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Enhancing the Pedagogical Content Knowledge of Teachers by Using an Evidence-based Inquiry Approach in the Chemistry Laboratory

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In this paper we will present an evidence-based model for the continuous professional development (CPD) of chemistry teachers, using the inquiry approach in the chemistry laboratory. The teachers had to fill protocols assembled in a portfolio that can be used to demonstrate evidence-based practice in chemistry teaching in the inquiry laboratory. Seven experienced chemistry teachers participated in a workshop, coordinated by three CPD providers from the Department of Science Teaching, at the Weizmann Institute of Science. The meetings, lasting about three hours, were conducted once a month. Of the seven teachers, some were videotaped while conducting inquiry-type experiments in their classes, and were interviewed immediately afterwards. Based on the findings, we concluded that the teachers became more reflective and more aware of their practice. In addition, we observed a change in their pedagogical knowledge and content knowledge regarding the inquiry teaching.

Theoretical Background

In chemistry education new standards are emerging regarding the content and pedagogy of teaching and learning. This necessitates a change in the way we professionalize the chemistry teachers. In Israel, the inquiry laboratory was integrated into the teaching and learning of high-school chemistry (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). An evidence-based model for the continuous professional development (CPD) of chemistry teachers was developed and implemented (Taitelbaum, Carmeli, Mamlok-Naaman, & Hofstein, 2008). Using the CPD model enables the teachers to gain the unique pedagogical content knowledge needed, so they will be good guides for their students. During the learning process in class, teachers should try to recognize the way students think in order to help them construct their understanding and create rich and meaningful interactions in the classroom. However, in order to use the inquiry approach, teachers need to undergo an intensive process of professional development, so that they will experience the same skills, knowledge, experience, and thinking habits as their own students (Winscihtl, 2003).

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Minstrell (2000) claimed that teachers should change their teaching strategies and adopt new strategies.

In Israel, chemistry teachers in Israel have begun to integrate inquiry-type experiments into the chemistry curriculum. In this study, our aim was to better understand the development of the Pedagogical Content Knowledge (PCK) of chemistry teachers who are involved in Professional Development workshops, focusing on the inquiry approach in the chemistry laboratory. According to Hofstein, Shore, and Kipnis (2004), teachers who are involved in this project should lead and tutor students by working in small groups (cooperative learning).

Encourage students to interact professionally, including sharing knowledge with their peers, community members, or experts. Help students to solve problems, to ask high-level questions, and to hypothesize regarding certain experimental phenomena. Assess their students continuously since teaching by inquiry requires a variety of alternative assessment methods. Make decisions regarding the level of inquiry (Katchevich, Hofstein, & Mamlok-Naaman, on-line). Align the experiment with the concept taught or discussed in the chemistry classroom.

Teaching science using the inquiry approach presents challenges both for the teachers and for students (Krajcik, Mamlok, & Hug, 2001; Clough, 2002). Since the teaching is student- centered, the teacher should (1) encourage the students to study, (2) teach in such a manner so that students' learning is challenging, and (3) help students to understand the subject matter (Tobin, 1990). Students should be involved in several steps: (1) conducting experiments according to the teacher's instructions, (2) making and organizing observations, (3) asking as many questions as possible, (4) choosing and rephrasing one question to be analyzed, (5) constructing a hypothesis for the research question, based on scientific principles, (6) designing an inquiry experiment to resolve the research question, (7) making and organizing observations once again, (8) analyzing and summarizing the inquiry experiment, (9) presenting the results to the whole class, and (10) asking more questions.

During the learning process the teacher should try to recognize the way students think in order to help them construct their understanding and create rich and meaningful interactions in the classroom (Gusky, 2003; Louck-Horsley, Love, Stiles, Mundry, & Hewson, 2003). However, in order to use the inquiry approach, teachers need to undergo an intensive process of professional development, so that they will experience the same skills, knowledge, and learning habits as their own students (Winscihtl, 2003). Moreover, they should also undergo the entire inquiry process, so that they will be able to better instruct their students (Krajcik, Mamlok, & Hug, 2001). According to Shulman (1987), accomplished practice in science teaching can be defined in terms of the knowledge that teachers use in their teaching. Teachers should change their teaching strategies and adopt new strategies (Minstrell, 2000). Moreover, they should gain adequate pedagogical content knowledge in order to be good guides for their students (Hoftsein, et al., 2005).

It seems valuable to think about what sub-domains PCK consists of and where it is derived from to understand teachers' professional development. Magnusson et al. (1999) offer a framework to divide PCK into five areas: 1) orientation with respect to teaching, 2) knowledge of the curriculum, 3) knowledge of the testing of knowledge, 4) knowledge about learners and 5) knowledge about strategies of passing on knowledge. Concerning the main sources PCK is developed from Grossman (1990) identified four areas: 1) observation of classes, both as a student and as a student teacher, 2) disciplinary education, 3) specific courses during teacher education, and 4) classroom teaching experience. Later, Appleton and Kindt (1999), and

5) Recommendations from trusted colleagues.

It is sound that these sources and domains form a broad and valuable framework to better understand what PCK means. Most sources, i.e. observations and recommendations are not always

recorded consciously and are often not critically reflected. That means that the development of PCK does not always take place on a well-founded and reflected base and often will not be in line with actual educational theory.

The inquiry project described here is part of a more comprehensive project conducted in the Science Teachers National Centers located at the Department of Science Teaching, The Weizmann Institute of Science. The main goal of this comprehensive project was to develop, through collaborative research with classroom teachers, a Continuous Professional Development (CPD) program that focuses on a set of characteristics and protocols that individuals can use to demonstrate evidence-based accomplished practice in science teaching, e.g., portfolios (Klenowski, 2002). In this research we monitored seven high-school teachers who were in their first year of teaching by using the inquiry approach. Our research questions are as follow:

1. What teaching strategies do the teachers use when working with a few small groups of students during the lesson?

2. What changes did the teachers undergo over time in their teaching style, concerning their guidance while students pose an inquiry question?

Methods and Sample

The research described is a qualitative research. In this paper we will describe a workshop of seven teachers from different schools, who are experienced high-school chemistry teachers, but novices in teaching using the inquiry approach. The teachers were offered to participate in a monthly workshop during the school year in order to promote their expertise beyond the initial preparation of a summer workshop in which they participated. The workshop was coordinated by three researchers from the Department of Science Teaching. We had seven meetings, once a month, three hours each. All meetings were videotaped.

The research tools were as follows:

Videotapes of 2-3 activities at each teacher's laboratory lessons. The videotapes contributed to our understanding of the teachers' professional development. The videotapes were digitized, and then analyzed according to categories which emerged during the analysis. Each teacher was videotaped during three inquiry-type activities throughout the school year: at the beginning, middle, and end of it. Each activity could last from two to three double lessons (45 minutes each). All videotaping came to about 15 lessons, per teacher, per year. Four of the teachers were also videotaped during their second year of teaching the inquiry-type laboratory. This comes to 30 lessons for each teacher.

*Teachers' portfolios***.** Each teacher was asked to construct a portfolio including three pieces of evidence, which were based on artifacts brought from their classes. Each portfolio was analyzed to determine the kind of pieces of evidence in it, and the teacher's reflection concerning the whole year.

Teachers' interviews. Semi-structured in-depth, face-to-face interviews were conducted with the teachers immediately after each observation. Each teacher was interviewed for 20-30 minutes, regarding: (1) the goals for conducting the specific inquiry-type experiment, (2) decisions made regarding the inquiry level, (3) reflection on the teacher's role using the experiment, and (4) difficulties that arose during the activity. The interviews were subscribed and analyzed. A few categories emerged from the interviews during the analysis, e.g., concerns regarding the inquiry approach. We will focus on two of them: (1) how to monitor the group work? and (2) how to guide the students in defining a good research question?

All interviews were videotaped. All teachers also participated in a year-long workshop.

Findings

The findings were analyzed according to the research questions:

1. The first research question: *What teaching strategies do the teachers use when working with a few small groups of students during the lesson?*

Analyzing the videotapes from the inquiry activity revealed that at the beginning of the school year most teachers hesitated to approach the groups and in fact kept some distance from them. They preferred to stand next to their desk and discuss the inquiry activity from there, with the groups, rather than approaching them. As time passed, however, teachers became more relaxed and familiar with the students and the inquiry skills, so they approached the groups more frequently and for longer periods of time during the lesson. We can demonstrate this through the data from one of the videos of one of the teachers. At the beginning of the year she approached the groups for a total time of 32.30 min, which was about 40% of that lesson. Five months later she approached the groups for a total time of 52.75 min, which was about 62% of that lesson. From the data, it seems that the total time she spent with each group varied greatly. That teacher explained, in the workshop, that by the end of the year she overcame her anxiety concerning her uncertainty in conducting open-ended inquiry-type experiments. Sharing her anxiety during the workshop with other teachers and the providers of the workshop, as well as practicing the inquiry approach at class, assisted her in overcoming it.

The videos also showed that when teachers approached a group, at the beginning of the year, they gave vague and elusive responses to students' questions and remarks, and quickly continued to the next group. The teachers reported in their "hot reflection" during the interview, and in the workshop that they were reluctant to reveal to their students information concerning the open-ended experiments, but rather wanted them to find it on their own. The dialogue with the students has also changed toward the end of the year. Two dialogues between one of the teachers and the students will serve as examples - one from the beginning of the year and the other from its end.

A dialogue from the beginning of the year:
Student: Is this a good question?
Teacher: Sure, every question can be a relevant question.

A dialogue from the end of the year:
Student: I think that I have an inquiry question.
Teacher: Yes please.
Student: How will this influence that (pointing to a picture of the experiment that he drew a few minutes ago)? We understood that the dependent variable…
Teacher: Good. It will be easier for you, if we will write the independent variable and the dependent variable, and then ask about the connection between them.
Student: The independent variable is the clear material and the blue material which we added, and the other variable is all the rest of the materials.
Teacher: No, you have to choose only one dependent variable. What do you want to check?

Based on the data collected from the teachers' portfolios and interviews, we could see that the dialogue with the students was much more meaningful and lengthy at the end of the year compared with the beginning of the year. The teachers claimed that they had much more confidence and got into the thick of things, while relying on the content of the inquiry approach. It is possible that there was a change in the teacher's pedagogical content knowledge (PCK) since the beginning of the year, regarding the group work as well as the inquiry approach

It is suggested, that even a minor change in the pedagogy, e.g., dealing with small groups can cause anxiety and influence the teacher's self-confidence (Taitelbaum, et al., 2008).

2. The second research question: *What changes did the teachers undergo over time in their teaching style, concerning their guidance while students pose an inquiry question*?

Most teachers reflected in their portfolios that they devoted a special frontal lesson to introduce this inquiry skill of "phrasing an inquiry question" to their students. The analysis of the videos showed that they presented the issues of dependent and independent variables as basic components for phrasing the inquiry question. In most classes the teacher needed to relate to this inquiry skill at least once more, using frontal teaching. Most teachers reported dissatisfaction from their students' inquiry questions until the end of the first year, even though there was improvement in their students' performance.
"It is difficult to guide the students in choosing a research question or to decide if the question is really an inquiry question… avoiding giving them the answer, avoiding phrasing it for them. I had to hold myself back each time, and not reveal too much in order to let them do the thinking ".

By analyzing teachers' discussions during the workshop, it is suggested that providing teachers with the opportunity to reflect upon their experience as well as assessing their own work (via the videos), are important tools for enhancing their professional practice (Putman & Borko, 2000). There was also an alignment between the teachers' reflection and the analysis of the videotaped observations. Throughout the year, the teachers asked the CPD providers for support and scaffolding-type ideas regarding their practice, e.g., guiding their students in asking questions (Davis & Honan, 1998) The need for support was generally based on the need to develop new pedagogical knowledge, as well as content knowledge, namely – the need to develop pedagogical content knowledge (PCK) in this field. This was true even with experienced teachers (Crawford, 2007; Tal & Argaman, 2005). We found that the scaffolding that they got due to their request for support, faded out throughout the year.

In summary, the findings showed the following changes throughout the year: The teachers changed their teaching strategies. They allotted more responsibilities to the students, and learned how to guide them in conducting discussions and in elaborating on the data of the experiments in small groups (Katchevich, Hofstein, & Mamlok-Naaman, on-line).

The dialogue between the teachers and the students improved. Most of the teachers reported in their portfolios about having difficulties when conducting a discussion with small groups of students. However, they claimed that it improved throughout the year. The major difficulty was to conduct the discussion patiently, guiding the students step-by-step, and to encourage them to answer questions and to find solutions. By watching the videotapes from one teacher class, we could see that throughout the year she gained more experience in approaching the groups of students and in discussing the experiments with them. One of the teachers mentioned in the interview at the beginning of the project, that used to give quick, short, and elusive answers to her students' questions, whereas at the end of the year she developed the ritual of proposing questions and providing answers, thus encouraging a nice discussion with each group (Hofstein, et al., 2005).

The teachers learned how to ask for support, and felt more confident in expressing their needs. Some of them involved the laboratory assistant in various classroom activities–not only in the laboratory tasks. Moreover, they often came to meet the project coordinators, or discussed their problems with them by phone or by E-mail. The support that the teachers needed and used was quite broad–from a frequent need for help and scaffolding for almost each classroom activity, to minimum communication through E-mail infrequently. They usually needed help in choosing the experiments, in planning the activities, in guiding their students with different other inquiry activities, or in assessing the students' reports (Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008).

The anxiety of the teachers concerning the implementation of the program diminished throughout

the year (Joyce & Showers, 1983). At the beginning, all the teachers were anxious, but at the end of the year, they claimed that the support that they received at the meetings helped them build their confidence in teaching by the inquiry approach. During the meetings they shared their ideas with their colleagues and with the coordinators of the project, talked about their teaching strategies, and reflected upon their work (Katchevich, Hofstein, & Mamlok-Naaman, on-line). The feedback that they got helped them improve their pedagogical content knowledge and encouraged them to continue with the project (Loughran, 2007).

Conclusions and Implications

Chemistry teachers should develop a different and new PCK in order to become professional in teaching using the inquiry approach. It is quite clear that a teacher who decides to teach using this approach is like a novice teacher who needs scaffolding and support at the beginning. However, this research supports the notion that chemistry teachers can improve their teaching by using the inquiry approach (Mamlok-Naaman, & Barnea, 2012). It was found that different teachers use different strategies in implementing the inquiry approach (Bybee, 2000). This variation ranges from a very high use of scaffolding from an experiment of a colleague, in which every step, decision, and assessment is mentioned, to postponing the time for stating the inquiry, and making observations during an expert teachers' lesson before teaching the same lesson by oneself, as well as implementing one skill at a time rather than implementing it as a full program (De Jong, Van Driel & Verloop, 2005).

We found that video-tape recordings provided reliable and valid evidence of the changes that the teachers underwent. The workshop enabled the teachers to create a community of practice, in which they had in-depth discussions while sharing their knowledge, giving feedback to each other on evidence and assessing vignettes of video recordings, and reflecting upon their practice. The combination of this, together with the interviews, provided us with an explicit and clear understanding of the teachers' professional development and growth. Towards the end of the year the teachers reported that they became more reflective, and that their anxiety concerning the implementation of the program decreased. Although making observations is a time- and money-consuming process, we recommend that teachers videotape their lessons, and create small teachers' groups to share and reflect upon their practice, and use those videotapes to initiate deep meta-cognitive thinking (Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008).

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