5 CHARACTERIZING THE TACIT RELATIONSHIPS BETWEEN BIOLOGY TEACHERS' CONTENT KNOWLEDGE (CK) AND OTHER PROFESSIONAL KNOWLEDGE COMPONENTS

Ronit Rozenszajn and Anat Yarden
Department of Science Teaching, Weizmann Institute of Science, Rehovot 76100, Israel
ronit.rozenszayn@weizmann.ac.il, anat.yarden@weizmann.ac.il

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.

Keywords: Pedagogical content knowledge; Content knowledge; Tacit knowledge; Personal Construct Psychology Theory; Repertory grid technique; Professional knowledge.

1. 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 & 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.

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 & 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 Psychology Theory (Kelly, 1955).

The Personal Construct Psychology 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 Psychology 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 Psychology 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 Psychology 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 tacit 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 the Rothschild-Weizmann Program for Excellence in Science Education, given at the Weizmann Institute of Science. 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 Psychology 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 Figure 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 5software (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. An additional validation of the outcomes was performed with another researcher that is familiar with the RGT. The overall validation rate was 95%.

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 Figure 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.

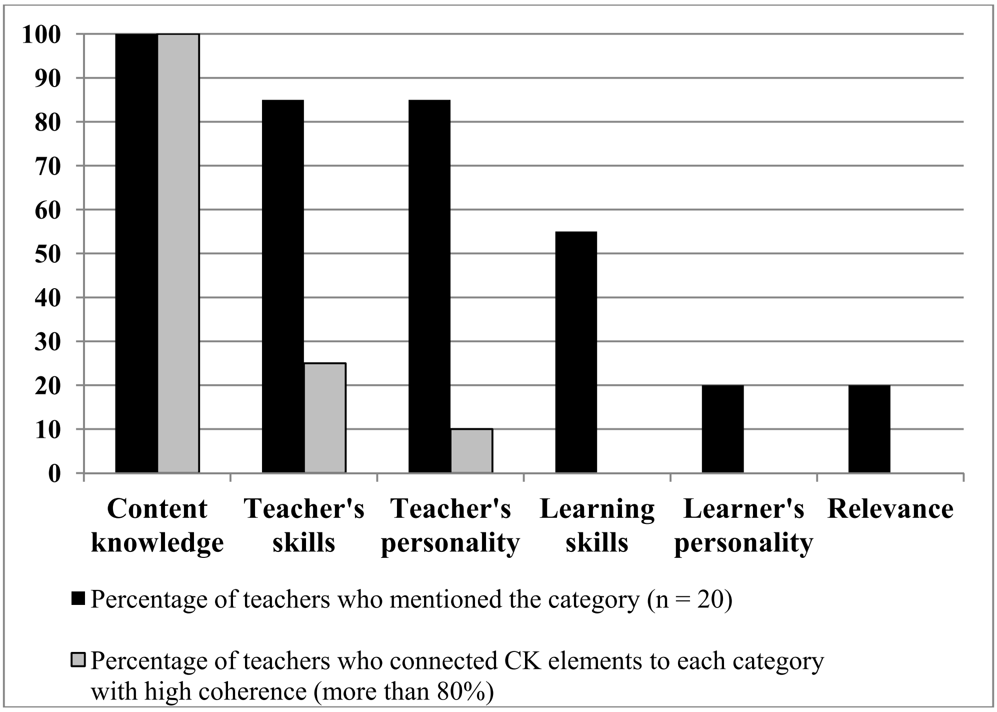

Figure 1. Percentage of teachers mentioning CK elements, and the percentage mentioning connections between CK elements and other elements.

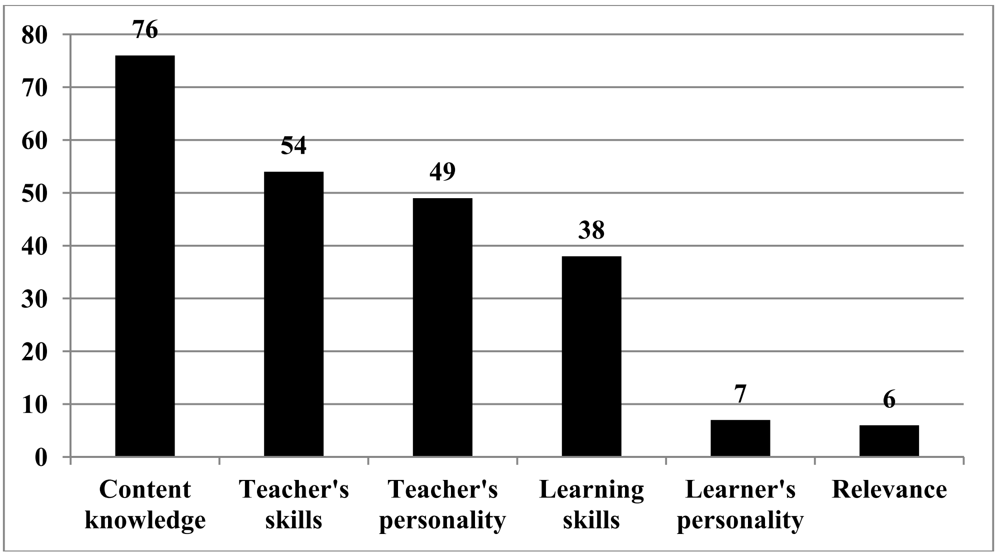

Figure 2. Diversity of elements of each category in the participating teachers' data.

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.

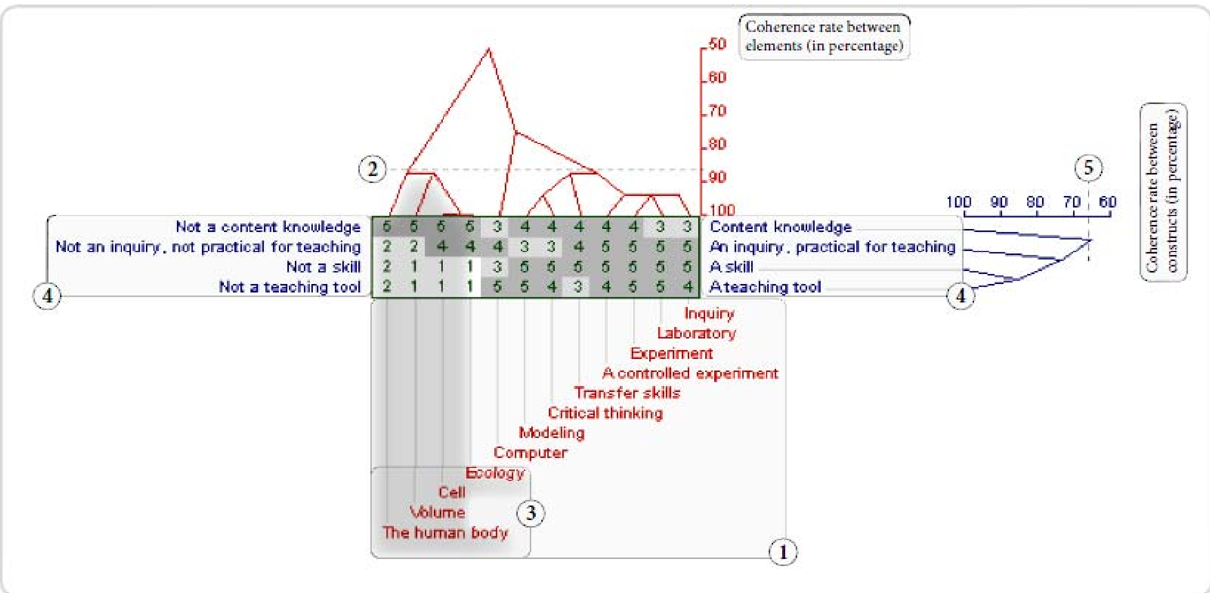

Figure 3. Analysis of Teacher A3's data using a repertory grid tree diagram (1) Elements; (2) coherence scale and its use in defining a group of elements (3) with more than 80% coherence; (4) constructs; (5) coherence scale and its use in defining coherence rate of the construct 'content knowledge' and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

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 (Rozenszajn & Yarden, 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.

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 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 & 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. 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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