Chapter 10
A Metacognitive Teaching Strategy for Preservice Teachers: Collaborative Diagnosis of Conceptual Understanding in Science

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Introduction

Instructional courses for preservice teachers are usually separated into disciplinary content courses and pedagogical courses. The separate teaching of content and pedagogy is problematic since it does not support the integration of subject matter knowledge and pedagogy required for developing pedagogical content knowledge (PCK) (Shulman 1986, 1987, 1990). This fragmentation of teachers' learning experiences leaves individual teachers the challenge of developing pedagogical content knowledge on their own during their practice as teachers (Ball 2000). However, it is not clear that the desired development of PCK by learning in and from practice (Ball and Cohen 1999) occurs naturally in the course of time. Yet, this knowledge is fundamental to the core tasks of teaching and is critical for developing the ability to teach well. Sabar (1994) suggests that special frameworks must be constructed to help the preservice teachers carry out this integration.

This chapter describes the design of a preservice science course which attempts to promote the attainment of both disciplinary knowledge and pedagogical content knowledge by using metacognitive teaching strategies. The study investigates how the use of these strategies contributes to the learning of content and pedagogy. The study was carried out in the context of a geometrical optics course for preservice teachers.

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What are important learning goals (content and pedagogy) for preservice teachers? What challenges do they present to teacher educators? Why is it important to use metacognitive teaching strategies to achieve these goals?

Concerning knowledge in the scientific domain, a central goal for preservice teachers as for other learners is to develop sound conceptual understanding and the ability to apply their newly acquired knowledge in solving problems. Research suggests that the attainment of these goals with learners of all levels is very challenging. Numerous studies document the fact that students' prior knowledge in science, as well as the knowledge developed in the course of studying science, involves conceptions that are incongruent with normative science. These conceptions are resistant to change (Eylon and Linn 1988; Pfundt and Duit 1994). Since preservice teachers have scientific conceptions similar to those of school students (Galili and Hazan 2000), teaching for conceptual understanding in preservice courses faces similar challenges.

A common feature of teaching strategies that promote the acquisition of conceptual understanding is students' "active engagement" (minds on). For example, Hake (1998) conducted a meta-study on introductory physics courses and used the Force Concept Inventory (FCI) developed by Hestenes et al. (1992) to evaluate students' conceptual understanding in the end of the courses. Hake found a significant difference between students who studied in courses using transmissionist teaching strategies and those that emphasized students' active engagement. Another common feature of teaching strategies that promote understanding and problem-solving is the use of metacognition and an explicit requirement to reflect on learning. There is consensus among researchers that metacognitive processes promote cognitive abilities and that metacognition is important for promoting learning processes (Brown 1994). Examples can be found in fields such as reading comprehension (Veenman and Beishuizen 2004), mathematical problem-solving (Kramarski and Mevarech 2003), and science teaching (Zion et al. 2005; Zohar 1999). Research shows that learning outcomes are improved when more metacognitive processes accrue (Lambert 2000) and that high-achieving learners apply more metacognitive processes than low-achieving learners (Rimor 2002).

Concerning pedagogy, an important goal is to model to preservice teachers effective teaching strategies that they will be able to use with their students. In addition, the teachers should be able to identify the critical characteristics of these strategies and also learn how to use them. Without modeling to the preservice teachers teaching approaches that are effective in attaining goals such as teaching for understanding in the context of a content course, it is very unlikely that the preservice teachers will be able to come up with such strategies on their own. In this chapter we question the common assumption that "teachers teach the way they were taught." The implicit experiencing of the teaching and learning strategies in the context of a disciplinary course may not be sufficient for constructing the desired pedagogical content knowledge. Special metacognitive scaffolding may be needed to identify and explicate the knowledge.

The design of the preservice course in the present study attempted to promote the above mentioned content and pedagogy goals by attending to the challenges that were mentioned earlier. The course employed a metacognitive instructional strategy *collaborative diagnosis of conceptions* (CDC), accompanied by continuous and explicit discussions about the content and pedagogical characteristics of the learning that took place. In the CDC strategy the preservice teachers carry out an activity individually, examine the answers collaboratively with peers, compare and contrast the answers, and attempt to come up with a consensual answer. Later in the course they try to identify conceptions that underlie various answers (their own and hypothetical students' answers) and are asked to come up with suggested activities to advance students' understanding. The strategy emphasizes the social aspect of learning, specifically referring to the influence of social interaction on the knowledge construction of the learner (Vygotsky 1978). The assumption is that learning is a social process, and in collaborative learning, knowledge is constructed through negotiation and discussion. In particular, research shows that the socially shared metacognition is especially effective in learning how to solve problems in groups, a focus of the CDC strategy. For example, Hurme et al. (2009), who investigated socially shared metacognition of preservice primary teachers in a computer-supported mathematics course, found that although initially the preservice teachers felt that the collaborative tasks were difficult, this feeling decreased when socially shared metacognition emerged. Consequently, learning increased.

The goal of the present study was to test whether, in the context of the disciplinary course which employed the strategies described earlier, the preservice teachers would develop their conceptual understanding as well as their pedagogical content knowledge. Another goal was to study the role of metacognition in the process of learning and to determine what scaffolding is needed to help preservice teachers integrate the content and pedagogical aspects of learning.

Pedagogical Content Knowledge

According to Shulman (1986, 1987), teachers' professional knowledge should involve several components, one of which is pedagogical content knowledge (PCK). Shulman describes PCK as "the most powerful analogies, illustrations, examples, explanations, and demonstrations….., the ways of representing and formulating the subject that makes it comprehensible for others" (1986, p. 9). He claims that this component characterizes the special knowledge acquired by teachers in their subject domains. Good teachers possess a strong PCK knowledge. Moreover, this knowledge is essential for designing curricula that enable students to construct a sound understanding of the domain knowledge. Shulman's view of teachers' knowledge led to a shift in understanding teachers' work by focusing not only on their behavior but also on their knowledge.

Although PCK is a notion commonly used by scholars, the main challenge is how to capture teachers' PCK, since teachers are often unaware of the knowledge they possess. Moreover, in their regular practice they do not need to explicate it. PCK is content dependent and is difficult to conceptualize for different subjects.

Its boundaries are blurry and it is not uniquely defined in the literature. Some researchers, however (e.g., Loughran et al. 2004), claim that teachers' PCK is recognizable in their approach to teaching specific content.

For our purposes, we will refer to the framework proposed by Magnusson et al. (1999) for conceptualizing PCK for science teaching. They described PCK as consisting of five components: (a) orientation toward science teaching, (b) knowledge and beliefs about the science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. In this chapter we focus on the third and fifth components dealing with knowledge and beliefs about students' understanding of specific science topics and about instructional strategies for teaching science. According to Magnusson et al. (1999), each of these components consists of several categories: (a) knowledge of students' understanding of science which includes the requirement of learning specific science concepts, and the areas of science that students find difficult, and (b) knowledge of instructional strategies includes knowledge of subject-specific strategies and knowledge of topic-specific strategies involving different representations and activities.

Definitions of Metacognition

Metacognition was formerly referred to as knowledge about and regulation of one's cognitive activities in learning processes (Brown 1977; Flavell 1979). Flavell defined the concept as follows: "Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them,…." and "Metacognition refers among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in the service of some concrete goal or objective" (Flavell 1976) (p. 232). Brown included in her definition the central distinction that metacognition refers to learners' understanding of their knowledge; an understanding that can be reflected in effective use of that knowledge and good performance on academic tasks (Brown 1977). Schraw and Moshman (1995) refer to the same basic distinction between *metacognitive knowledge* (i.e., what one knows about cognition) and *metacognitive control processes* (i.e., how one uses that knowledge to regulate cognition). They categorize metacognitive knowledge into three kinds of metacognitive awareness: declarative knowledge, procedural knowledge, and conditional knowledge. Metacognitive control processes involve the active monitoring and regulation of cognitive processes. Such processes are central to planning, problem-solving, evaluating, and many aspects of learning.

One of the components of metacognitive knowledge is metastrategic knowledge that refers to explicit knowledge regarding the thinking about strategies being used during instruction. Findings from several studies show that the metastrategic knowledge of teachers is insufficient for sound teaching of higher-order teaching skills (Zohar 2006). Zohar and collaborators (Zohar and Peled 2008;

Zohar and Ben David 2008) have shown, however, that this knowledge can be improved by explicit instruction and that such knowledge can affect students' cognitive and metacognitive thinking.

More recently, Veenman and Van Hout-Wolters (2006) summarized several of the terms we commonly associate with metacognition, including metacognitive beliefs, metacognitive awareness, metacognitive experiences, metacognitive knowledge, a feeling of knowing, judgment of learning, theory of mind, metamemory, metacognitive skills, executive skills, higher-order skills, metacomponents, monitoring comprehension, learning strategies, heuristic strategies, and self-regulation. This long list of terms underscores the importance of specifying what view of metacognition is being taken in a particular study. In the next section we describe how we used metacognition in this research.

Metacognition in This Research

Since the construct of metacognition is not unequivocally defined, its characterization in this research is based on two different sources: (1) choice of relevant aspects from several definitions from the literature (top-down) and (2) categories emerging from analysis of class discourse and the learners' reflection after a CDC lesson (bottom-up).

Most of the definitions presented in the previous section make a clear distinction between metacognitive knowledge and the metacognitive regulation or control processes. We follow this distinction. Figure 10.1 presents the framework that was used in this research to characterize the CDC tasks, the learners' performances, their discourse, and their reflections. In the present study we focus mainly on metacognitive knowledge, and therefore we elaborate on its various components. Following the literature and our own focus, we identify four central categories (see Table 10.1). In category B1, *knowledge about people*, we underscore both the understanding of one's own thought processes (B1_1) and the thought processes of others (B1_2). This aspect is very central in the CDC strategy, which is a collaborative strategy that aims to promote preservice teachers' knowledge about alternative ways of thinking and in particular how to understand their students. Category B2, *metastrategic knowledge*, is also central in our study since it plays an important role in the development of the teachers' conceptual knowledge as well as their understanding of the CDC strategy and the actions involved in carrying out its various steps. In the section "CDC in Action" we provide an example of the important role of metastrategic knowledge. The third category, B3, *knowledge about tasks*, is a central component in teachers' pedagogical content knowledge. The teachers need to understand how the specific optics tasks that they study are structured and how they promote learning. This understanding will enable them to design learning experiences for their students. The fourth category, B4, *knowledge about knowledge integration*, involves knowledge about two aspects concerning knowledge integration. One aspect, B4_1, is concerned with understanding

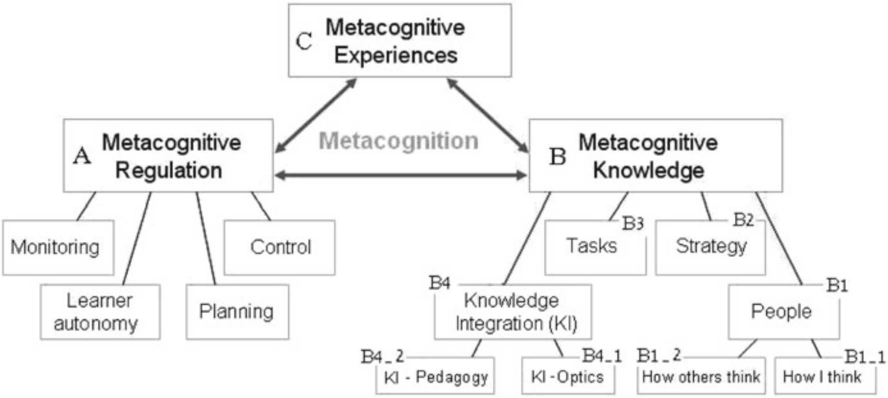

Fig. 10.1 Metacognition categories in this research

Table 10.1 The metacognitive categories in the context of this study

The category	Description (in the context of this study)
A: Metacognitive regulation	
	Capabilities involved in regulating actions (monitoring, planning, and control) and in independent learning
B: Metacognitive knowledge	
B1: Knowledge about people	**Knowledge about thought processes**
B1_1: How I think	Understanding my thought processes
B1_2: How others think	Understanding the thought processes of others
B2: Knowledge about strategy (metastrategic knowledge)	**Knowledge about the structure of an instructional strategy and how it promotes learning**
B3: Knowledge about tasks	**Understanding the structure of tasks and how they promote learning**
B4: Knowledge about knowledge integration (KI)	
B4_1: Knowledge about KI in optics	Understanding the structure of concepts and principles in optics and how they relate to alternative (normative and nonnormative) ways of relating the concepts and the principles
B4_2: Knowledge about pedagogy related to KI	Understanding how general pedagogical knowledge (PK) can be applied in the context of teaching optics to respond dynamically to students' normative and nonnormative scientific ideas (PCK)
C: Metacognitive experiences	

relationships between alternative ways (normative and nonnormative) of structuring the concepts and relationships in optics and how a given structure affects the way learners solve problems in this domain. This type of knowledge plays a central role in the preservice teachers' ability to identify the sources of various patterns of student solutions and to design instruction that responds to students' ideas. For example, if a learner's knowledge structure does *not* relate the act of "seeing" to rays emitted from an object (or scattered from it) and to the interaction of these rays with the eye ("entering the eye"), this has consequences for the way the student solves a range of problems about field of sight. The other aspect of this category, B4_2, is concerned with the ways to respond dynamically to students' scientific ideas (normative and nonnormative) in a manner that takes into account the students' knowledge structures and leads them to reconsider their ideas. As described above, the CDC strategy provides learning opportunities to the preservice teachers for developing their metacognitive knowledge. But at the same time the enactment of this strategy requires the learners to monitor, plan, and control the actions involved in interacting with peers and resources. For example, when there is disagreement between members of the group, they have to make decisions when to seek additional information from external resources such as experiments, computer simulation, or the teacher, and what resource to use for the particular situation. Hence the learners have opportunities to develop also metacognitive regulation (category A). As depicted in Fig. 10.1, there is a mutual relationship between metacognitive regulation and metacognitive knowledge; as in the former example, understanding how others think (category B1_2) influences the plan for deciding about the effective resource to resolve the conflict.

The CDC Strategy

The CDC strategy was developed to enable preservice teachers to learn the subject matter of a particular topic in physics and to reflect on thinking, learning, and teaching. In the present research the physics topic was geometrical optics. The CDC strategy aims to develop the preservice teachers' deep understanding of content by helping them to identify their prior conceptions and to link their new knowledge in optics to their previous knowledge. This strategy addresses diSessa's claim about fragmentation in learners' knowledge (diSessa 1988) and is aimed to promote knowledge integration (Linn and Eylon 2006, 2011). At the same time the CDC strategy also aims to develop pedagogical content knowledge. It aims to enhance one of the important skills of teaching: the ability to follow closely the students' conceptual understanding and to respond accordingly with appropriate instruction. This focus enables the preservice teachers to develop their pedagogical content knowledge (PCK) about ways to interact in the future with their students using a similar instructional strategy. The learning process was supported by a web-based collaborative environment (Ronen et al. 2006) that helps in constructing the collaborative learning. During the course the preservice teachers did not meet students, but they were exposed to students' work and to students' answers to the assignments that they did during the course.

The CDC strategy can be characterized along two dimensions. One dimension involves the act of diagnosis (see section "The Diagnosis Dimension"), and the other dimension describes aspects of collaboration involved in carrying out the strategy (see section "The Collaboration Dimension").

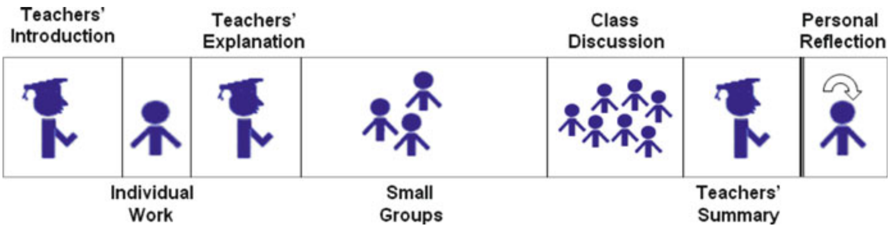

Fig. 10.2 Structure of a typical lesson

CDC in Action

The CDC activity is part of a lesson. Figure 10.2 shows the structure of a typical lesson including a CDC activity. The course involved five cycles of implementing the CDC strategy: in lessons 1, 5, 7, 10, and in the final test which took place after the last meeting. The implementations started with partial application of the various elements of the CDC strategy and evolved toward a full implementation toward the end of the course.

To be more concrete, Fig. 10.3 shows an example of a CDC activity that was carried out in the middle stages of the course. As shown in the figure, the steps of the activity can be represented on a two-dimensional matrix characterizing the diagnosis and collaborative aspects of each step. The arrows present the sequence of actions in the particular example. The figure also shows the concrete activity. The CDC activity usually culminates in a class discussion aimed at exposing all the learners to the groups' conclusions, and at building a common knowledge base that includes both the subject matter and pedagogical aspects.

The Diagnosis Dimension

The diagnosis dimension consists of five elements, most of which provide opportunities for promoting metacognitive thinking (see Fig. 10.3 for an example):

1. *Create an artifact*: This element of the activity is carried out individually and is aimed at eliciting learners' prior conceptions. The learners are asked to represent their thoughts about a scientific phenomenon usually involving a visual representation. This artifact will be used later in the strategy as a tool for explaining their thoughts. Although this element by itself is not metacognitive, it is important for creating the setting that will help metacognitive thinking in the other elements.
2. *Compare and contrast artifacts*: The learners are asked to find the differences between their individual artifacts. This activity encourages the learners to address their own thinking and to compare it to that of their peers (category B1 in Fig. 10.1). Through this process the learners recognize the essential features of their own representation and learn about other representations. As a result,

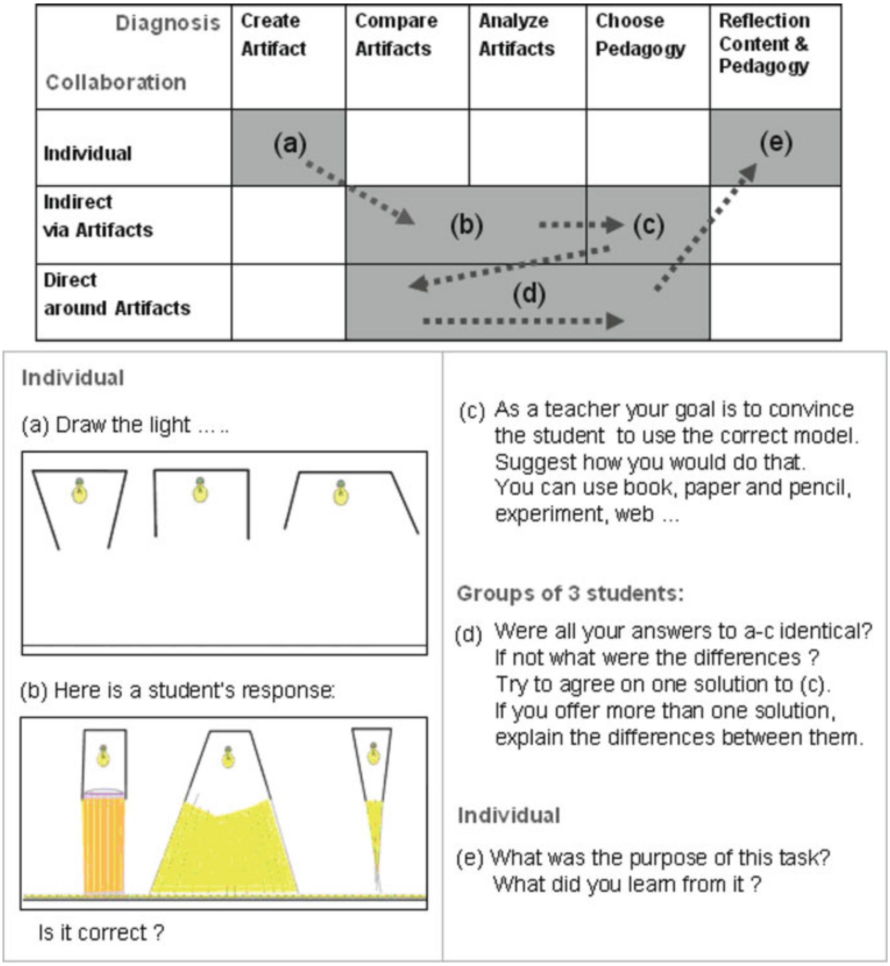

Fig. 10.3 An example of a CDC activity

they can deepen their understanding and possibly even change it with the help of their peers.

3. *Analyze artifacts*: The learners are asked to evaluate the scientific validity of the artifacts, the source of conceptions leading to the formation of the different artifacts, possibly reaching a consensus about the "best" artifact. To carry out this process, the learners have to acquire metacognitive knowledge about the ways their peers think about scientific phenomena and how they are applied in concrete cases. The learners also have to identify normative and nonnormative scientific ways of thinking about the optical phenomena and to conjecture what are the sources of their own ideas and the ideas of others. In this stage, the preservice teachers learn about the scientific knowledge, how this knowledge is built, and

how alternative conceptions come about. By the end of this stage they decide what conception is better and why (categories B1and B4 in Fig. 10.1).

4. *Choose a pedagogical strategy*: The learners are asked to choose, on the basis of their diagnosis, a pedagogical strategy for helping students promote their conceptual understanding. To carry out this step, the learners need knowledge about tasks (B3) and about knowledge integration both in optics and in pedagogy (B4). The learners have to connect the knowledge they acquired in the previous stage about how others think to the pedagogical knowledge on how they can change this way of thinking. During the process they have to explicate their pedagogical metastrategic knowledge and explain their decisions to their peers (categories B1 and B4 in Fig. 10.1).
5. *Reflect on content and pedagogy*: The learners are asked to reflect on the activity from two points of view: The first is about the content they have learned, and the second involves the pedagogy characterizing the teaching and learning strategies. In the reflection they have to explicate what they have learned (categories B1, B2, B3, and B4 in Fig. 10.1).

The Collaboration Dimension

The CDC strategy involves three levels of collaborative work:

1. *Individual work*: The learners carry out an activity by themselves.
2. *Indirect collaboration via artifacts*: The learners can work on artifacts created by others.
3. *Direct collaboration around artifacts*: The learners work collaboratively around artifacts on one or more of the various aspects of diagnosis (e.g., comparing and contrasting their artifacts).

The Study

The Research Goals and Questions

This study aimed at investigating the impact of the CDC strategy on the preservice teachers' content knowledge, in particular, learners' conceptual understanding after completing the course, their ability to apply the knowledge, and their diagnostic skills (research question 1 below). Since the CDC is a metacognitive instructional strategy which involves diagnosis of conceptions (see section "The CDC Strategy"), we expected it to enhance the attainment of the above mentioned learning outcomes.

Another goal of the study was to study the acquisition of pedagogical content knowledge by the preservice teachers. In particular, we were interested to investigate whether teachers would be able to characterize the instructional approach that they experienced, since one of the central considerations in designing the CDC strategy was to model a strategy they would be able to use in the future. Following a pilot study which showed that many of the preservice teachers were unable to provide a reasonable characterization of the instructional approach (see "Results" below), activities of structured reflection were added to the course. Thus another goal of the present study was to investigate whether this metacognitive scaffolding promoted the teachers' PCK (research question 2 below).

An additional issue that concerned us was the role of metacognition in the learning process (research question 3 below).

Accordingly, the following questions were studied:

1. What were, after completing the course, the preservice teachers' achievements in the conceptual, application, and diagnostic questions in the posttest?
2. How well could the teachers explicate the characteristics of the course after completing it? How did the addition of structured reflection on pedagogy influence this aspect of the preservice teachers' PCK?
3. What was the role of metacognition in the process of learning with the CDC strategy?

Methodology

The study was carried out in the context of a preservice geometrical optics course for elementary school teachers given in an academic college of education in Israel. It is one of the basic science courses for preservice science teachers in a 4-year B. Ed. program. The length of the course was 28 academic hours, 2 h each week. This course was implemented in two different versions, A and B, that differed in the way in which they integrated the CDC strategy into the teaching of the course.

Sample

The preservice teachers who participated in the study were divided into two groups: Group A ($n=16$) studied the first version of the course, and group B ($n=19$) studied the second version. Following the study of version B, additional five groups of preservice teachers ($n=70$) studied with this version.

In order to compare the composition of groups A and B, we located the scores of the students in groups A and B in two science courses studied prior to the course that is the focus of the present study. The comparison indicated that the groups were similar in their average scores in these tests, but group B was more heterogeneous than group A. Further support to this conclusion was given by the physics teachers who taught these courses who claimed that the groups were similar in composition and ability.

The Versions of the Course

In the two versions of the course, the students carried out several times collaborative diagnosis of conceptions (CDC) activities that were followed by reflection on the content. As described above, the CDC strategy supports metacognition on the learning of content by exposing the learners to different conceptions and by giving them an opportunity to discuss and reconsider their ideas. The implementation of the strategy in this regard was similar in the two versions of the course, but the versions differed in the amount of metacognitive scaffolding of the pedagogical aspects of learning. The *first version, A*, involved only a general discussion of the pedagogical implications of the approach. In the *second version, B*, each lesson, in particular, a lesson involving the CDC strategy, was followed by structured reflection on the pedagogy and content that were studied in the particular lesson. For example, one of the strategies involved habitual reporting and discussion of learning that occurred in the conceptual and the pedagogical areas. The learners were asked to answer two questions at the end of each lesson: What have you learned about optics during the lesson? What have you learned about teaching optics? The collaborative work was facilitated by a computer-based environment allowing students to test their ideas and to compare them to their classmates' ideas. Class discussion was added, which helped in exposing the learners to the conclusions from the work of different groups and in building a common knowledge base.

Research Tools and Analysis for Questions 1 and 2

After completing the course, all teachers were given a posttest and a questionnaire to assess their achievements in optics and their pedagogical content knowledge (PCK).

The Posttest

The test included three types of questions: five questions testing conceptual understanding, five questions testing application of optics knowledge, and one question testing the diagnostic capability of the preservice teachers. The reliability of the test is $\alpha_{\text{Cronbach}} = 0.78$. Figures 10.4–10.6 present examples of each question type. The conceptual question in Fig. 10.4 requires both a visual representation and a verbal explanation and can expose common conceptions of learners. In many courses students are not required to answer such conceptual questions. Also the diagnostic question in Fig. 10.6 is not a standard question. In addition to testing content directly, this question tests to what extent the preservice teachers can uncover the conceptions underlying the different answers and also tests the teachers' ability to suggest remedies, both important elements of PCK. The application question exemplified in Fig. 10.5 is a standard application question in geometrical optics courses.

A rubric for analyzing the answers was developed and validated by five physics educators. All tests were graded by two physics teachers.

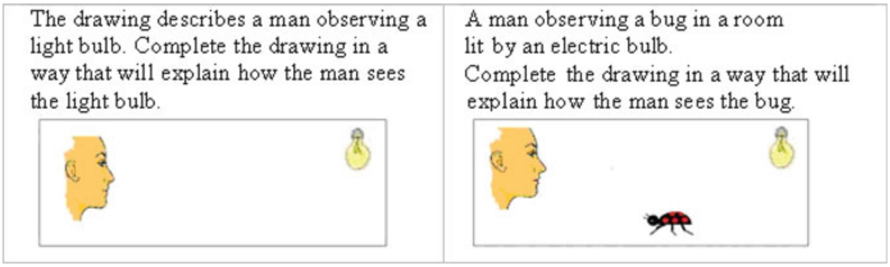

Fig. 10.4 Examples of conceptual questions

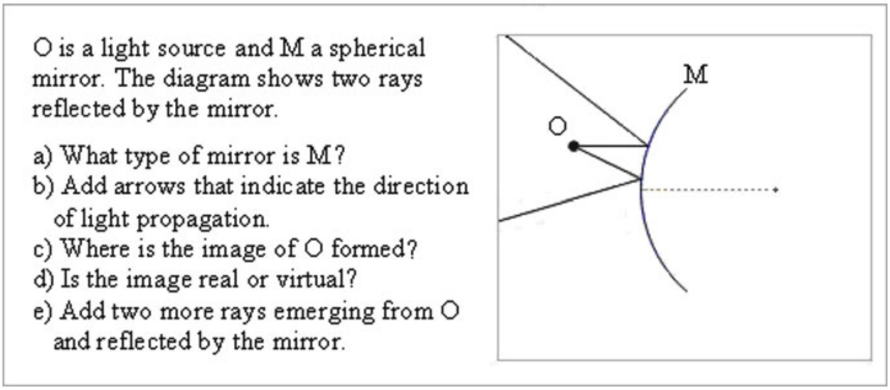

Fig. 10.5 An example for an application question

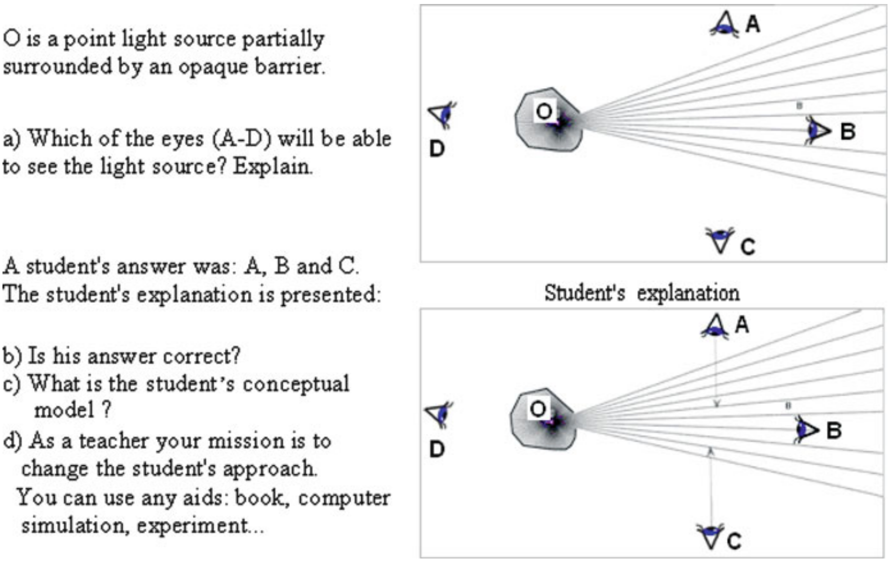

Fig. 10.6 An example for a diagnostic question

The Pedagogical Questionnaire

The questionnaire examined the teachers' ability to characterize the instructional strategy and its utility for learning and teaching.

The questionnaire included four open questions:

1. What methods were used in the course?
2. In what ways did these methods help you learn optics?
3. In what ways did the course help you as a preservice teacher?
4. What do you think a teacher should do to promote conceptual understanding of students in the domain of optical geometry?

The analysis of the answers was carried out as follows:

1. The research team predefined the following characteristics of the instructional strategy: individual work, group work, teacher summary, exposure to knowledge, identifying conceptions, comparing with peers, discussions, persuasion.
2. The answers of all the students in groups A and B were categorized according to these characteristics.
3. For each student, the percentage of predefined characteristics that he/she mentioned was calculated. This percentage constituted the pedagogy score reported in the results.

Research Tools and Analysis for Question 3

Since the CDC is a metacognitive strategy, we expected it to lead to metacognitive discussions during the CDC activity and in the reflections after the CDC lesson. Consequently, all the discussions among the students during the CDC activities were audio and video recorded and transcribed. In addition, all the artifacts created during these discussions as well as students' reflections after the CDC lessons were collected.

Analysis of the Transcripts

1. The transcripts were divided into episodes, each characterized by a different theme.
2. Each episode was divided into turns, each characterized by a specific speaker.
3. The discourse of the participants (learners and teacher) inside an episode was described by who is the speaker, who is active regarding the response, what is the interaction, what is the content of the discourse (scientific concepts, pedagogical issues, metacognitive phrases), how do the learners convince each other, and what are the metacognitive elements in the learner's discourse.

Analysis of Learners' Reflections

We identified the metacognitive elements in the learners' reflections after a CDC lesson and related them to the definition of metacognition in this study (Fig. 10.1).

Results

Research Question 1: Content Knowledge

Overall, the preservice teachers in group A that studied the CDC strategy only (without additional structured reflection) performed well on the posttest (average = 89.0, SD = 7.2). As indicated in Table 10.2, they had high scores on the conceptual and diagnostic questions and relatively lower scores in the application questions. A similar pattern was found in group B that received structured reflection in addition to the CDC and in five additional groups ($n_{total} = 70$) that studied with version B (not reported here in detail). These findings are not surprising since the CDC strategy focuses on advancing conceptual understanding and developing diagnostic skills. The relatively lower scores in the application questions can be explained by the fact that the total time of the course was not changed, and less time was spent on practicing standard application tasks. Although we did not carry out a systematic comparison with previous courses, according to the instructors of this course, the average performance of the students on the application questions in the present study was very similar to that of students in previous disciplinary courses in the same topic that did not use the CDC strategy. The level of conceptual understanding was, however, much higher in the new course.

Research Question 2: Pedagogical Content Knowledge

Table 10.2 shows that group A had a high score (average = 91.4) in the diagnostic question that tested teachers' skill in diagnosing conceptions underlying a certain answer and in suggesting possible remedies. However, the preservice teachers in

Table 10.2 Content knowledge and pedagogical knowledge at the end of the course

	Conceptual		Application		Diagnostic		Pedagogy	
Group (N)	Mean	Mean	STD	STD	Mean	STD	Mean	STD
A (14)	94.0	83.1	13.0	6.6	91.4	5.3	32.0	15.0
B (19)	82.6	74.7	19.3	17.8	92.0	10.2	75.0	20.0
K–W[a]	$\chi^2_1 = 0.41$ (NS)		$\chi^2_1 = 1.68$ (NS)		$\chi^2_1 = 0.82$ (NS)		$\chi^2_1 = 7$ $p < 0.005$	

[a]*K–W* Kruskal–Wallis test

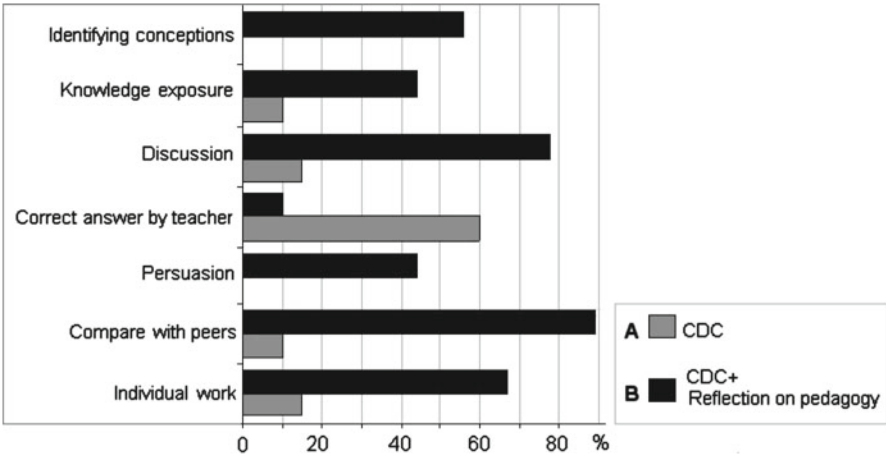

Fig. 10.7 Distribution of pedagogy categories written by the learners in groups A and B

this group were weak in characterizing the pedagogical approach (average = 32). As described above, the structured reflection in version B was added in an attempt to enhance students' performance in this aspect. The results in Table 10.2 indicate that indeed group B had much higher pedagogy scores than group A (average = 75). Thus the structured reflection was very effective in alleviating the preservice teachers' pedagogical content knowledge.

The lower pedagogy scores of learners in group A indicate that overall they identified significantly less characteristics of the instructional approach than learners in group B. Figure 10.7 presents a more detailed view of the comparative distribution of the characteristics that emerged from the categorization of the answers concerning the open question about pedagogy. It shows the percentage of learners who mentioned the various characteristics at least once. The dominant characteristic in group A was "the provision of correct answers by the teacher." This characteristic, which does not express what actually occurred in the class, was mentioned by 60% of the learners while only 10% of the learners in group B mentioned the same characteristic. In contrast, a large proportion of the learners in group B mentioned the major characteristics of the CDC strategy.

Additional support for these findings was found in the interviews: Learners in group B explicated the structure and rationale of the CDC strategy; they realized the importance of the collaborative nature of this strategy and how the strategy can help in communicating about optical phenomena. They also highlighted the fact that the strategy helped them develop the skill of persuasion based on scientific experiments.

It is reasonable to assume that the differences between groups A and B in characterizing pedagogy can be attributed to the reflection on content and pedagogy that was integrated into the CDC version of group B. Additional support for this interpretation can be found in the results presented in Fig. 10.8. This figure presents the distribution of the category "active learner," a component of the metastrategic

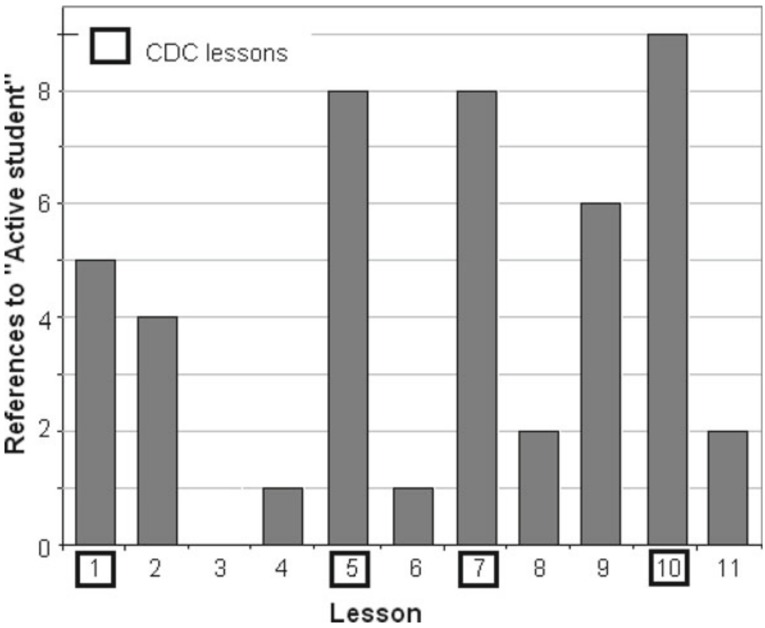

Fig. 10.8 Reference to the category "active learner" mentioned in learners' reflections during the lessons of the course

knowledge, mentioned in students' reflections. As indicated in the figure, this aspect was mentioned in most of the lessons and was most prominent in lessons involving the CDC strategy. There was an increase throughout the CDC lessons, suggesting that students developed higher sensitivity to this characteristic of the lesson. The following quote from a preservice teacher's reflection after a CDC lesson demonstrates her understanding of active learning in the CDC strategy:

"Students have to think about a phenomenon *by themselves* and only in the second stage can they contribute to a fruitful discussion, which can lead to a scientific answer."

The lessons in which the category was mentioned by fewer learners were teacher centered, involving activities such as the teachers' summary of a topic.

Research Question 3: The Role of Metacognition in Learning

In this section we examine how the learners reached the desired goals of this course and what obstacles they experienced. We carried out an extensive discourse analysis, focusing on different aspects such as the development in students' conceptual and pedagogical knowledge within a given lesson as well as throughout the course, the patterns of interaction among students, and the role of the teacher (not presented

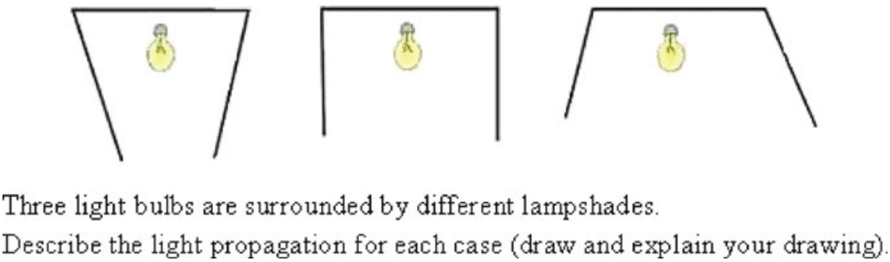

Fig. 10.9 The CDC assignment

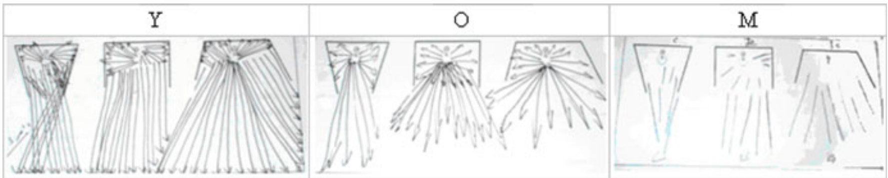

Fig. 10.10 The learners' answers in the first stage

here). We present below a case study illustrating some examples of the findings. In particular, we focus on the attainment of metastrategic knowledge.

A Case Study: Studying with the CDC Strategy

The following example describes a CDC activity involving three preservice teachers; it shows how the learners acquired metastrategic knowledge concerning the "compare and contrast" component of the CDC strategy. In the first stage, the preservice teachers worked individually on the question presented in Fig. 10.9 and drew the answers presented in Fig. 10.10.

In the second stage of the CDC strategy, the learners were asked to compare their answers. The comparison of the artifacts requires metastrategic knowledge involving two major steps: First, the learners have to characterize for each artifact the main features of the visual representations, and then they have to compare these features in the different artifacts. The relevant features are related to the basic principles of geometric optics leading to the following questions: Does the light originate from the source? Are the light rays represented by straight lines? Is the light scattered in all directions? Does the light change its direction? In comparing the answers, the preservice teachers first concluded that: "All the answers are the same: they are all correct." This result suggests that they could not identify the important features that differentiate between the answers. Table 10.3 presents the discourse that followed including (in bold) the teacher's interaction with the group (O, Oved; M, Miriam; Y, Yossi), our interpretation, and reference to the categories of metacognition in Fig. 10.1 and Table 10.1. As can be seen from the table, the teacher guided the

Table 10.3 The discourse in the "compare and contrast" CDC component in the task shown in Fig. 10.9

Speaker	Statement	Comments	Metacognitive categories
Teacher	**In the first stage you have to compare your answers**	Clarification about the task	B3
M	They are all the same	The learner does not recognize any differences	
Teacher	*Does this drawing resemble the others? Are they really the same?*	The teacher suggests to the learner to reexamine his reply	
M	It looks alike	The learner still does not recognize the differences	
Teacher	*Look here and here. Are they the same drawings?*	The teacher directs the learner's attention to specific details in the drawing	
M	No	The learner (finally) realizes the difference	
Teacher	*Since you say no, what are the differences?*	The teacher asks for clarification	
Y	*It is not the same, because the angles are different*	The learner mentions the *angle* (a relevant scientific concept)	B4
O	Here it is parallel	The learner mentions the *parallelism of rays* (a relevant scientific concept)	B4
Teacher	*OK. So here you see parallel light rays and there you don't; in what way are they similar?*	The teacher directs the learner to additional relevant comparisons and introduces more accurate scientific language	B4
Y	They are similar because they don't cross the barrier	The learner relates to the *barrier* (a relevant scientific concept)	B4
M	Also in the beginning the light stays inside the square		
M	The upper side looks the same Yes, the upper side is the same		
Teacher	*Look at this drawing – there is something different*	The teacher suggests that they focus on a certain part of the drawing	B2
Y	Yes, it is different	The learner identifies another difference	

(continued)

Table 10.3 (continued)

Speaker	Statement	Comments	Metacognitive categories
Teacher	*Why is it different?*	The teacher asks for clarification	B4
Y	Because the light is not scattered toward the upper side	The learner identifies the nature of the difference (no scattering upside)	B4
Teacher	*Yes, it is not scattered upside; what about downside?*		
Y	This is equal to this		
Teacher	*What are the differences?*		
M	They [the rays] are not parallel		B4
Teacher	*This is almost parallel; what else?*		
M	Here there are more [rays]…		
Teacher	*Here there are more rays; what else?*		
M	Here there are fewer rays.		
Teacher	*Are there additional differences?*		
M	The spacing [among the rays] here is different from the spacing there		

preservice teachers to identify the important features of the answers using several metacognitive elements. Consequently, the learners were able to differentiate between the drawings. The fact that similar difficulties to compare and contrast answers were also observed in other teams highlights the complexity of this apparently simple step in the CDC strategy. As a result of getting experience in diagnosis, in the end of the course all students knew how to carry out this step of the strategy.

The brief case study described above is characteristic of what happened in the other steps of the CDC strategy, each of which has some associated metastrategic knowledge required for its execution as well as some relevant cognitive knowledge (e.g., how to apply a certain principle in geometric optics). Since the course tries to build the learner's subject matter knowledge as well as pedagogical content knowledge, the teacher had to guide the learners in both the metacognitive and cognitive aspects.

Metacognitive Knowledge Demonstrated During the CDC Discourse

The CDC strategy includes several metacognitive elements and provides the learners with an opportunity to develop their metacognitive thinking. Do the learners make use of this opportunity? We investigated this issue by analyzing the discourse among learners who worked in small groups on the CDC activities, and the learners' reflection after a CDC activity. The following are examples from the discourse that highlight the metacognitive way of thinking demonstrated by the learners. We relate the examples to the categories of metacognition in Fig. 10.1 and Table 10.1.

In the discourse there were phrases that show elements of metacognitive thinking. The learners talked about *what they understood* as indicated in the phrase "I think what influences…." They realized *when they understood something* as exemplified in the statement "Now I understand, last time I did not understand." They could identify *what helps them understand* and *what helps them explain their ideas* as illustrated in the following phrases: "the drawing gives us a tool for explaining," and "it is very clear, I did the experiment and that is what you see in the experiment." They commented on *procedural knowledge that is essential for understanding and for communicating* in this subject matter: "We have to look at the ray diagram," "We have to look at the difference between the rays," and "This is a problem; that is why you have to draw a line from here to there." These exemplary excerpts show that the learners discussed how to use visual explanations; they used ray diagrams in class, but the connection between a ray diagram and a phenomenon is not obvious, and the discourse around the artifacts encouraged them to think about the representation and how it can help them and others.

Another aspect of metacognitive knowledge that is demonstrated in the discourse is *understanding what and how others think*: "…because he thought that he can see the rays," "everyone thought about a different light source," and "he thought that the lampshade changes the light scattering." The discourse demonstrates *diagnostic skills* in the learners' way of thinking. Moreover, there is also evidence of learners *understanding the fundamental parts of the strategy*: "Working in small group is good, because we compare our answers." These examples show that during the discourse, learners talk about their own thinking and about how others think – central elements of metacognitive knowledge.

Evidence for Metacognitive Knowledge in the Learners' Reflection

At the end of each lesson, the learners in group B were asked to answer two reflective questions: What have you learned in the lesson about optics? What have you learned about teaching optics? The purpose of those questions was to promote metacognitive thinking about the lesson regarding both the content and the pedagogy. The following excerpts demonstrate that the learners reported about the development of their metacognitive ability: "This strategy helps me understand others' views and through the discussion I could determine exactly what concepts they know." This learner emphasizes the role of the discussion in understanding what other learners think. The excerpt shows that the learner can reflect on the lesson he had participated in and can recognize its pedagogical aspects. The following excerpts illustrate the understanding of how the strategy helps the learner: "I can learn from my mistakes and from my peers' mistakes"; "Working with peers helps me understand the scientific concepts"; "There are answers that without a discussion with peers you cannot understand them; the discussions help me very much"; "The drawings gave me a tool for explaining phenomena"; "We used the simulation to learn about the phenomena." These examples mention some of the fundamental aspects of the strategy, which were recognized by the learners. The learners also reflect on affective parameters: "The learning was very interesting"; "The task was challenging"; "It was a pleasant lesson." Another aspect that was found among the learners' reflections is about the teaching and learning strategies that were used: "It is important to work in small groups because you can get new ideas from peers in the group"; "It is important for learners to work individually on a task before they work in small groups."

In sum, the examples we presented illustrate how during the discourse the learners thought about their own way of thinking and how in the reflection after the lesson they demonstrated a metacognitive way of thinking. The learners identified the main components of the learning strategy and realized how the strategy helped them to learn.

Learners' Epistemology

Unfortunately, the CDC strategy did not contribute equally to all learners; for some learners it was very useful whereas for others it was not. The contribution did not depend only on the design of the task or the teacher's scaffolding, but also on the personal parameters of the learners. One of the parameters we identified was the learners' epistemology concerning the goal of learning. In this regard we found two different styles of interaction during the collaborative stage of the CDC. One style of interaction was driven by the desire to find the correct answer, and not to understand why the answer is correct or what led to the correct answer. Another style of interaction was driven by the desire to understand how another group member thinks, or to explain to the group member one's own way of thinking. In these discussions we found a deeper understanding of the physical concepts and how the correct answer is connected to those concepts. The detailed analysis of the results reveals that for the latter group the CDC strategy was far more beneficial than for the first group. These results are congruent with the findings of Abd-El-Khalick and Akerson (2009), who found that metacognitive training and use of metacognitive strategies by prospective elementary teachers influenced their view of the nature of science and ability to explicate more informed views of the nature of science.

Discussion

A common recommendation to teacher educators is that preservice teachers should learn the content by methods that they will be expected to use in their teaching (McDermott 1976). The CDC strategy was developed with this purpose in mind. Thus the strategy is designed to enhance learners' understanding of the content by providing them with opportunities to elicit their conceptions, to discuss them with peers and with their teachers, and to sort out the ideas. We hypothesized that through this process, learners will be able to advance their understanding and develop normative science ideas, and they will also develop their diagnostic capabilities of students' optical ideas.

The results of the study indicate that the preservice teachers developed a high level of conceptual understanding that goes beyond the achievements in traditional courses. They also developed diagnostic capabilities that are neither taught nor tested in traditional courses. At the same time the learners' scores on traditional application questions were not significantly different from those in traditional courses. Thus the CDC strategy indeed has the quality of being a strategy that teachers can use in their classes if they aim to promote their students' conceptual understanding.

Moreover, we suggest that this strategy may provide preservice teachers important learning opportunities not only as learners of the content but also toward becoming prospective learner-centered teachers. The strategy involves a special kind of collaboration with peers in the process of learning: The learners collaboratively diagnose conceptions and their sources, they try to persuade each other in order to reach consensus, and in advanced parts of the course they also discuss ways of supporting students who have mistaken answers in improving their understanding. We propose that through this kind of collaboration the preservice teachers can learn important pedagogical ideas: They have an opportunity to realize that different learners may have different ideas about the same situation and to learn about the alternative conceptions in the particular science topic (e.g., geometrical optics), they can investigate the sources of such ideas and thus become proficient diagnosticians within the particular topic, and they can also think about ways to negotiate meaning and come up with convincing arguments. These are all important elements of pedagogical content knowledge (PCK). These benefits can materialize, however, only if teachers realize the essential characteristics of the instructional strategy and understand their importance. Is this prerequisite guaranteed if we only apply and model the strategy to the teachers as described above? The results of the present study indicate that it is not enough to use the desired teaching strategies – special care should be taken in order to promote the preservice teachers' awareness of the course's teaching strategies as part of their pedagogical content knowledge (PCK). Namely, it is important to scaffold the preservice teachers in developing explicitly their metastrategic knowledge concerning the pedagogy that was used. Metacognition was found to be important for promoting pedagogical content knowledge (PCK). The results reported on pedagogical knowledge of the learners indicate that learners in group A (no reflection on pedagogy) identified significantly less characteristics of the instructional approach than learners in group B (reflection after each lesson). The results show that without scaffolding the reflection on the structure and rationale of the teaching strategy, the teachers did not realize the importance of the collaborative nature of the strategy, and how the strategy can help in communicating about optical phenomena.

The CDC strategy did not contribute equally to all learners: For some learners it was very useful whereas for others it was not. The contribution did not depend only on the design of the task or the teacher's scaffolding; it also depended on the learners' personal epistemology. If one wants to change learner epistemology, one should use the CDC strategy in several courses. A one-semester course is not enough. An interesting future question is whether the preservice teachers will use a similar strategy with their future students.

These results suggest that it is possible to promote PCK in content courses with the help of metacognitive support. Preservice teachers do not do this integration by themselves. The teacher educator in the course should scaffold the pedagogical awareness. We suggest that this should be a compulsory part of the lesson; just providing the opportunity is not enough.

The CDC together with the metacognitive support requires a change in the role of the teacher in the class, toward becoming a guide that supports students' negotiation of meaning among themselves. The teacher in this research was an expert teacher–researcher who knew how to implement the strategy well. The discourse analysis of this teacher's interaction with the groups (not presented in this chapter) showed several effective strategies, mostly metacognitive ones, that this teacher enacted. The knowledge that such a teacher has to possess is extensive, both deep understanding of the particular topics and metastrategic knowledge about effective ways to enable students to learn from each other and advance by themselves through collaboration. Hence, in order to implement this strategy effectively, it is necessary to educate teacher educators as well as leading teachers who will later impart their knowledge to other teachers.

To summarize, our findings indicate the potential benefits that accrue for preservice science teachers that use metacognitive interventions in a content course, for the integrated acquisition of content and pedagogical content knowledge. One of the skills that the CDC strategy can develop is *learning to listen* (Arcavi and Isoda 2007). In the course described in this chapter, the preservice teachers learn to listen to each other. We hope that in this way they will learn how to listen to their future students as well.

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