Chapter 12
Designing a Metacognitive Approach to the Professional Development of Experienced Science Teachers

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Abstract In this chapter we present a metacognitve approach to the professional development of science teachers. We designed two courses based on the Design Principles Database (DPD). Our aims were: to characterize the design principles of both courses, to expose expressions of metacognition among the teachers and examine the changes they designed and applied in their teaching units and teaching processes, and to characterize the resources which effected the development of the teachers' metacognitive knowledge. The participants were 21 teachers, 17 children, a laboratory assistant, and the two researchers. The data included: both courses' design and activities, the researchers' reflections, interviews, the teachers' teaching units, and observations of the children's physics lessons. The data was analyzed using qualitative methods. Our findings show that the courses we designed engaged teachers in constructing their own knowledge as well as collaborating as a group of learners. We identified six key resources which influenced the metacognitive development of the teachers: the courses in this study; other courses; the researchers' insight; the teachers' teaching experience; peer suggestions and children's reflections. The present study strongly encourages teachers to develop and design activities, as well as testing them in a supportive environment which can help them understand their own beliefs as well as promote their metacognitive knowledge.

Keywords Metacognitive knowledge · Professional development · Design principles · Peer learning · Reflection

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Abbreviations

AAAS	American association for the advancement of science
CDC	Collaborative diagnosis of conceptions
DPD	Design principles database
FD	Forum discussions
KI	Knowledge integration
ME	Metacognitive experiences
MK	Metacognitive knowledge
NCTM	National council for teachers of mathematics
NRC	National Research Council
PCK	Pedagogical content knowledge
PD	Professional development
PL	Professional learning

12.1 Introduction

This chapter presents a collaborative self-study of two teacher educators who recognize the importance of researching their own practice, leading to a better understanding of the complex nature of teaching and learning about teaching.

Loughran [1] stated that teacher educators need to be good teachers of teaching so that the complex nature of teaching and learning becomes more evident to their students of teaching. Yet being a good teacher of teaching requires much more than just being a good teacher, and this is where self-study comes in as an important force shaping teacher education practices. The authors belong to the Science Education community, and in this chapter we wish to elaborate the design and implementation of two courses which are part of a two-year M.Ed. program designed for experienced high school science teachers who are interested in their own personal and professional development and intend to continue teaching in school. In both courses, "Principles of developing teaching units in Physics" and "Excellence in Science and Mathematics", the teachers were asked to develop teaching units in science and mathematics.

In the first course the teachers were also given the opportunity to teach the units they had developed to children participating in an enrichment program at the college. Since both authors are interested in promoting metacognitive knowledge (MK), and the fact that according to Zohar and Barzilai [2], fewer than half of the studies (37.9 %) on metacognition in science education dealt with MK, we chose to examine our work through the metacognitive lens, checking our own understanding of this concept together with the professional development (PD) of the teachers we teach. We believe that MK and metacognitive experiences (ME) are essential for the development of good, established teachers.

12.2 Theoretical Background

12.2.1 Professional Development of In-service Science Teachers

The reform of science and mathematics education in recent decades has led to the design and implementation of various professional development (PD) programs for science teachers, supported by the major science and mathematics bodies (American Association for the Advancement of Science (AAAS) [3], National Council for Teachers of Mathematics (NCTM) [4–7]).

Teachers' PD is part of the understanding that teachers must be lifelong learners, and that teaching is a complex and demanding profession which should involve the development of teachers' skills and attitudes so they may improve their students' learning [8]. Constructivism serves as the philosophical foundation of this reform, which calls for a new way of thinking about science teaching and learning.

Since most high school physics teachers come from a very conservative, teacher-centered way of teaching, a good PD program must involve the changing of the teachers' beliefs and understanding of teaching and learning, in order to deal with the quality of science teaching which seems to remain largely confined to knowledge transfer and is threatened in many countries by a shortage of qualified teachers. Scholars have shown that teachers consider new teaching practices as practical when (a) efficient procedures are available to translate innovative ideas into concrete instruction; (b) the change proposed sufficiently fits their current practice and goals; and (c) implementation of the innovation requires limited investment and the expected benefits are substantial [8].

One major characteristic of effective professional development for Science teachers is the development of MK about teaching and learning science. The National Science Education Standards [6] outlined goals for the PD of both in-service and pre-service science teachers. These goals suggest that the preparation of science teachers should include constructivist experiences which allow learners to gain both content knowledge and pedagogical skills through developing their MK. These experiences should enhance the science teachers' ability to provide similar experiences in their own classrooms [9]. This ability is interwoven with metacognitive knowledge about science teaching and learning.

Choosing the characteristics and content may be the most important decision taken in planning a PD program. The research literature [8] emphasizes six core features of an effective PD programs which are used as an organizing frame: focus, active and inquiry-based learning, collaborative learning, duration and sustainability, coherence and school organizational conditions. Eylon et al. [10] developed an evidence-based professional development program for physics teachers. Focusing on knowledge integration, they emphasize the need for a long PD program centered on evidence-based materials which the teacher tests in class and can afterwards discuss in the PD environment.

Nilsson [11] discusses professional learning (PL), describing a group of teachers working together collaboratively with a researcher to identify important aspects of students' learning regarding a specific topic, attempting to improve their teaching in a systematic manner. This is a cyclical process in which teachers reflect on the necessary conditions for learning specific content and how to meet these conditions in the learning situation. The teachers explore their teaching in order to identify which features may be critical for their students' learning. It seems self-evident that teachers need to know the subject matter they are required to teach.

The reform papers indicate that teachers need to have a deep and complex understanding of science concepts, the ability to make connections among them, and apply them in explaining natural phenomena or real-world situations [3, 6]. Teachers must also have content-specific teaching strategies. Moreover, teachers should have meta-strategic knowledge; they need to recognize the role of prior knowledge, particularly students' misconceptions, in shaping student comprehension.

In general, when teachers are more comfortable with teaching a particular topic, they are more likely to allow student questioning and discussion, which are essential features of inquiry.

PD focusing on content providing teachers with opportunities for active learning and connected to daily life in school is more likely to produce enhanced knowledge and skills. Teachers require rich pedagogical knowledge in order to create highly interactive learning environments which address the needs of all students.

As student preconceptions are a central issue in Science teaching, teachers need to be able to identify their students' preconceptions and design instructional strategies accordingly. Another changing perspective on PD suggests that learning activities should preferably be situated and meaningful, implying that they should be embedded within the regular work context. Learning activities are more effective when they are characterized by clear connections with daily practice in which problems, questions and solutions are integrated.

12.2.2 Teachers' Metacognitive Knowledge

Metacognition is a key component of active learning. It is defined as cognition about cognition [12], and involves thinking about one's own cognitive processes [12, 13], as well as the ability to monitor, regulate and evaluate one's thinking. Flavell [12] suggests that metacognition consists of both Metacognitive Experiences (ME) or regulation, and Metacognitive Knowledge (MK). MK includes knowledge of strategies that might be used for different tasks, knowledge of the conditions under which these strategies might be used, knowledge of the extent to which the strategies are effective, and knowledge regarding persons (the self and others) [12].

Schraw and Moshman [14] categorize metacognitive knowledge into three kinds of metacognitive awareness: declarative knowledge (what), procedural knowledge (how), and conditional knowledge (why and when). ME involve monitoring and regulation of cognitive processes, which consist of planning and monitoring cognitive activities and checking their outcomes [13, 15]. If teachers wish to relate to the pragmatic aspect of metacognition development or enable its expression among children, they need sound knowledge of metacognition and pedagogical knowledge in the context of teaching metacognition [2]. Unfortunately, research indicates that metacognition is almost invisible to Science teachers. Ben-David and Orion [16] showed that Science teachers could not explain or provide detailed examples of metacognitive-level thinking. However, following a training program, the teachers' pedagogical thinking in the context of metacognition has improved.

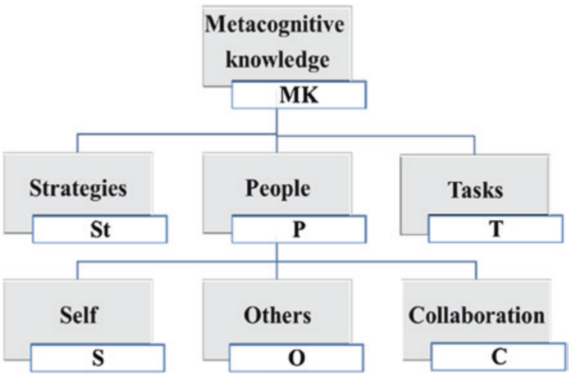
Baumert et al. [17] found that compared to teachers' subject-matter knowledge, pedagogical content knowledge (PCK) was a more powerful predictor of instructional quality. In analyzing 90 lessons taught by 10 teachers, [18] provided evidence linking teachers' PCK to the mathematical quality of instruction: teachers with stronger PCK made fewer mathematical errors, responded more appropriately to students, and chose examples which helped students construct meaning of the targeted concepts and processes. Teachers with weaker PCK were not successful at selecting and sequencing examples, presenting and elaborating upon textbook definitions, and using representations [19]. Well-established PCK cannot be separated from teachers' MK which includes knowledge about curriculum materials, tasks and strategies.

12.2.3 Metacognition in the Present Study

In the present study we focus mainly on metacognitive knowledge, relating to the following components (see Fig. 12.1):

- Knowledge of people. How one examines and monitors his/her own thinking processes; how one examines others' ways of thinking; how one interacts and collaborates with his/her colleagues and praises or gives constructive feedback.
- Knowledge of the task. How one presents his/her understanding of the task: what is the task about, its rationale, structure and components, reasons and

Fig. 12.1 MK components in the present study



explanations regarding the task structure/activities, the importance of the task, and when to apply the task or its components.
- Knowledge of strategies. How one can employ strategies to improve performance with regard to the task.

12.3 The Study

12.3.1 The M.Ed. Program Structure

The fundamental assumption of this program [20] is the constructivist philosophy that individuals build their own knowledge by incorporating what they learn into what they already know [21, 22]. In translating this philosophy into practice in the development of the program, we addressed two main aspects: learning from active engagement and learning based on personal experience.

Radford (1998, p. 74) [23] claimed that "teachers are most likely to internalize science concepts and teaching methodologies when both their hands and minds are engaged in the process". The curriculum of the M.Ed. program aims at developing concepts and teaching methods which emphasize the development of scientific and pedagogical skills as well as disciplinary enrichment, along with learning and experiencing research methods in Science and Mathematics education.

The program is designed for teachers with a Bachelor's degree and a Teaching Certificate in Science or Mathematics in secondary schools, with at least three years' teaching experience, who are interested in their own personal and professional development and intend to continue to teach in school. The program consists of 24 credits earned over two years, and is divided into two main parts: one part for all the students, in which they are presented with a wide pedagogical basis encompassing terms and concepts shared by all science and mathematics teachers; and a second part, which covers three specializations: biology, mathematics and physics education, in which the students learn updated scientific and pedagogical content knowledge.

The curriculum offers advanced studies in different areas: teaching and learning, science and mathematics education, research on teaching and learning mathematics and science, and advanced scientific topics in the teacher's professional discipline. The two courses described below are part of the M.Ed. program.

Course 1—"Excellence in Science and Mathematics" The course focuses on gifted and talented students, revolving around math and science activities which enhance the development of higher order thinking skills as well as creativity. The teachers learn about effective curriculum and instructional models for gifted and talented students, as well as the characteristics of good teachers for the gifted, in addition to the issues of gender and giftedness with regard to science and math.

Course 2—"Principles of Developing Teaching Units in Physics" The course focuses on comprehension of the main design principles for effective Physics lessons, and is divided in two. In the first semester the teachers learn how to design a physics unit and how to evaluate students' comprehension. In the second semester the teachers are given the opportunity to teach these units to children participating in an enrichment program at the college. The implementation is documented and supervised by the researcher, and following each lesson the teachers and the researcher analyze the lesson and decide how to improve the next lesson's design. The teachers were asked to write a journal, documenting all the design decisions and their on-going reflections. The children who participated in the program were asked to reflect after each lesson on its design, suggesting how it may be improved. The reflections were documented in a forum which was part of a web-site that the teachers developed throughout the semester.

12.3.2 The Study Goals

The study goals are the following: (a) characterize the design principles of both courses as shown in the researchers' descriptions; (b) expose expressions of metacognition among the teachers and examine the changes they designed and applied in their teaching units and processes; (c) study the interactions among researchers, teachers, children in order to understand the teachers' metacognitive knowledge and skills.

12.3.3 Participants

The participants included 21 teachers from the M.Ed. program participating in the course "Excellence in Science and Mathematics". Four of them also participated in the course "Principles for developing teaching units in Physics". Additional participants were 17 children (6th grade) participating in an enrichment program for talented students in the college, a laboratory assistant and the two researchers who were the course advisors.

12.3.4 Data Collection

The data included: (a) both courses' design and activities; (b) researchers' reflections; (c) interviews with the teachers; (d) an in-depth interview with the laboratory assistant; (e) the teachers' teaching units and activities; (e) observations of the teacher's Physics lessons. The teachers' reflections and their FD references are analyzed based on the metacognitive knowledge components as defined in this study (Fig. 12.1).

12.4 Findings

12.4.1 The Courses' Design Principles

Four meta-design principles based on the Design Principles Database (DPD) were implemented in the courses. The DPD is a public mechanism enabling researchers and curriculum designers to share design knowledge and activities. Designers can publish, connect, discuss and review design ideas [24]. The design principles in each course are presented below:

Course 1: Excellence in Science and Mathematics

Principle 1: learning from and with peers This principle enables the teachers to benefit from their colleagues' ideas, introduces new perspectives and motivates them to interpret their ideas. As mentioned earlier, this course was on-line. It included seven forum discussions (FD) which usually lasted one to two weeks. This time period enabled the teachers to think, raise questions and discuss relevant issues with their colleagues and the course instructor.

The discussed subjects were related to the knowledge the teachers had acquired in each lesson. Each FD had its guiding instructions. These were also used as assessment criteria to evaluate each discussion.

For example, in the fourth FD, which focused on curriculum models for gifted and talented students, teachers were asked to critically examine the various models according to what they have learned and read in the course. They were then asked to provide feedback to peers and discuss their preferences. The course instructor gave feedback and clarification regarding the teachers' discussion when necessary.

In the last discussion, the teachers introduced a part of their teaching activity to their peers and asked them to participate or try to solve a problem and then provide formative feedback and suggestions for improvement.

Principle 2: making thinking visible This principle allows the teachers to integrate knowledge, reflect upon new information and engage in linking, distinguishing, or reconciling their own or their peers' ideas. In the course, the teachers met this principle on their own when they wrote their reflections regarding their activity and collaboratively when they participated in FD throughout the course.

Principle 3: make contents accessible The course included a variety of components: simulations, media resources, academic materials, on-line activities and FD. These components exposed the teachers to a rich learning environment and allowed them to connect ideas and reconsider their existing ideas. It scaffold their inquiry process and generated new connections within their science content knowledge and regarding their ways of thinking. Making the content accessible enabled the teachers to reflect on their reasoning. This reflection helped motivate them to develop and design science teaching activities, to gain meaningful learning experience.

Principle 4: Promoting autonomy so students can become lifelong learners This principle involves establishing a rich, comprehensive learning environment encouraging teachers to take responsibility for their learning and develops them as lifelong learners. In this course, the teachers were required to design their own activities, explore a variety of resources, and introduce their activities in the FD on the course web-site. This enabled them to relate to colleagues' questions and feedback.

The teachers' activities were open-ended and allowed for expression of creativity and higher order thinking skills. The teachers' reflections were used as a 'window' to their thinking processes as well as a mirror to their development as learners.

The teachers were asked to find the proper resources which can help them in constructing the tasks for the children, involving them in a reflective process eliciting their own thinking regarding teaching and learning, helping them to think critically about their teaching practice, and making effective decisions in real time in the classroom.

Course 2: Principles for developing teaching units in Physics

Principle 1: learning from and with peers This course was designed for supporting social interaction among the teachers, so that they could benefit from their peers', instructors' and students' ideas.

Learning from their peers includes planning together, observing their peers teaching in class, and collaborative reflection on the planning and implementing of the teaching units. Learning from their advisor, the course moderator, and the laboratory assistant includes all the talks (both formal and informal) which took place between the teachers and the course advisor.

The laboratory assistant introduced new laboratory equipment and gave the teachers an opportunity to check the equipment, making sure they know how to operate it and understand the physics it demonstrates. Learning from the children includes listening to the children's talks, conducting open discussions about the teaching units, and reading the children's reflections on the course forum.

During implementation of this project the teachers experienced a new way of interacting with students, asking them to reflect on the lesson activities and design. This kind of interaction was not used by them in school, and they did not have any prior knowledge of it.

Moreover, this kind of experience was unfamiliar to them even as learners. It might be a frightening experience, listening to the students, understanding what they enjoy, what the thought should be improved, and how.

The experienced teachers come from an environment where they are the authority. They do not ask their students those kinds of questions and the feedback they usually get originates from formal subject matter tests.

The children also indicated that this was a new experience for them; their teachers in school have never asked them those kinds of questions.

> In school my teachers aren't interested in me, they don't care if we enjoy anything or understand it, school is really boring, here we felt that you really appreciate our opinion, you were listing to us it was a delightful experience.

Principle 2: making thinking visible This meta-principle is divided into two types of ideas: (a) making thinking visible so teachers can learn about others' ideas and communicate their own ideas to others; (b) designing models or communicating complex concepts using visualization in order to make complex scientific phenomena visible.

The course design used this principle in two forms, the first by giving the teachers an opportunity to share their MK about the proper activities in the physics laboratory. Moreover, the teachers had to write a reflective journal about their experiences during the design process, so that they could explicitly understand the mental processes they were experiencing.

Because the teachers had to explain their decisions to their peers and instructors, it broadened their perspectives, promoting their knowledge integration process. Obtaining a combination of perspectives helped the teachers acquire more coherent knowledge about designing scientific tasks for children. The second way was leading the teachers towards use of various visualization tools and integrating them in the lesson (simulations, demonstrations, videos, etc.).

Principle 3: make contents accessible The implementation of this meta-principle was divided into two types. The first was connecting to the teachers' prior knowledge regarding science teaching by building on their own knowledge and experience.

During each cycle the course moderator asked the teachers what do they usually do in their classes and what kind of activities do they implement at school, giving them confidence in the task; then helping them to articulate the tacit knowledge they have about teaching through class discussions on those activities, connecting them to the theory and redesigning them to fit to the specified objectives.

The second type of implementation of this meta-principle was by directing the teacher to designing activities connected to the children's world, bringing examples from everyday life, helping the students to connect the scientific concepts to the day-to-day knowledge the already have. Thus the teachers could acquire the MS about building experiences which can help the students integrate their scientific knowledge.

Principle 4: Promoting autonomy so students can become lifelong learners Implementation of this meta-principle in the course was achieved through encouraging the teachers to design their own activities and find the proper resources that can help them construct the tasks for the children; involving them in a reflection-on-action process that will elicit their own thinking on teaching and learning, helping them to think critically about their teaching practice, and making effective decisions in real time in the classroom.

12.4.2 Expression of Teachers' Metacognition

In this section we present teachers' metacognitive knowledge as expressed by the teacher's reflections in both courses. It seems that the design of both courses promoted the MK of the teachers in relation to people, tasks and strategies. In the following section we focus on two case studies of experienced physics teachers who participated in both courses. Those stories demonstrate the teachers' PD throughout both courses and their MK development (see Table 12.1).

Khaled's story: This story was constructed from data collected from Khaled's reflections in both courses, from observations of the lessons he had implemented in the talented children's course, and from interviews. Khaled is an experienced high

Table 12.1 Teachers' metacognitive knowledge expressions

Metacognitive knowledge		Quote
Knowledge of people	Self	*I felt discomfort, I was not sure if I could build an activity that actually teaches in a constructivist way. This was my weakness.* So, I started to read about the Pythagoras sentence and examined the complexity of the quiz
		The task was very special to me. *I thought differently. I put myself in the place of the student and began to think how they understand the subject and enjoy learning it. It took me a while!*
		I started to look differently at students! I went through a change! Today, *I find myself thinking how to introduce a problem in a challenging way*
		While thinking how to develop my activity (fractal), *I realized that there is no reason to "hold" with subjects that I am familiar with and that I can give a place to my imagination!* But, another problem arose. I had a lot of ideas. All were good! I started to think which idea is the most suitable to gifted youth and to the process-product model. *I knew that as a tutor, my skills are not so good*, so I prepared very detailed inquiry instructions within the task
	Others	Nivin and Jakob supported my idea. They actually directed me! *Jakob analyzed the problem and its complexity* and Nivin's *clarifying questions* caused me to change part of the activity
	Collaboration	The exposure to peer feedback enabled me to understand my colleagues' thinking techniques and the assessment process they conducted. At first, I was afraid of the exposure, but the *discussion was conducted in a constructive way and with respect*. *I raised a question to Jacob and he explained his rationale. I felt that we contributed to one another*; they helped me understand that my task is good!
Knowledge about the task		My activity is suitable for gifted children. *It develops scientific thinking skills, creativity and requires concentration. It's based on the epistemology model as it focuses on the meaning of "structures" and on interdisciplinary learning because, the "golden ratio" appears in nature, in art, in architecture, and in math*
		The task structure was different at the start. Later on, I organized it in a way that *it was logical to go through two dimensions to 3D*
		The activity includes multidisciplinary aspects and represents that the whole is greater than the sum of its parts. I will give it at the end of the learning process, in the "Amirim" program
Knowledge about strategies		*I learned that inquiry skills are not so simple to apply. Teachers need to check at what stage the students are in the process of inquiry, to give them instructions and to stimulate their curiosity with a short but attractive activity or trigger.* One that can motivate them to do the task. In the summary stage (of the activity), I prepared reflection questions, but now *I know that I will enable students to choose which question they prefer to answer*. The ability to choose is very important to the gifted students

school physics teacher, teaching in an Arab school in northern Israel. During this project he was in his second year of the M.Ed. program, and he participated in both courses. He is part of a small group of physics teachers attending the M.Ed. program. Khaled had taken the first course, "Excellence in Science and Mathematics", online and developed a teaching unit about diving. Khaled claimed that diving is a very broad topic, incorporating different disciplines such as Physics, Biology, Chemistry and Mathematics, and he wanted to focus on decompression sickness.

This issue relates to the respiratory system, the vascular system, diving depth, and rate of increase of the water. All these combine Biology and Physics as well as Mathematics, and can be taught to talented children. Khaled underwent a profound change during the course. His thinking has changed and now he is more open, thinks of interdisciplinary subjects and includes authentic and interesting topics in his lessons.

By the end of the course, he wrote:

> The sea is a mystery. It gave me inspiration. I know the dangers associated with it and think that this is an important subject to teach. Now, I'm thinking about the other way,

> what happens to the human body in heights? Is the process reversed? What are the dangers? I also think of skydiving as an interesting subject to teach and explore next time.

In the second course, “Principles of developing teaching units in Physics”, Khaled planned to use some of the materials but could do only the beginning of the unit. He had many doubts concerning his ability to teach Hebrew-speaking talented students. He thought it would be hard for him to connect to the children, he was afraid they would not understand his language and even his jokes. During the first lesson the children were divided into four groups, each group headed by one of the teachers.

The group that worked with Khaled immediately connected with him and participated in the task he gave them. At the end of the lesson one of the children came to Khaled, asking him to be his school teacher. Khaled told the child that he teaches in an Arab speaking school, so it would be hard for him to learn. The child said that it does not matter, he wants to learn with him. This interaction contributed to Khaled’s confidence regarding his ability to connect to the children, even from a different culture, and to be a significant mentor for them. Moreover, some children asked Khaled for his personal email and started to communicate with him, asking for his advice regarding problems in their regular school.

In one of the lessons we had a mother who came to observe. She was sitting at the end of the class, away from her son, near the researcher. In the middle of the lesson she told the researcher that Khaled is an extraordinary teacher, that he has a unique way to reach the children, that he interacts with each child in the correct way in order to encourage him/her. She also mentioned the interaction Khaled had with the children in the course forum, noting his gentle approach. At the end of the lesson she went to Khaled, shook his hand and told him how she appreciates the work he is doing with all the children, and particularly with her son.

Khaled pointed out in his reflections that while observing Michal he analyzed her interaction with the children, and could clearly understand the better way to teach them. He realized that the children enjoyed the experiments and wanted to do them by themselves, rather than being passive in the lesson. He noted that the children ask a lot of questions and are very interested in the scientific phenomena that Michal had introduced to them.

One of the main features in the course design was getting feedback from the children by asking their opinion about the lessons in an open discussion in the class and in the forum that was opened for them on the course website. Khaled wrote about it:

> The concept of getting feedback from the students was a new experience for me, I think it is missing in the school where I teach.
>
> The truth is that this resource helps teachers to assess and evaluate the teaching methods they use, and teachers can improv e themselves by listening to the students, especially by asking questions like: what was missing in the activity, what do you want to know, what kind of activity suits you? I am sure I’ll use reflection of students in future classes.

The story of Michal: Michal is an experienced physics teacher working in a religious girls’ school in northern Israel. She has six children and is juggling between her commitment to her home as a wife and mother, to the school where she is the Physics coordinator, and to her studies at the college. During this project she was in her third year of the M.Ed. program at the college. Throughout the development phase she constantly tried to connect to her practical knowledge, bringing examples from her prior classroom experience. In her school she teaches physics in addition to science to non-science students, believing that all children should learn some science in high-school, even if they major in Arts or other subjects.

Michal had some experience working with talented students at her school. In the course "Excellence in Science and Math" she developed an activity that included scientific ideas relating to radiation and the principle of energy conservation. The activity was developed for a regular class that included talented children as well. The activity goals were to identify students' misconceptions, reconstructing them in a more accurate manner. She designed an activity that combined other disciplines (e.g., photosynthesis in biology).

According to her, even when students declare they know there is something called The Energy Conservation Law, in everyday life they treat it as if the energy disappears. Misconceptions in science were an important subject for Michal. This was expressed in the activities she designed in the course "Principles for developing teaching units in Physics" as well.

Michal chose the physics of the rainbow, a subject she had done scientific research on and is part of her M.Ed. final project. From the beginning of the course, she tried to connect every piece of new teaching concept to her understanding of her own practical experience, for example while discussing the need to identify students' preconceptions, she immediately tried to connect it to her own project, discussing how to identify children's pre-conceptions of the rainbow. She discussed this issue in class with her peers and with the class moderator.

Doing this, she could get a better understanding of the concept, and have the ability to implement it properly in class. Michal tried it later with the children, testing her assumptions, discovering what really works. She implemented the CDC teaching strategy [25] introduced in class with the children. Because we applied a cyclical procedure, whereby after each lesson we analyzed the classroom practice, Michal could get a better understanding of the teaching strategy and how it is actually carried out in class.

Michal is a highly reflective teacher, extremely self-critical, but although she is very verbal, she does not tend to write down her reflections. She had a firm conception of what one should do in class. The experience with children that were not her usual students opened her to new insights and challenged her own beliefs about what and how one could teach.

While teaching the physics of the rainbow, she used a PowerPoint presentation about several physical phenomena that can be observed in the rainbow. It had a lot of information, and after the lesson she felt that the children had learned a lot. However, reading the children's reflections caused her to rethink the effectiveness of the presentation. One of the children wrote:

> We have learned a lot during this lesson, and it was very interesting, but we are a special group of children that are very interested in science, I think that presenting a PowerPoint

> presentation during the whole lesson could be very hard to children that are not interested in science like us, I think you should do a more active lesson…

Another child wrote:

> You presented us with a presentation that included a number of phenomena that can be observed in the rainbow, I think you should have taken each phenomenon, teach it, explain it and afterwards go to the next phenomenon, but I enjoyed the lesson very much and learned a lot.

In her last lesson Michal demonstrated the creation of a rainbow with a device that was developed by Cohn [26]. Using this device, the students could see with their own eyes all the phenomena they had learned about in class. It was a very special experience for the students, for the teachers and for Michal herself. In the class discussion with the children after the demonstration, we asked them what was so special in the demonstration, and how they thought it contributed to their understanding the physics of the rainbow. One of the children said:

> During the lesson you told us about the different phenomena, I think I understood what you wanted to teach, but I had to believe you that those phenomena really can be seen in the rainbow, now I saw them with my own eyes, and that makes the difference for me, I could see that physics works…

Michal is now preparing to teach about the rainbow at her school. It will be interesting to see the changes she will make to the design of her activity. Michal, Khaled and the other Physics teachers participating in the course designed the course for talented children. The design process was a collaborative effort facilitated by the course advisors. Figure 12.2 presents the course environment, including the main components developed by the teachers.

The activities developed were both hands-on and minds-on, and were constructed according to the models taught in the course. The environment includes many modern technologies which can be incorporated in the lesson. The activities used the children's mobile phones as lab equipment, combined with more traditional equipment. Simulations were used as an important visualization tool which

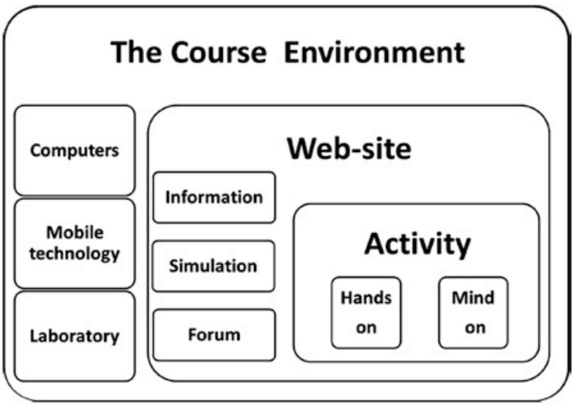


Fig. 12.2 The course environment

can help the students understand the physical concepts by making the complex scientific phenomena visible.

The course design includes construction of an internet site serving as a place where the children can find more information and participate in a FD sharing their reflections after each lesson. The internet site was open for parents to view what was happening in class.

12.4.3 Resources for the Teachers' Meta-Cognitive Development

Viewed comprehensively, we note that a number of key resources influenced the teachers' meta-cognitive development as it is shown in Fig. 12.3. We address each resource, providing an explanation and examples of the data collected in the study.

The courses in the present study: The courses stated in this chapter were developed based on the rationale that meaningful learning occurred when teachers experience significant learning while planning and constructing activities, as well as interacting with fellow learners, course instructors, professional experts and their students. The principles enabled a learning environment where teachers integrate knowledge, conduct analysis and synthesis, consider their ideas and those of their colleagues and promote their professional development as teachers and as lifelong learners. The teachers noted use of the various materials and media included in the course:

> As aids I used the articles studied in the course, the material so clearly worded in the partitions, the videos included in the course. In addition, studies in the course helped me

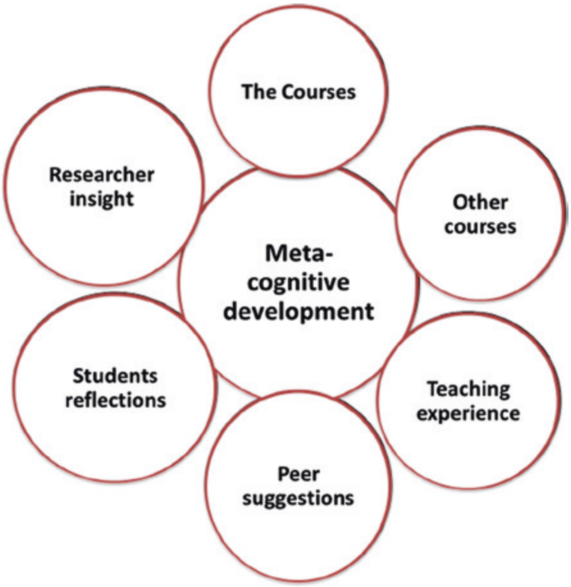


Fig. 12.3 Resources for teachers meta-cognitive development

greatly with the planning stages. For instance, knowing what the conditions are for promoting investigative learning, I made sure to incorporate them in the planned activity (T).

Other courses: The data we collected show that teachers were also influenced by other courses studied, helping them design and build their own activities, as expressed by Neta and Khaled:

The courses "Thinking about thinking" and "Critical thinking", greatly aided me in the steps required of me to make changes to the activity. For instance, I implemented what I learnt in your previous course, to make use of clarification questions, raise arguments, present examples and come up with ideas for future solutions (Neta).

The two online courses I took with you greatly helped me in planning and provided me with new concepts that I was unaware of previously, through which I learned of the power of reflection which is a source of immense influence on planning and improving. Also, at the training seminar in which we dealt with non-conventional solutions of mathematical problems, we also used reflection to adjust and improve the content I chose. I must admit that I have a fear of choosing content, in having to choose carefully in order to interest the students and of course we mustn't forget the additional course in which we conveyed material to talented students and all this was connected to the course materials learnt (Khaled).

Teaching experience: An additional source is teaching experience. The teachers who participated in this study are experienced teachers, and indicated whether this assisted them in developing activities and/or influenced their meta-cognitive thought processes. Khaled, who is a very experienced teacher, noted that conducting thinking about thinking was new to him and he had not experienced it before:

I must admit that the "thinking about thinking" process is critical to the field of teaching, a process I did not use at all in my teaching two years ago (before beginning studies in the faculty). Although this process throws you into an infinite spiral of thoughts, it can help form opinions and new approaches for the next plan.

Peers suggestions: Feedback collected from colleagues taking the two courses discussed in this chapter was stated as one of the main resources affecting the teachers' and their colleagues' thinking processes; particularly with knowledge regarding the task, in relation to the self as a learner and in relation to others. This was reflected in the changes made in planning the activities, in the manner in which teachers gave feedback to their colleagues and in the interaction during the lessons themselves (both with the students and as part of the online forum). D and M are relating these issues:

Peers feedback is one of the most important stages of planning; the colleagues' feedback is a powerful tool for improvement. Their comments helped a great deal in making alterations. I recall N.'s reference made me look at the activity from a completely different standpoint; switch to a broader perspective, three dimensional. Overall, I understood that beyond technique, it is worthwhile to integrate other realms such as the presence of the phenomenon in nature and architecture. (D)

From the colleagues' feedback and the sessions presented I learnt about their planning processes, the structure of the sessions and the nature of the questions raised. The entire issue of learning from colleagues is vital and you can essentially evaluate yourself and see where you stand. (M)

Children's reflection: The children reflections as well as the classroom discussions with the children about the course served as important resources for the teachers. Although all the teachers were experienced with many hours of classroom practice behind them, they did not have the habit of listening to student's views. This was a new experience for the children as well. Some of the children had very developed metacognitive awareness and could reflect very deeply about the strategies and tasks used in the lessons.

Many children expressed how much they enjoyed the course: "Physics is the best course we have". "We like the experiments and the hands-on activities." "This is much better than the Science lessons at school, Science at school is boring…."

Researchers' insight: Throughout the online course, face to face meetings were held with a number of students. These meetings were a continuation of discussions conducted in the forum during the course. In these meetings we discussed the processes they experienced during the different stages of developing the activities. Some came during the planning stages and others during more advanced stages. Students also related to that. For example, T. mentioned that following a discussion she understood that there were other areas available to her and she could expand the activity planned and include interdisciplinary aspects and future references. In the face-to-face course the design process was cyclical, conducted with the researcher, reflecting the researcher's insight at each step. Thus the teachers had the opportunity to discuss the design process with their peers and with the researcher.

12.5 Discussion

In this chapter we focused on the design and study of a metacognitive approach to the PD of high-school science teachers. We designed two courses based on meta-design principles known to provide a well-established environment enabling meaningful learning [27]. We provided the teachers with some new experiences that we think are essential for their PD. The first one is participating in a long term PD program for teachers that can promote their knowledge integration (KI) [28, 29] by connecting new theoretical concepts to their practical knowledge, using an evidence-based approach [10]. This was particularly evident in the teachers who participated in both courses.

Those teachers were exposed to a variety of content such as theories, models and examples of teaching resources including lab experiments and simulations. The teachers designed, made changes to their design, and experienced an iterative process of improving their activities.

This practice is supported by several researchers who argued that PD of a longer duration is more likely to contain the kinds of learning opportunities necessary for teachers to integrate new knowledge into practice [8, 30]. The second is providing an opportunity for the teachers to elicit their conceptions with regards to the activities they developed for the talented students, to discuss them with their peers and with their instructors, and to reflect on their own thinking. Our findings show that the courses we designed engaged teachers in constructing their own knowledge as well as collaborating as a group of learners.

The knowledge they acquired was not restricted to content knowledge, including the teachers' MK as well. These conditions of shared knowledge enabled the teachers to recognize the differences between engagement and awareness while guiding students to implement metacognitive strategies [31]. The third experience gives the teachers the opportunity to apply their teaching units in a supportive environment, leading to a successful experience in implementing their new and inspiring ideas.

This required close supervision by the courses advisors together with the laboratory assistant in order to prevent flaws leading to failures. Once having discussions with the teachers after each lesson, analyzing the stronger and weaker parts of their experience, led to a deeper understanding of the design process as well as of the main components of a task able to promote scientific understanding.

In this study we identified six key resources which influenced the metacognitive development of the teachers: (a) the courses in this study; (b) other M.Ed. courses; (c) the researchers' insight; (d) the teachers' teaching experience; (e) peer suggestions and (f) children's reflections. We found that each resource empowered the teachers, adding new layers to their metacognitive knowledge.

The interviews with the teachers and their reflections indicate that both courses, as well as other courses in the M.Ed. program, have impacted the teachers in designing their activities. In addition, it seems that the researcher's insight provided throughout the courses helped the teachers become aware of their own thinking processes and able to express them verbally. This awareness is significant, as we know that teachers are often unacquainted with the knowledge they possess. Moreover, in their regular practice they do not need to express it [25].

Teachers' teaching experience was also a major contributor to their metacognitive development. Teachers related to knowledge in physics, biology, chemistry and mathematics they already had, to strategies that they were familiar with and to diverse types of tasks (e.g., simulations, lab experiments, and riddles). The fifth resource was the teachers' peer feedback. It seems that this was one of the elements that affected the teacher's knowledge regarding the activities, and raised their self-awareness in relation to strategies they have adopted and the interactions they had with the students. It is worth noting that, in a regular class, experienced teachers teach on their own. Here, teachers had an opportunity to be present in a lesson taught by an experienced colleague, to watch and learn from him/her and even to experience co-teaching.

This experience along with the teachers' peer feedback facilitated the teachers' cognitive apprenticeship [32] and their MK development throughout the year. The last recourse we identified was the children's reflections.

Children were asked to write a reflection at the end of each lesson and refer to the knowledge they acquired, the teaching strategies that the teachers implemented, and the lab experiments. At the end of each lesson, the teachers rushed to read the children's feedback. This feedback regarding the teachers' presentations, quizzes, simulations and lab experiments helped to construct the teachers' MK. This was expressed in the teachers' reflections and in changes the teachers enacted in their lessons. One of the interesting references that the children raised in their reflections was the fact that the teachers actually listened to them, and wanted to know their opinions.

The children explicitly stated in their feedback that the teachers were really interested. This was something they had never experienced in their regular school where the teachers never asked them to express their opinions nor provide suggestions for improving the lesson/activity/teaching strategies. This ought to be considered in teaching all students, but in particular in teaching talented students. Research shows that talented students who experience inquiry learning in an environment enabling them to give and receive reflective feedback to and from different agents (e.g., peers, teachers, experts, tutors, parents) develop their reflective and inquiry skills [33].

To sum up, it seems that the courses we developed and implemented offered the teachers a supportive and constructive learning and teaching environment. They enhanced their knowledge of students' understanding of science and thinking processes. This is similar to Darling-Hammond et al. [34] who argued that "to understand deeply, teachers must learn about, see, and experience successful learning-centered and learner-centered teaching" (p. 598).

In conclusion, we agree with Zohar and Barzilai [2] who claim that teachers need to understand what metacognition means and practice metacognitive thinking with respect to classroom activities. They need to explicate MK and practice MS with respect to the activities that take place in the classroom. We concur with other researchers [2, 16, 19, 35] that teachers' metacognitive proficiency is crucial, and that metacognition should find its way into routine Science instruction. Our study strongly encourages teachers to develop and design activities and test them within a supportive environment, practice which can help them in understanding their own beliefs as well as promote their metacognitive knowledge.

We believe that the teachers' own understanding of the complex teaching mechanism has changed, and they will take this experience into account while designing activities for their students in the future. As Khaled stated:

> The process of getting feedback from the students is missing from the school where I teach, now I realize that this resource can help teachers to assess and evaluate their own teaching methods, and can give the teacher the opportunity to improve himself by asking the students questions like: what do you want to know; what was missing in the lesson; what kind of activity concerns you more; therefore, I am sure I will use students' reflection in the future in my classes.

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