Examining pre-service chemistry teachers' pedagogical content knowledge and influences of teacher course and practice school

Examinando el conocimiento del contenido pedagógico de licenciados en química y las influencias de un curso de formación y de prácticas

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Abstract

This study examined pre-service chemistry teachers' pedagogical content knowledge (PCK) in the context of a teacher education program which includes both university-based course work in science education and teaching in practice schools. The study focused specifically on the development of pre-service chemistry teachers' PCK of teaching electrochemistry to grade 11 students and how this development is influenced by the program. The results showed that the influence of the teacher course decreased throughout the program while the influence of the practice school increased. A gap between course 'theory' (emphasizing student-centered strategies) and school 'practice' (emphasizing teacher-centered strategies) was clearly shown. Implications for science teacher education programs are discussed.

Key words: *pre-service chemistry teachers, pedagogical content knowledge, influencing factors.*

Resumen

Este estudio examina el conocimiento del contenido pedagógico (CCP) de licenciados en química en el contexto de un programa de formación de profesores que consta de un curso de didáctica de las ciencias desarrollado en la universidad y de prácticas en una escuela. El estudio se centra específicamente en el desarrollo del CCP en la enseñanza de la electroquímica para estudiantes del grado 11 y en cómo el programa influye en este desarrollo. En muchos de los profesores se observó que la influencia del curso disminuía durante el programa de formación a medida que avanzaba la práctica en la escuela. Se observó una desconexión entre la "teoría" del curso (estrategias centradas en el estudiante) y la "práctica" en la escuela (estrategias centradas en el profesor). Se discuten implicaciones para los programas de formación de profesores de ciencias.

Palabra clave: *licenciatura en química, conocimiento pedagógico, factores de influencia.*

INTRODUCTION

In his famous article, SHULMAN (1986) introduced pedagogical content knowledge (PCK) as central to the knowledge base of teachers. He described PCK as "that special amalgam of the content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding." (SHULMAN, 1987, p. 8). His articles have strongly stimulated the interest in teachers' PCK. In developing PCK, teachers should gain an understanding of a range of issues such as knowledge of strategies for subject matter teaching and knowledge of students' difficulties in understanding subject matter (LEDERMAN, et al., 1994). In the present study, pre-service chemistry teachers' PCK was investigated in the context of a program that included teacher course units and teaching practices in secondary schools. The focus was on the development of PCK of teaching electrochemistry. It is well-known that this curriculum topic is difficult to teach and to learn (DE JONG & TREAGUST, 2002). However, little is known about the development of pre-service teachers' PCK concerning this topic and influences of teacher course and practice school.

BACKGROUND OF THE STUDY

Various scholars, elaborating on Shulman's articles, have conceptualized different components of PCK. For instance, SMITH and NEALE (1989) considered PCK as having three components: (i) knowledge of students' conceptions of subject matter, (ii) knowledge of strategies for teaching subject matter, and (iii) knowledge of shaping and elaborating the content of teaching. COCHRAN, et al. (1993) described a model of PCK that results from an integration of four components: (i) pedagogy, (ii) subject matter, (iii) student characteristics, and (iv) the environmental context of learning. MAGNUSSON, et al. (1999) conceptualized five components of PCK: (i) orientations toward subject matter teaching, (ii) knowledge of the curriculum, (iii) knowledge of assessment, (iv) knowledge of strategies for subject matter teaching, and (v) knowledge of students' understanding of subject matter. The present study is focused on the two latter components.

With regard to the PCK component of teaching strategies, we agree with MAGNUSSON et al. (1999) that this covers a range of knowledge levels, for instance, the quite general level of knowledge of phases of subject matter teaching and the more specific level of knowledge of particular teacher demonstrations or student experiments. With regard to the PCK component of students' understanding, we assert that this also embodies knowledge of students' learning difficulties. Finally, we recognize that knowledge of students' understanding of subject matter often develops concurrently with knowledge of teaching strategies. For instance, the better teachers understand their students' difficulties with respect to a certain topic, and the more representations and activities they have at their disposal, the more effectively they can teach about this topic.

The development of PCK is a complex process and influenced by several factors. Grossman (1990) identified four sources that are potentially important with respect to PCK development: (a) subject disciplinary education, which constitutes the basis for knowledge of topic-specific representations for teaching; (b) observation of classes, which may promote knowledge of students' conceptions and learning difficulties; (c) classroom teaching experiences, including the use of school textbooks, which may promote knowledge of topic-specific teaching activities; (d) specific courses or workshops during teacher education. Some scholars suggest that the most important contributions are made by disciplinary education (SANDERS, et al., 1993; KÄPYLÄ, et al., 2008; ROLLNICK, et al., 2008) and classroom teaching experiences (VAN DRIEL, et al., 2002). Although the efficacy of teacher education programs might be in question (SMITH & NEALE, 1989), CLERMONT, et al. (1993) asserted that a significant improvement in PCK occurred as a result of a specific workshop. Finally, HEWSON, et al. (1999) showed another influencing factor: mentors at the practice schools, especially their classroom teaching. In conclusion, as there have been not many studies on the ways PCK develops over time, the relative impact of each of the factors mentioned before is quite unclear. The present study is focused on two factors: teacher course and practice school.

Examining PCK is not easy because PCK is quite unarticulated and tacit in nature. A research tool that is very appropriate to take the 'hidden' character of PCK into account is the use of lesson plans (VAN DER VALK & BROEKMAN, 1999). By comparing plans that are prepared before teaching and again after teaching, PCK development can be identified. More information about this development is collected by interviewing the teachers and asking them to explain their plans (LEE and LUFT, 2008). The present study is using this research tool.

CONTEXT AND RESEARCH QUESTIONS

The present study was conducted in the context of a pre-service teacher education program at Balikesir University, Turkey, that prepares secondary school chemistry teachers. The first part of the program covered courses on chemistry (seven semesters); the second part covered courses on (chemistry) education (three semesters). The latter part was relevant to the present study. In this part, the pre-service teachers took course units on general education and chemistry education. In the eight semester, they also observed chemistry lessons at practice schools; in the ninth semester they began to teach classes supervised by their school mentors. Finally, in the tenth semester, the pre-service teachers taught in their 'own' classes for a period of three

months (about six lessons per week). In addition, they took course seminars for sharing experiences and for reflecting on their teaching practice.

In the present study, pre-service teachers' PCK refers to their teaching of the difficult topic of electrochemistry. According to the Turkish secondary school chemistry curriculum, this topic covers the issues of redox reactions, redox titrations, galvanic cells, and electrolytic cells. These issues are taught to grade 11 students (aged 16 to 17). Many chemistry teachers in Turkish secondary schools usually prefer traditional teaching strategies such as presenting nearly all information to be learnt by the students and prescribing nearly all student activities. In other words, teacher-centered strategies are dominant (NAKIBOGLU & SARIKAYA, 1999). The study was guided by the following research questions:

(i) What pre-service teachers' PCK of teaching electrochemistry topics can be identified in the beginning of the teaching period in the school and at the end of this period?

(ii) What influence of the teacher course and the practice school on this PCK can be identified?

METHOD

Participants and procedure

The subjects involved in the study were nine pre-service teachers (5 females and 4 males; average age was 22). They individually prepared two 40-minute lesson plans for students of grade 11. This grade is the third year of the secondary school and is also the third year of lessons in chemistry but the first year of lessons in electrochemistry. Before the first lesson plan (written at the beginning of the ninth semester), the pre-service teachers took course units on general education (teaching strategies, lesson planning, and so on) and chemistry education (school chemistry textbooks, practical work, and so on). They also visited their practice schools to discuss and observe lessons of their mentors, but lessons about electrochemistry were not observed or discussed. The second lesson plan was written about seven months later, at the end of their teaching period. Between both lesson plans, the pre-service teachers took several follow up course units, for instance, the unit 'misconceptions in chemistry' that partly focused on students' difficulties in understanding electrochemistry. They also taught several chemistry topics, among them electrochemistry, in their classes. When preparing both lesson plans, the pre-service teachers (referred to below as PT 1 to PT 9) were permitted to consult current school chemistry textbooks, and they did. For preparing the first lesson plan, they had to choose a particular part of electrochemistry. The topics chosen were: willingness of metals to be reduced or oxidised (PT 1), half-reactions (PT 2), half-reactions and standard cells (PT 3 to 6), concentration effects on cell potentials (PT 7), and electrolysis (PT 8, 9). For preparing the second lesson plan, the pre-service teachers had to take the same topics chosen before.

The pre-service teachers were interviewed individually about both lesson plans after the analysis of both lesson plans was finished (about four weeks after the second lesson plan). During this semi-structured interview, they were asked to clarify the teaching strategies used in each lesson plan, to report how they take possible students' learning difficulties into account, and to explain differences between their first and second lesson plan (as found by our lesson plan analysis).

Data collection and data analysis

The main research data sources consisted of written lesson plans, post-planning interviews, and course seminar discussions related to the teaching experiences. All interviews and course seminar meetings were audio taped and transcribed.

Pre-service teachers' PCK was analysed by using a set of four analysis categories: (i) PCK of using teacher-centered and student-centered teaching strategies, (ii) PCK of presenting practical work (teacher demonstrations and student experiments), (iii) PCK of presenting representations (drawings and schemes), and (iv) PCK of students' difficulties in understanding electrochemistry. The strategies in the first category were described in terms of expository teaching (ET), guided-discovery teaching (GDT), open-inquiry teaching (OIT), and learning cycle teaching (LCT). These strategies were taken from the teacher course textbooks that the pre-service teachers have used. The ET strategy is considered as teacher-centered, whereas the three other strategies are defined as student-centered. The LCT strategy includes mostly three-phases: exploration, invention, and application. In this strategy, either the strategy of GDT or OIT can be incorporated.

The lesson plans, interview transcripts, and seminar discussions were analysed in a stepwise procedure. First, both lesson plans were analysed by using the categories mentioned above. Next, the interviews and seminar discussions were analysed by using the same set of categories. Then, the analysis results for the first lesson plan were compared with the results for the second lesson plan to identify PCK development. Finally, the lesson plans were compared with the content of the teacher course textbooks and the school chemistry textbooks to identify influences of the teacher course and the practice school. Data about these influencing factors were also obtained from the interviews and the seminar discussions.

To establish the content validity and reliability of the analysis, the first and second author separately analyzed the lesson plans and the interview transcripts by using the same sets of analysis categories. Both authors compared and discussed the individual analyses, aiming to reach consensus about the interpretation of the data.

FINDINGS

PCK of using teacher-centered and student-centered teaching strategies

The teacher course textbooks paid more attention to the student-centered teaching strategies than to the teacher-centered strategies (see preceding section). However, the pre-service teachers reported in the course seminar meetings that their mentors mainly used teacher-centered strategies. An overview of the strategies used by the pre-service teachers in the lesson plans is given in Table 1.

Table 1
Teacher-centered and student-centered teaching strategies in the lesson plans

Type of strategy (*)	Pre-service teacher	
	First lesson plan	Second lesson plan
Teacher-centered: ET	3,4,6,7	1,2,3,4,5,6,7,9
Student-centered: LCT (incl. GDT)	1,2,5,9	-
Student-centered: GDT and OIT	8	-
Student-centered: GDT	-	8

(*) ET = Expository Teaching; LCT = Learning Cycle Teaching; GDT = Guided-Discovery Teaching; OIT = Open-Inquiry Teaching.

The pre-service teachers who prepared student-centered teaching strategies for their first lesson plan (PT 1, 2, 5, 8, 9) argued, in general, they were influenced by the preceding course units on chemistry education. The pre-service teachers who prepared the expository teaching strategy for the first lesson plan (PT 3, 4, 6, 7) argued, in general, they were influenced by observations of lessons of their mentors. They explained their observations by reporting that their mentors used teacher-centered strategies because of their concerns of fulfilling the regular school chemistry curriculum in time. Regarding the second lesson plan, these pre-service teachers asserted another influencing factor: their experiences with teaching in their own classes in between the first and second lesson plans. The latter factor was also reported by the pre-service teachers who changed from a student-centered strategy towards a teacher-centered strategy. As one of them expressed:

> *Since I realized that the expository teaching strategy was mostly used at the secondary school where I went for my teaching experiences, I also tended to use this strategy when preparing my second plan.* (PT 1)

A further clarification was given by two of the pre-service teachers (PT 2, 5) by saying that, because of their teaching experiences, they realized that they would be able to provide more knowledge within the given time limits through preparing the expository teaching strategy.

The structures of the lesson plans including the LCT (incl. GDT) strategy were more or less the same. In the exploration phase of the learning cycle, the pre-service teachers used an experiment as a discovery activity. For instance, one of the pre-service teacher said:

> *A zinc-copper galvanic cell without an external circuit was prepared. It is said to the students that an experiment will be done but any knowledge is not given to the students. The two electrodes are connected by an external circuit with a voltmeter. Students record their observation and are asked to explain the deflection on the voltmeter.* (PT 5)

In the invention phase of the learning cycle, the pre-service teachers mostly started with asking questions to elicit students' interpretations of the observations and, thereafter, the core concepts and principles were addressed by giving a lecture. The same pre-service teacher as before said:

> *If there is an electrical current, its reason is discussed by the students. After collecting students' interpretations, information about the processes in the experiment is given.* (PT 5)

In the application phase of the learning cycle, the pre-service teachers asked the students to use their acquired knowledge in new situations. For instance, PT 5 asked the students to apply their knowledge of a particular zinc-copper galvanic cell for designing other galvanic cells.

The structures of the lesson plans including the ET strategy also had many points in common. First, the pre-service teachers asked questions aimed at leading the students to remember relevant prior knowledge. Then, they used various teaching activities for facilitating students' learning. For instance, one of them wrote:

> *The teacher explains the definitions of the concepts of half-reaction and galvanic cell while drawing a zinc-copper galvanic cell on the black board. Students listen while the subject matter is being taught, answer the questions being asked, and ask about anything that they do not understand.* (PT 4)

Finally, the pre-service teachers asked questions in order to determine whether the students understood the subject matter taught.

A comparison of the lesson plans with the teacher course textbooks used by the pre-service teachers showed that all of them used one or more strategies given in these textbooks. The structures of the lesson plans including the strategy of LCT (incl. GDT) or the strategy of ET corresponded a lot with the structures given in the textbooks. The structures of the lesson plans including the strategy of GDT and/or OIT were not given in the textbooks.

PCK of presenting practical work

Six of the nine pre-service teachers incorporated practical work in one or both lesson plans. An overview is given in Table 2.

Table 2
Teacher demonstrations and student experiments in the lesson plans

Type of activity	Pre-service teacher	
	First lesson plan	Second lesson plan
Enacting teacher demonstrations	6	5, 9
Offering student experiments	1, 2, 5, 8, 9	8

One of the pre-service teachers (PT 9) offered a student experiment for electrolysis in her first plan, but she replaced it by a teacher demonstration in her second plan. When asked for the reason for this change, she indicated time constraints. The same change in teaching strategy was found in the lesson plans of PT 5 who prepared the teaching of half-reactions and standard cells. However, this pre-service teacher offered another explanation based on the type of teaching strategy that she had chosen:

> *In my first plan, I used the learning cycle. When I was using the discovery teaching strategy, I preferred to have a student experiment there. However, in my second plan, I preferred to use a teacher demonstration because I was using the expository teaching strategy. In other words, the strategy I used had impact on my choice for either a student experiment or a teacher demonstration.* (PT 5)

A comparison of the lesson plans with the school chemistry textbooks used by the pre-service teachers showed that nearly all teacher demonstrations and student experiments in the plans were adapted from practical work given in the textbooks.

PCK of presenting representations

Five of the nine pre-service teachers incorporated representation in one or both lesson plans. An overview is given in Table 3.

Table 3
Drawing and schemes in the lesson plans

Type of representation	Pre-service teacher	
	First lesson plan	Second lesson plan
Drawing	3, 7, 9	3, 4
Scheme	7, 9	2

A variety of drawings and schemes was presented. For instance, PT 3 wanted to explain the events in galvanic cells by presenting a drawing of a zinc-copper cell in the beginning of her first lesson. At the end of this plan, she wanted to test students' knowledge by asking questions related to a drawing of another cell, a nickel-silver cell. In her second lesson plan, she wanted to ask the same questions and to repeat the drawing from her first lesson plan. PT 9 prepared the teaching of 'electrolysis' and, in the first lesson, she wanted to explain the events in an electrolytic cell by presenting drawings and schemes including information at the sub-microscopic level (ions, electrons).

A comparison of the lesson plans with the school chemistry textbooks used by the pre-service teachers showed that all drawings and schemes in the plans correspond a lot with drawings and schemes given in the textbooks.

PCK of students' difficulties in understanding electrochemistry topics

The lesson plans showed that the pre-service teachers rarely identified students' difficulties in understanding electrochemistry topics. Only one pre-service teacher (PT 3) demonstrated any intention in her second lesson plan to check whether the students had any difficulties in understanding, however, no elaboration was given. The interviews showed that four of the nine pre-service teachers (PT 1, 3, 7, 8) argued that they paid attention to students' learning difficulties when writing teaching goals for their second lesson plan.

The absence of paying attention to students' difficulties in the first lesson plans was explained by one of the pre-service teachers as follows:

> *I prepared my second plan after I had taken the course unit about students' misconceptions in chemistry. I had no idea about this topic before. However, having taken the course lecture, I became aware of it.* (PT 3)

The impact of the preceding course unit on knowledge of students' learning difficulties was also asserted by PT 1. In the interviews, another influencing factor was also mentioned. Six of the nine pre-service teachers (PT 1, 2, 4, 7, 8, 9) stated that they remembered the difficulties in their own learning of electrochemistry, not only from their earlier experience as school students but also from recent experiences as university students.

Analysis of the interviews also showed that all pre-service teachers answered the question about how to account for possible students' difficulties in understanding electrochemistry topics. Five of them (PT 2, 3, 6, 7, 8) wanted to enact teacher demonstrations or to offer student experiments. Four of them (PT 1, 4, 5, 9) wanted to prepare other topic-specific strategies, for instance, a pre-service teacher who prepared a lesson on half-reactions and standard cells wanted to present a scheme of a cell to counteract students' conception that the identity of the anode and the cathode depends on the physical placement in a cell:

> *This misconception can be prevented by writing anode and cathode on different positions. That is, writing each of them sometimes on the right side of a scheme, and sometimes on the left side.* (PT 4)

A comparison of the suggested remedial teaching strategies with the school chemistry textbooks used by the pre-service teachers showed that nearly all suggestions were based on information in the textbooks.

CONCLUSIONS AND DISCUSSION

The findings about *PCK of using teaching strategies* (teacher-centered, student-centered) indicated that three patterns can be identified.

* Pattern 1: using student-centered strategy (LCT, incl. GDT) in the first plan followed by a teacher-centered strategy (ET) in the second plan (four pre-service teachers).

* Pattern 2: using a student-centered strategy (GDT and OIT) in the first plan followed by a revised student-centered strategy (GDT) in the second plan (one pre-service teacher).

* Pattern 3: using a teacher-centered strategy (ET) in the first plan and repeating this strategy in the second plan (four pre-service teachers).

A majority (five) of the pre-service teachers showed a development of this PCK category. Two main factors can be indicated in the beginning of the teaching period: the teacher course and the mentor at school. The first factor caused a preference for student-centered teaching strategies, while the second factor caused a preference for teacher-centered strategies. Neither factor was more dominant; each of them was related to about the same number of pre-service teachers. At the end of their teaching period, the most dominant factor influencing the pre-

service teachers was their own classroom teaching experiences which prompted a preference for teacher-centered strategies among nearly all pre-service teachers. Their remarks suggest that they were confronted with the pressure of the expectations of their mentors and their classes to teach in the familiar way, that is, expository teaching, and the pressure to teach a topic within a short period of time. Finally, we conclude that there a weak match between the teaching strategies mainly used in the schools and the strategies that are emphasized in the teacher course units.

The findings about *PCK of presenting practical work* (teacher demonstrations, student experiments) indicated that a majority (five) of the pre-service teachers showed a development of this PCK category. This development includes the deletion of any demonstrations or experiments (done by three pre-service teachers) or the replacement of experiments by demonstrations (done by two others). Deleting demonstrations or experiments can be influenced by time pressure experienced after teaching in their own classrooms. Replacing experiments by demonstrations can also be influenced by time pressure but to a lesser extent or can be related to the development of PCK towards a teacher-centered teaching strategy. A minority (four) of the pre-service teachers did not show PCK development. The absence of this development includes the continuation of incorporating student experiments (by one pre-service teacher) or the continuing lack of any practical work (by three pre-service teachers). We consider that the continuation of offering student experiments belongs to the continuation of a student-centered teaching strategy by the pre-service teacher under consideration. Regarding the continuing lack of using any practical work, we assert that this can be explained by the actual time pressure in the teaching period and the perceived time pressure before this period.

The findings about *PCK of presenting representations* (drawings, schemes) of subject matter indicated that five pre-service teachers incorporated representations in one or both lesson plans. One of them (PT 3) repeated the same type of representation in the second plan. Two of them (PT 2, 4) used representations in their second lesson plan for the first time, while some others (PT 7, 9) did not repeat any representation in their second lesson plan. In conclusion, a minority (four) of the pre-service teachers showed a development of their PCK of presenting representations of electrochemistry topics, although not in the same direction. Four pre-service teachers (PT 1, 5, 6, 8) did not use any representation at all in their plans. Maybe they omit this use because of expected or experienced demands on their teaching time.

The findings about *PCK of students' difficulties* in understanding electrochemistry topics indicated that only a minority (four) of the pre-service teachers showed a development of this PCK. They pointed out the influence of the teacher course unit on 'misconceptions in chemistry' as well as the influence of their personal learning difficulties in understanding electrochemistry. Indications of the influence of their own teaching experiences on the second lesson plan were lacking. This is somewhat surprising because, in their lessons about electrochemistry topics, the pre-service teachers will have encountered a variety of students' difficulties in understanding the topics. Moreover, as De Jong, et al. (2005) found, pre-service teachers are able to detect the main learning difficulties of their students after the lessons and to write reflective reports about these difficulties. The present teacher course also included reflective meetings for sharing teaching experiences with peers and for reflecting on their teaching practice. It can be concluded that these meetings did not significantly contribute to pre-service teachers' learning about students' difficulties from own teaching experiences.

To conclude, we present some implications for science teacher education from this study. Firstly, we will remark that course work and teaching in practice schools are essential component of these programs. However, for many pre-service teachers, the influence of the teacher course decreases throughout the program, while the influence of the practice school (mentor, own classroom teaching) increases. Moreover, a gap between teacher course 'theory', (mainly emphasizing student-centered strategies) and school 'practice' (mainly emphasizing teacher-centered strategies) is seen. To try to bridge this gap, we recommend designing pre-service teacher education programs that integrate to a large extent the activities in workshops and seminars with the activities in the practice schools. For instance, the pre-service teachers could be encouraged to analyze the content of school textbooks in detail and critically, especially when preparing lesson plans, and to discuss the results with their peers, their university supervisor and their school mentor.

Secondly, in line with the former suggestion, it would be useful to enhance the intensive and regular cooperation between supervisors at school and mentors at school. These mentors could be invited to participate in teacher course workshops that are focused on a number of different teaching strategies, especially student-centered strategies. Other workshops could include the fruitful use of student experiments, teacher demonstrations, and laboratory management.

Thirdly, we assert the importance for pre-service teachers to develop sufficient PCK of student' difficulties in understanding subject matter. In the teacher course, pre-service teachers could be asked to discuss articles about students' learning difficulties and how to take these difficulties into account. They could also be invited to reflect on their own learning experiences as a student at school and university. In the practice school, pre-service teachers could be asked to analyze students' response to written tests or interview questions.

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