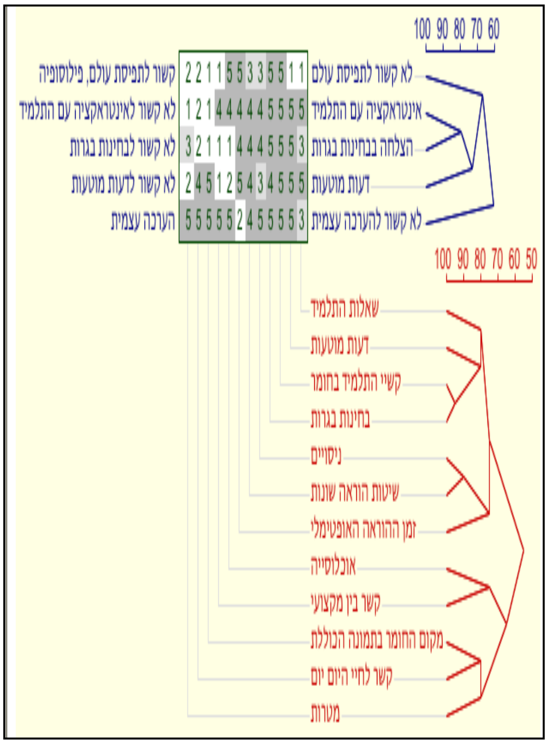
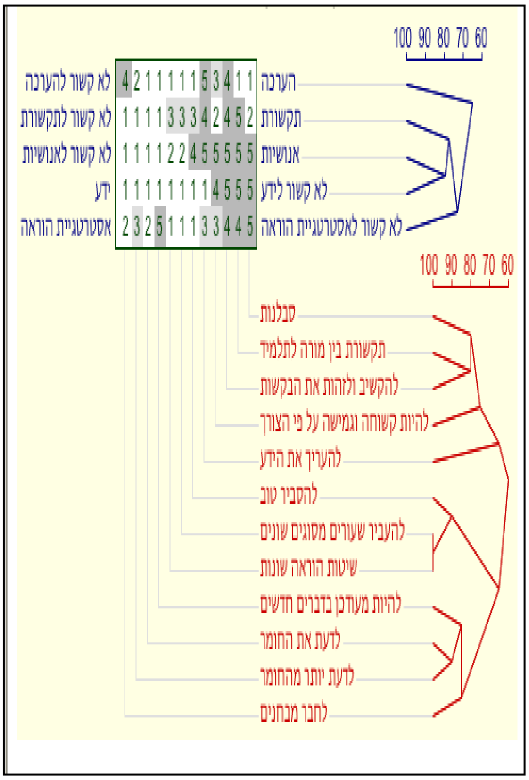
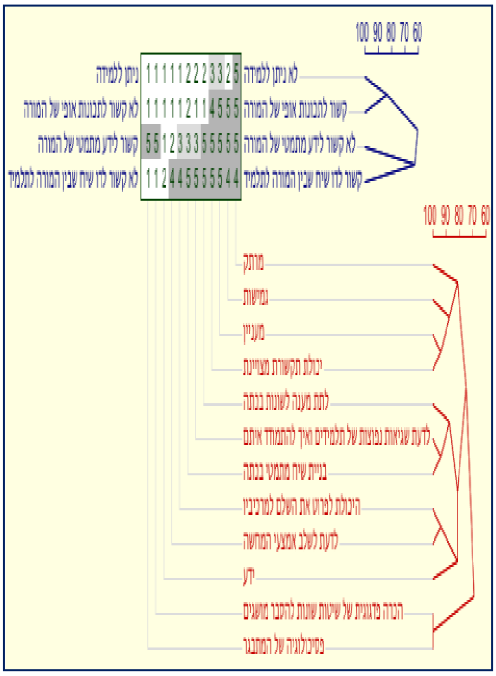
לא חברתי 5 5 5 4 3 3 3 3 4 4 3 4 חברתי
לא קשור לרוגע 3 5 5 5 4 3 3 4 4 4 4 4 קשור לרוגע
לא אישי 1 4 5 5 5 4 3 3 3 3 4 5 אישי
לא קשור למוטיבציה 3 3 4 3 3 3 3 3 3 3 5 5 מוטיבציה
לא קשור למקצועיות 2 3 4 4 3 4 4 5 5 4 5 5 מקצועיות
פיזי 1 5 5 5 5 5 5 5 5 5 5 5 לא פיזי
100 90 80 70 60 50
נכון להשלם
תוכן
שליטה באסטרטגיות הוראה
מודע לדרכי התמודדות עם פתרון קשיים
מודע לתפיסות התלמידים
גיוון דרכי הוראה
סבלנות לקשיי תלמידים
הבעה
מצבי לחץ
יחסים תקינים במשפחה
יחסים תקינים עם עמיתים
יכולת מוטורית

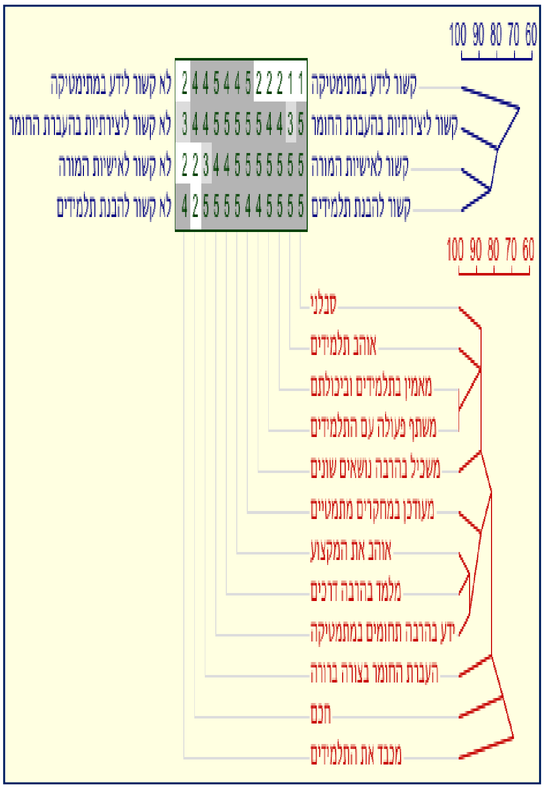


100 90 80 70 60
קשור לתפיסת עולם, פילוסופיה 2 2 1 1 5 5 3 3 5 5 1 1 לא קשור לתפיסת עולם
לא קשור לאינטראקציה עם התלמיד 1 2 1 4 4 4 4 4 5 5 5 5 אינטראקציה עם התלמיד
לא קשור לבחינות בגרות 3 2 1 1 1 4 4 4 5 5 5 3 הצלחה בבחינות בגרות
לא קשור לדעות מוטעות 2 4 5 1 2 5 4 3 4 5 5 5 דעות מוטעות
הערכה עצמית 5 5 5 5 5 2 4 5 5 5 5 3 לא קשור להערכה עצמית
100 90 80 70 60 50
שאלות התלמיד
דעות מוטעות
קשיי התלמיד בחומר
בחינות בגרות
ניסויים
שיטות הוראה שונות
זמן ההוראה האופטימלי
אוכלוסייה
קשר בין מקצועי
מקום החומר בתמונה הכוללת
קשר לחיי היום יום
מטרות



Mathematics teachers' repertory grids

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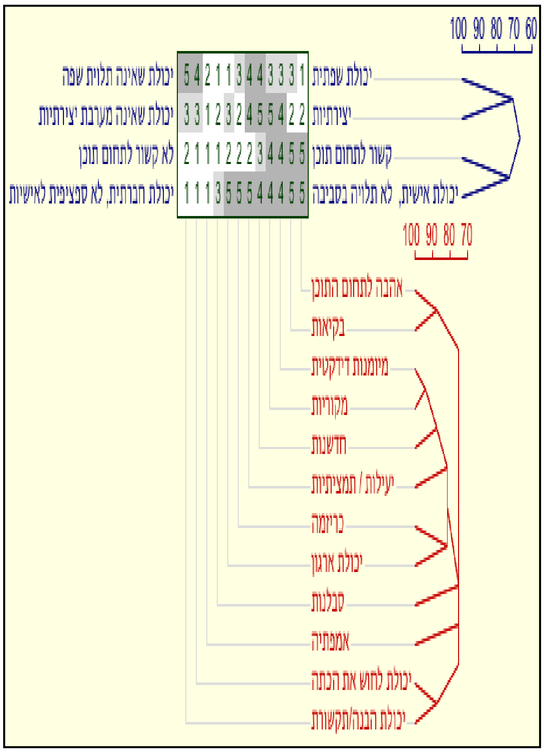
קשור לידע במתימטיקה 24454452211 לא קשור לידע במתימטיקה
קשור ליצירתיות בהעברת החומר 34455555443 5 לא קשור ליצירתיות בהעברת החומר
קשור לאישיות המורה 22344555555 5 לא קשור לאישיות המורה
קשור להבנת תלמידים 42555544555 5 לא קשור להבנת תלמידים
100 90 80 70 60
סבלני
אוהב תלמידים
מאמין בתלמידים וביכולתם
משתף פעולה עם התלמידים
משכיל בהרבה נושאים שונים
מעודכן במחקרים מתמטיים
אוהב את המקצוע
מלמד בהרבה דרכים
ידע בהרבה תחומים במתמטיקה
העברת החומר בצורה ברורה
חכם
מכבד את התלמידים


100 90 80 70
קשור לתבונות אישיות 555554444111 לא קשור לתבונות אישיות
קשור לרצון להשקיע בתלמיד 555444555354 לא קשור לרצון להשקיע בתלמיד
קשור לפתיחות 544445455553 לא קשור לפתיחות
קשור לידע מתמטי 115544455555 לא קשור לידע מתמטי
100 90 80 70 60
ידע בתחום
להתעניין בחומרים קשים
לדעת הסטוריה ופילוסופיה של המדע
לדעת לשלב דרכי הוראה שונות
לגרום לתלמיד לרצות ללמד
גמישות
פתיחות
לעזור לתלמיד
אינטואיציה
לדעת לענות על שאלות
להיות אדם נחמד
להיות פתוח לתוצאות של תלמידים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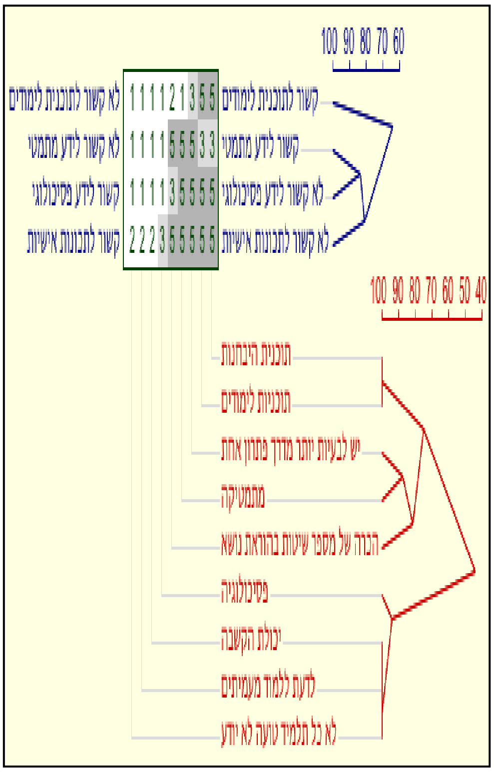
יכולת שפתית 54211344333 1 יכולת שאינה תלוית שפה
יצירתית 33123245542 2 יכולת שאינה מערבת יצירתיות
קשור לתחום תוכן 21112223445 5 לא קשור לתחום תוכן
יכולת אישית, לא תלויה בסביבה 11135554445 5 יכולת חברתית, לא ספציפית לאישיות
100 90 80 70
אהבה לתחום התוכן
בקיאות
מיומנות דידקטית
מקוריות
חדשנות
יעילות / תמציתיות
כריזמה
יכולת ארגון
סבלנות
אמפתיה
יכולת לחוש את הכתה
יכולת הבנה/תקשורת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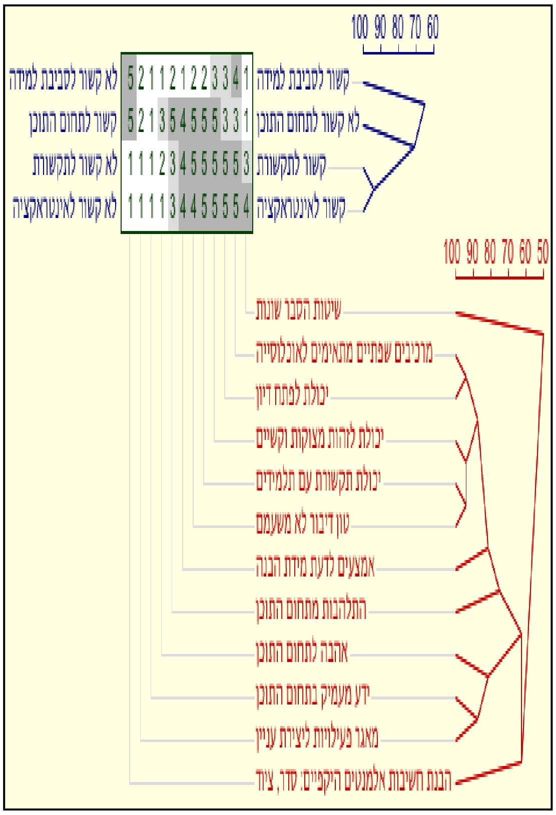
קשור לתוכנית לימודים 111121355 לא קשור לתוכנית לימודים
קשור לידע מתמטי 111155533 לא קשור לידע מתמטי
לא קשור לידע פסיכולוגי 111135555 קשור לידע פסיכולוגי
לא קשור לתבונות אישיות 222355555 קשור לתבונות אישיות
100 90 80 70 60 50 40
תוכנית היבחנות
תוכניות לימודים
יש לבעיות יותר מדרך פתרון אחת
מתמטיקה
הכרה של מספר שיטות בהוראת נושא
פסיכולוגיה
יכולת הקשבה
לדעת ללמד מעמיתים
לא כל תלמיד טועה לא יודע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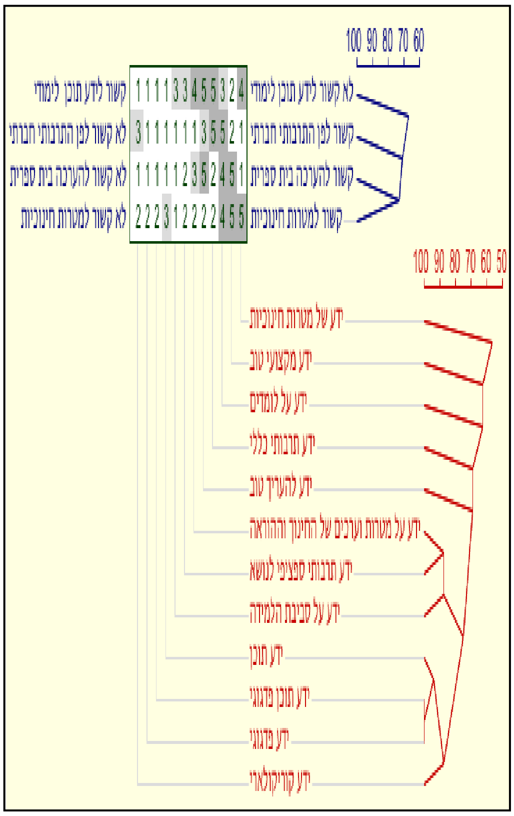
לא קשור לסביבת למידה 5 2 1 1 2 1 2 2 3 3 4 1 קשור לסביבת למידה
קשור לתחום התוכן 5 2 1 3 5 4 5 5 5 3 3 1 לא קשור לתחום התוכן
לא קשור לתקשורת 1 1 1 2 3 4 5 5 5 5 5 3 קשור לתקשורת
לא קשור לאינטראקציה 1 1 1 1 3 4 4 5 5 5 5 4 קשור לאינטראקציה
100 90 80 70 60 50
שיטות הסבר שונות
מרכיבים שפתיים מתאימים לאוכלוסייה
יכולת לפתח דיון
יכולת לזהות מצוקות וקשיים
יכולת תקשורת עם תלמידים
טון דיבור לא משעמם
אמצעים לדעת מידת הבנה
התלהבות מתחום התוכן
אהבה לתחום התוכן
ידע מעמיק בתחום התוכן
מאגר פעילויות ליצירת עניין
הבנת חשיבות אלמנטים היקפיים: סדר, ציוד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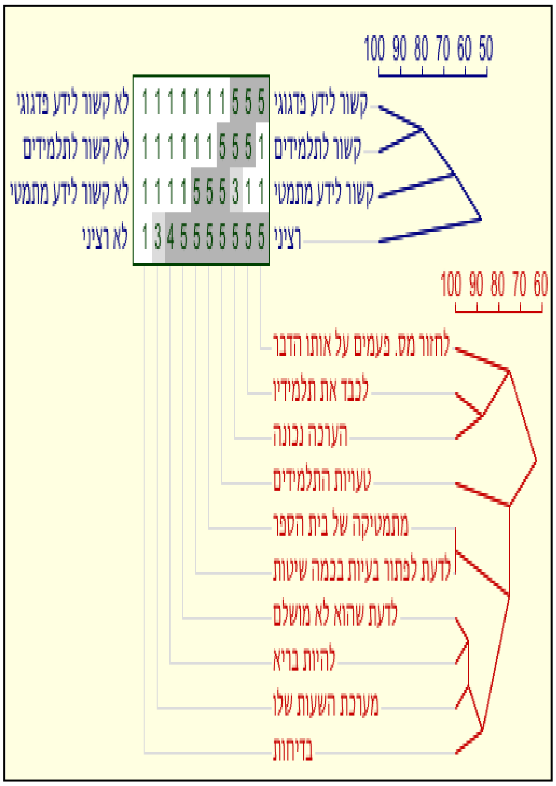
קשור לידע תוכן לימודי 1 1 1 1 3 3 4 5 5 3 2 4 לא קשור לידע תוכן לימודי
לא קשור לפן התרבותי חברתי 3 1 1 1 1 1 1 3 5 5 2 1 קשור לפן התרבותי חברתי
לא קשור להערכה בית ספרית 1 1 1 1 1 2 3 5 2 4 5 1 קשור להערכה בית ספרית
לא קשור למטרות חינוכיות 2 2 2 3 1 2 2 2 2 4 5 5 קשור למטרות חינוכיות
100 90 80 70 60 50
ידע של מטרות חינוכיות
ידע מקצועי טוב
ידע על לומדים
ידע תרבותי כללי
ידע להעריך טוב
ידע על מטרות וערכים של החינוך וההוראה
ידע תרבותי ספציפי לנושא
ידע על סביבת הלמידה
ידע תוכן
ידע תוכן פדגוגי
ידע פדגוגי
ידע קוריקולארי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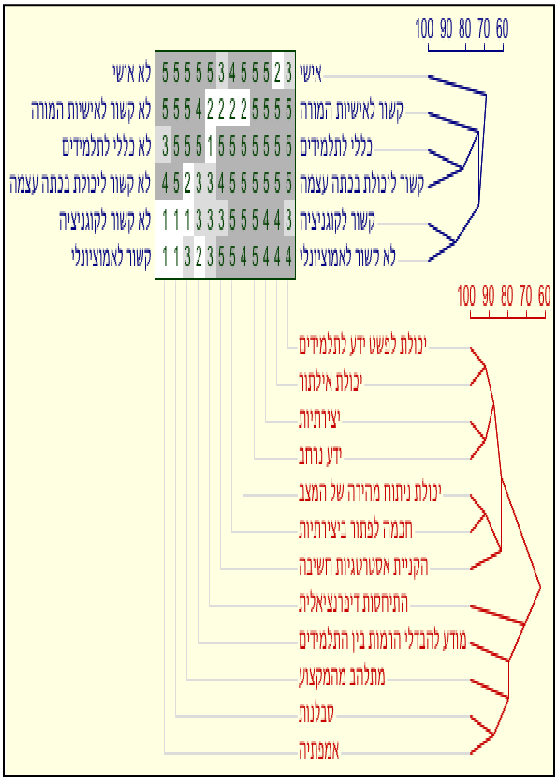
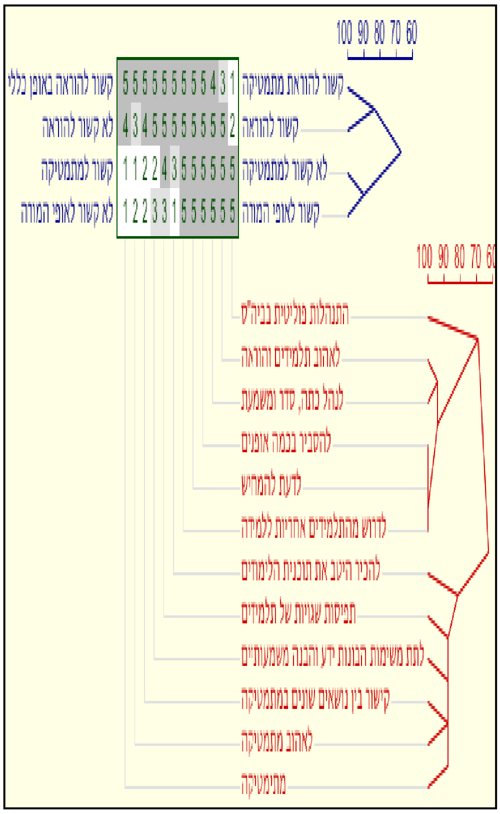
לא קשור לידע פדגוגי 1 1 1 1 1 1 1 5 5 5 קשור לידע פדגוגי
לא קשור לתלמידים 1 1 1 1 1 1 5 5 5 1 קשור לתלמידים
לא קשור לידע מתמטי 1 1 1 1 5 5 5 3 1 1 קשור לידע מתמטי
לא רציני 1 3 4 5 5 5 5 5 5 5 רציני
100 90 80 70 60
לחזור מס. פעמים על אותו הדבר
לכבד את תלמידיו
הערכה נכונה
טעויות התלמידים
מתמטיקה של בית הספר
לדעת לפתור בעיות בכמה שיטות
לדעת שהוא לא מושלם
להיות בריא
מערכת השעות שלו
בדיחות


100 90 80 70
לא מקצועי להוראה 3 4 4 4 5 5 5 5 5 5 5 5 מקצועי להוראה
לא קשור להופעה 4 5 4 4 4 4 4 4 4 4 5 3 קשור להופעה
לא קשור לניהול 5 3 3 3 3 3 5 5 5 5 5 3 קשור לניהול
לא קשור לידע מתמטי 3 3 3 3 3 3 5 5 5 5 5 5 קשור לידע מתמטי
לא קשור לדיוק 3 3 3 3 3 3 3 3 5 5 5 5 קשור לדיוק
100 90 80
חומר הלימוד
דיוק
יצירתיות
יודע עוד מקצוע
גישה לפרט
מנהיגות
אקטואליה
הסטוריה
תרבות החברה
בדיחה
סטייל)מראה(
סבלנות


100 90 80 70 60
לא אישי 5 5 5 5 5 3 4 5 5 5 2 3 אישי
לא קשור לאישיות המורה 5 5 5 4 2 2 2 2 5 5 5 5 קשור לאישיות המורה
לא כללי לתלמידים 3 5 5 5 1 5 5 5 5 5 5 5 כללי לתלמידים
לא קשור ליכולת בכתה עצמה 4 5 2 3 3 4 5 5 5 5 5 5 קשור ליכולת בכתה עצמה
לא קשור לקוגניציה 1 1 1 3 3 3 5 5 5 4 4 3 קשור לקוגניציה
קשור לאמוציונלי 1 1 3 2 3 5 5 4 5 4 4 4 לא קשור לאמוציונלי
100 90 80 70 60
יכולת לפשט ידע לתלמידים
יכולת אילתור
יצירתיות
ידע נרחב
יכולת ניתוח מהירה של המצב
חכמה לפתור ביצירתיות
הקניית אסטרטגיות חשיבה
התיחסות דיפרנציאלית
מודע להבדלי הרמות בין התלמידים
מתלהב מהמקצוע
סבלנות
אמפתיה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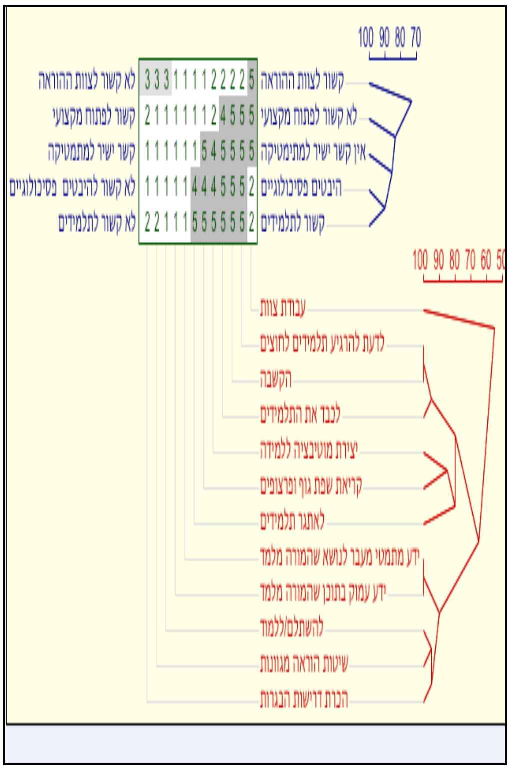
קשור להוראה באופן כללי 5 5 5 5 5 5 5 5 5 4 3 1 קשור להוראת מתמטיקה
לא קשור להוראה 4 3 4 5 5 5 5 5 5 5 5 2 קשור להוראה
קשור למתמטיקה 1 1 2 2 4 3 5 5 5 5 5 5 לא קשור למתמטיקה
לא קשור לאופי המורה 1 2 2 3 3 1 5 5 5 5 5 5 קשור לאופי המורה
100 90 80 70 60
התנהלות פוליטית בביה"ס
לאהוב תלמידים והוראה
לנהל כתה, סדר ומשמעת
להסביר בכמה אופנים
לדעת להמריש
לדרוש מהתלמידים אחריות ללמידה
להכיר היטב את תוכנית הלימודים
תפיסות שגויות של תלמידים
לתת משימות הבנות ידע והבנה משמעותיים
קישור בין נושאים שונים במתמטיקה
לאהוב מתמטיקה
מתימטיקה


100 90 80 70
לא קשור לצוות ההוראה 3 3 3 1 1 1 1 2 2 2 2 5 קשור לצוות ההוראה
קשור לפתוח מקצועי 2 1 1 1 1 1 1 2 4 5 5 5 לא קשור לפתוח מקצועי
קשר ישיר למתמטיקה 1 1 1 1 1 1 5 4 5 5 5 5 אין קשר ישיר למתימטיקה
לא קשור להיבטים פסיכולוגיים 1 1 1 1 1 4 4 4 5 5 5 2 היבטים פסיכולוגיים
לא קשור לתלמידים 2 2 1 1 1 5 5 5 5 5 5 2 קשור לתלמידים
100 90 80 70 60 50
עבודת צוות
לדעת להרגיע תלמידים לחוצים
הקשבה
לכבד את התלמידים
יצירת מוטיבציה ללמידה
קריאת שפת גוף ופרצופים
לאתגר תלמידים
ידע מתמטי מעבר לנושא שהמורה מלמד
ידע עמוק בתוכן שהמורה מלמד
להשתלם/ללמוד
שיטות הוראה מגוונות
הכרת דרישות הבגרות