

Maija AHTEE, Tuula ASUNTA, and Helena PALM
University of Jyväskylä, Department of Teacher Education

STUDENT TEACHERS' PROBLEMS IN TEACHING 'ELECTROLYSIS' WITH A KEY DEMONSTRATION

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ABSTRACT: This study is concerned with student teachers' conceptions about teaching the topic of electrolysis and difficulties they encounter. The aim of the study was also to find out how the student teachers understand the meaning of a key demonstration that would show the main features of the phenomenon. During this study eight chemistry student teachers were invited to write a lesson plan on the topic of electrolysis for lower secondary level, grade 8 pupils (age 14 to 15). The written lesson plans and the semi-structured interviews were collected and analysed by using a set of analytical categories. Only two of the eight student teachers had a clear view that electrolysis is a process where an electric current drives the reaction in a non-spontaneous direction. The role of the key demonstration was rather to attract interest than to activate thinking. Furthermore, the student teachers had difficulties to connect the previously taught concepts to electrolysis to form an integrated whole. The student teachers were concerned about their subject knowledge and they expressed their need to read more about the subject in order to be able to teach it properly, but only one was particularly worried whether her pupils would learn this topic. [*Chem. Educ. Res. Pract. Eur.*: 2002, 3, 317-326]

KEYWORDS: student teachers; electrolysis; lesson plan; lower secondary school; key demonstration; pedagogical content knowledge

INTRODUCTION

In science teacher education, it is important to be aware of the existing ideas and concerns that student teachers have about teaching particular curriculum topics. This paper presents how chemistry student teachers plan to teach the topic of electrolysis and their worries related to it. This is a continuation of the international study of de Jong (1998) and de Jong *et al.* (1999) focusing on pedagogical content knowledge and teaching concerns of prospective science teachers.

Chemistry teachers' content knowledge forms the basis for formulating and presenting particular chemistry topics in a comprehensible way to different pupils. This also means that the student teachers have to possess deep understanding about the nature and structure of chemistry. As student teachers start their pedagogical studies after studying at the Department of Chemistry they tend to concentrate on clarifying their own knowledge on the topic, on discovering the connections of the topic to general structure, devising suitable demonstrations to illustrate the main features of the phenomenon in question, and so on. When student teachers prepare themselves to teach a specific topic, it is important that they identify and clarify the unique problems of the topic (Nussbaum, 1997). But they tend to see teaching

more as the transferring of content knowledge than as a way to help pupils to understand specific subject matter i.e., in constructing meanings. The latter includes knowledge of how to organise, represent and adapt different issues in the specific topic to the diverse interests and abilities of pupils. It also includes knowledge of teaching methods suitable for the topic, of the points which make the topic easy or difficult, of pupils' typical misconceptions, and strategies effective in changing misconceptions. The pedagogical content knowledge, PCK, includes all the knowledge which a (chemistry) teacher needs in order to teach a subject (chemistry) effectively. In teaching a certain topic the teacher has to synthesize subject matter knowledge (factual, procedural, syntactic), pedagogical knowledge (aims, students' learning and understanding, instructional strategies, assessment, classroom management) and contextual knowledge (students, school, community) into a meaningful compound to be presented during the chemistry lesson. The acquisition of PCK is thus a central task in learning how to teach (Shulman 1987; Geddis 1993, Magnusson *et al.* 1999).

Van der Valk and Broekman (1999) point out that planning a key demonstration will urge student teachers to reflect on their knowledge of subject matter in a new way, namely to compare it to their knowledge of school science and to pupils' ideas. Furthermore, as Woolnough (1994, p. 87) comments, "*Apart from the cognitive benefits, with the teacher talking through a scientific principle around the demonstration experiment to focus students' attention, the affective benefits of a memorable demonstration can be considerable.*" One of the main questions for the student teachers is to identify what kind of demonstrations would show the main features of the phenomenon that they have to teach. The key demonstration should also get the pupils interested in the topic and activate their thinking process, which does not happen if the pupils are not willing and committed.

We chose the topic of electrolysis for four main reasons. *First*, electrolysis has proved to be a difficult topic for pupils to learn and also for teachers to teach. Among the chemical topics and concepts which cause most students difficulties are oxidation and reduction, chemical equilibrium and mole (Finley *et al.* 1982; Butts and Smith 1987). Furthermore, high school students have difficulties in understanding electric current (Garnett and Treagust 1992). *Secondly*, electrolysis can be detected through colour transformation or bubble formation or some material being covered with another. Therefore, it contains themes that can easily motivate the eighth graders to ask questions and start to look for possible explanations. *Thirdly*, electrolysis has everyday applications which should be familiar to the student teachers, such as electroplating or cleaning of metals. Our *fourth reason* is that when the word "electrolysis" is mentioned, most of the pupils think that it has something to do with physics and students do not readily integrate their knowledge across physics and chemistry (Taber 1998).

At the University of Jyväskylä the student teachers in chemistry carry out their pedagogical studies after their studies at the department of chemistry. This means that they are accustomed to think and explain reactions at microscopic and symbolic level. However, at lower secondary level the pupils (13 to 15 years) have more or less their first introduction to chemical phenomena and they should be given as truthful and complete picture as possible about what can happen in a certain phenomenon at macroscopic level. This picture should also lead the pupils toward explanations at microscopic level. This means that in the pedagogical studies the student teachers should be guided to look at the learning and teaching problems in a certain topic from the pupils' level and point of view so that they can adjust their own knowledge of chemistry accordingly. For this we need to know the student teachers' subject matter knowledge and their ideas about the pedagogical form that is suitable to the particular group of pupils.

In this study our main research problem “*What kind of difficulties and concerns do the student teachers have when planning to teach electrolysis?*” was divided into two sub-problems:

1. What kind of needs do the student teachers have as to their subject knowledge related to electrolysis?
2. What kind of needs do the student teachers have as to their pedagogical content knowledge?

METHOD

Student teachers participating in the study

Eight student teachers (five females and three males; average age 23) were involved in this study. They all had chemistry as their major subject and four of them had physics as a minor subject. All of them were at the end of their chemistry studies; they had studied chemistry at least 50 study weeks during three years. The topic of electrolysis they had approached as a part of electrochemistry: - the courses of analytical chemistry (Harris, 1999) and physical chemistry (Atkins, 1998). As to their pedagogical studies the student teachers had carried out the basic general pedagogical studies (approximately 20 study weeks) and were now starting subject oriented pedagogical studies and teaching practice. Their other minor subjects were mathematics, computer science and biology. Four of them had some previous teaching experience, which varied from seven hours to six and half months. Four of them had no teaching experience except at the university training school during their studies.

Collection and analysis of the data

The student teachers were invited to draw up individually plan for a 45-minute lesson on the topic of “*electrolysis*” for lower secondary level, grade 8 pupils (aged 14 to 15) and start their lesson by *using a key demonstration*. Key ideas in a certain topic of chemistry lesson can differ significantly from key ideas in teaching this topic at lower secondary level. Key ideas in a certain topic stand for the logical structure of the discipline whereas in teaching this topic among other things students' preconceptions and learning difficulties have to be taken into account. According to Kagan (1992) secondary pre-service teachers do not have adequate knowledge of the key ideas in their disciplines, and they lack understanding of the organisation and connectedness of topics in their discipline. Kagan also points out that pre-service teachers tend to create plans that attempt to accomplish too much and often undertake activities that are too complex.

The student teachers had one and a half hours to draw up their plan without the use of books or other material. It is known that in planning their lessons the teachers are inclined to follow the textbook they are using (Sánchez & Valcárcel, 1999). We wanted the student teachers to use their own creativity and therefore the availability of a textbook could prevent the student teachers to plan a lesson of their own (van der Valk & Broekman, 1999). They were instructed that during the previous lessons the reactivity of metals, oxidation and reduction, and electrochemical activity had been introduced to pupils. On the following day the student teachers had to fill a questionnaire and attend a half an hour semi-structured individual interview that was tape-recorded.

The student teachers' statements were tape-recorded during the interview and transcribed into protocols. These protocols were compared with the written lesson plans and

questionnaire answers. All this information was read repeatedly and analysed in an iterative way by using the following categories:

1. Knowledge of the topic
2. Reasons for selecting the key demonstration
3. Proposed teaching sequence and pedagogical content knowledge
4. Expected difficulties and concerns

RESULTS AND DISCUSSION

1. Knowledge of the topic

Only two of the eight student teachers took as their starting point the fact that electrical energy causes a chemical change. They connected electrolysis to the process in which a flow of electrons causes reduction at the cathode and oxidation at the anode, and thus they paid attention to the fact that the ions in the solution acted as current carriers. Here is a short description of one of the plans:

The student teacher has the equipment needed for the demonstration ready and he starts his key demonstration by switching the electric current on. He uses $ZnCl_2$ - solution and he draws the picture of this arrangement of apparatuses on the blackboard. Then he starts looking for the most important questions with the pupils. He wants the following questions to be asked and if pupils do not ask them he himself will:

- *Why does the reaction only start when the electric current is switched on?*
- *How does salt behave in water solutions?*
- *You observed bubbles at one of the electrodes; why is that?*
- *You also observed something at the other electrode; why is that?*

Then he draws Zn^- and Cl^- ions to the electrolysis vessel and explains the meaning of the anode and the cathode and presents the reaction equations.

Three student teachers did not present electrolysis properly; they either did not give a proper definition or presented their demonstration superficially. And the other three student teachers did not explain what electrolysis means, neither did their key demonstration function properly. For example, one described the set-up of the demonstration briefly: *Iron electrodes connected to a 4.5 V battery and set in a $CuSO_4$ solution.* He did not explain what could be seen but only wrote: *“Then we will wait to see what happens.”* One described a salt bridge demonstration, which is fairly complicated as a first introduction to electrolysis. Probably it was just a demonstration which came to her mind from her recent chemistry studies. Another student used a set-up – a copper plate in $CuSO_4$ solution – probably trying to recall an experiment in which copper metal can be purified but he could not explain what would happen. On the other hand, five student teachers showed their understanding of redox reactions. They also wrote these reactions for the pupils. In summary it can be said that the student teachers described what happens in an electrolysis phenomenon but they did not ponder why it happens. These examples clearly show that it is very difficult even for a good chemistry student to go to the essence of the phenomenon just on the basis of their university chemistry studies.

Only two of the student teachers had drawn a suitable picture, the others only showed some parts of the necessary equipment in their drawing, usually a beaker. The student teachers had difficulties in recognizing 'the sign for the electrodes' and which ions would be present in the electrolyte solution. Earlier Garnett and Treagust (1992) found senior high

school students to have difficulties in relation to the sign of the anode and cathode, in understanding the charge on the anode and cathode as well as in predicting the products of electrolysis. Also Sanger and Greenbowe (1997) in their study found that some introductory college chemistry students believe that oxidation occurs at the cathode and reduction occurs at the anode. Some students tried to identify the anode and cathode by transferring the charge of anions and cations as the potential sign (- or +) of the electrodes. The student teachers should pay attention to their knowledge of physics e.g., how the positive and negative charge carries current in an electric field.

The variation of key demonstrations that the student teachers used were:

- 1) to plate a key or iron nail with copper (two students);
- 2) ZnCl_2 solution, electrodes not specified (one student);
- 3) NaCl solution, carbon electrodes and an indicator (one student);
- 4) CuSO_4 solution and a copper plate (one student);
- 5) CuSO_4 solution with an iron electrode and FeSO_4 solution a copper electrode (one student);
- 6) CuSO_4 solution and two iron electrodes (two students).

Two demonstrations were explained well (plating of a key with copper and use of ZnCl_2 solution), but these were familiar to the student teachers, either from their teaching experience or from their ongoing teacher training. The last three demonstrations were not properly described and they would not be suitable as key demonstrations anyway.

2. Reasons for the key demonstration

The student teachers' reasons for selecting the key demonstration could be divided in two categories:

- Concrete observations can be made (four students): *The electroplating of a key by copper is a concrete and practical example and one can easily see that something happens when running this experiment.*
- The remembered one (five students): *This was the first one that I remembered.*

In the answers in the first category the student teachers pay attention only to the external properties of the demonstration. They do not focus on whether the critical points for understanding the electrolysis phenomenon are present or not. The answers in the second category also indicate that the student teachers have not thought why this demonstration has been shown to them. They only tried to memorise what could possibly happen in the demonstration.

When we tried to get the student teachers to respond to the questions, such as what kind of properties the key demonstration should have, or why a key demonstration is useful or necessary, the student teachers did not specify how their key demonstration would help pupils to understand electrolysis. The student teachers did not see how their suggested demonstration would enhance the accessibility of the content of electrolysis to the pupils by serving as anchor for their cognitive structures. They did neither think the key demonstration as a useful reference to reveal pupils' misconceptions or learning difficulties. Only one student teacher commented that the pupils would recognise that in electrolysis an electric current affects on the composition of compounds. The student teachers mainly mentioned general reasons like: to arouse pupils' interest, to lead in to the topic, to visualise the phenomena, to motivate the pupils to learn, to help the pupils to learn, and to compel the pupils to think what happens. Five student teachers stressed only the experiential significance for a key demonstration:

- *It should arouse pupils' interest and they should see that something happens.*
- *It should be such that pupils would remember something later on.*

Four student teachers also saw that a key demonstration should have a character to arouse thinking without giving it a distinct role:

- *It should be simple, easy enough and practical. It should arouse interest and pupils would remember it and such that the respective knowledge can be used later.*
- *It should visualise the phenomenon and arouse questions.*

3. Proposed teaching sequence and pedagogical content knowledge

In the introduction to the topic of the lesson one student teacher wanted to revise the reactivity of metals, oxidation and reduction and electrochemical series, *because "they are part of electrolysis"*. Four student teachers used questioning to find out what the pupils knew about reduction and oxidation from previous lessons. One student teacher clearly counted on pupils knowing what they had been taught earlier, and another used the electrochemical series as a starting point. And one student teacher did not pay any attention to the items learnt during the previous lessons. The rest three student teachers thus seemed to take it as self-evident that pupils would have learnt everything that had been taught earlier. They did not ask themselves how deeply they had learnt it and how it would help to understand electrolysis.

Two of the student teachers planned to set up the experimental equipment together with pupils and explain it while presenting it, whereas six of them had the set-up ready at the beginning and just relied that pupils would make the essential observations without any guidance. Four student teachers mentioned specific observations like gas formation that pupils may pay attention to, three of them tried also to connect the observations to the subsequent reasoning but only two focused also on the meaning of the electric circuit. Two student teachers just spoke generally about making observations, and the remaining two paid no attention to making observations. All student teachers planned to carry out the demonstration themselves and all except one were prepared to ask several questions during the presentation:

- *What happened, what was oxidising and what caused the reaction?*
- *What happened to the key, what plating did it have, and where did this plating material come from?*

Six student teachers also tried to involve pupils in discussion and activate them to ask questions about what happened in the demonstration and why. However, they did not give any examples on what kind of answers they were expecting pupils to give. It can be concluded that the student teachers were familiar with experimental work and its importance in learning science. However, many of them were operating at a fairly general level and did not concentrate on what happens in electrolysis or what is essential in understanding electrolysis.

Five of the student teachers wrote down the reaction equations on the electrodes, five discussed applications of electrolysis, and five planned to carry out more laboratory work with pupils and let them practise electrolysis. One of the latter mentioned that during the laboratory work pupils could test their own hypotheses based on the key demonstration. Two student teachers gave pupils some homework.

When student teachers were asked what pupils might think after seeing the key demonstration, we obtained the following answers:

- *They would be astonished and try to find some explanation for what they had seen.*
- *I don't know, maybe they would be interested to look at this in the textbook.*
- *When they see bubbles, they would think that something is changing into gas and the others would think why the solution is turning red.*
- *First reaction would be - terrible – and then maybe – nice, we can do something ourselves.*

It should be noticed that all eight student teachers planned to discuss with pupils during this teaching period and allow them time to think about what happened and why:

- *I would let pupils ask questions concerning the demonstration.*
- *We would think together what happened and why.*
- *We would discuss the reactions and evaluate them and I would try to present applications and examples.*

However, none of them said anything about how pupils might understand electrolysis. Most of them stressed that pupils should know about oxidation and reduction and electrochemical series and probably assumed that on that basis pupils would understand electrolysis. One of them especially pointed out that pupils would understand through practical examples and their own experiences.

When the student teachers were questioned how the pupils would understand electrolysis after teaching, four student teachers said that some pupils would understand it, one said that most of the pupils would not understand it, but there would always be one or two pupils in the class who would, and one student teacher was convinced that pupils would understand oxidation and reduction. According to two student teachers, pupils would not understand because electrolysis is an abstract phenomenon and one noted that at least his teaching would help pupils to remember the corresponding reactions.

Student teachers were fairly sceptical about pupils' knowledge of the topics or concepts taught before the topic of electrolysis. Two of the student teachers thought that pupils would understand the meaning of electrochemical series whereas according to the rest of them pupils would know almost nothing about it. Their opinions on the reactivity of metals were as following:

- *I cannot really say.*
- *That one metal is reactive and another is not.*
- *It depends how carefully the reactivity of metals has been taught to them.*
- *Pupils think that iron rusts and gold does not.*
- *That alkali metals are reactive.*
- *Pupils will know things that they have met in practise.*

To summarise, the student teachers seemed to have a fairly obscure idea of how to take into account the previously taught phenomena and concepts while simultaneously connecting chemical thinking with electrolysis. Consequently, electrolysis was treated more as an isolated example of oxidation-reduction reactions.

Expected difficulties and concerns

The student teachers taking part in this study were convinced that pupils' previous knowledge of the topic of electrolysis would be small. They expected that some pupils might have heard about different applications of electrolysis but for most of them even the word electrolysis would be unfamiliar. Altogether they considered the topic abstract to pupils and

thought that real understanding might remain slight when pupils mainly concentrated on looking at or carrying out the experiment. However, they had no special suggestions for overcoming the abstractness or for dealing with the strangeness of the topic.

Seven student teachers were worried about their own content knowledge.

- *I am worried about my insufficient subject knowledge especially at high school level.*

Six student teachers complained that they did not remember the topic electrolysis well enough or that they would need to check their facts. One confessed that she did not understand electrolysis at all. Altogether, they were inclined to rely on textbooks to help them in preparing their teaching properly. Two student teachers accused chemistry teaching at the upper secondary school of being too theoretical and that without experiments electrolysis is difficult to understand. Only one student teacher remembered that she had done some practical work on this topic at school. It is interesting to note, however, that none of them actually worried about their own understanding of electrical phenomena.

As to the presentation of the topic, two student teachers mentioned that this kind of experimental approach was new to them. In their earlier studies on the topic of electrolysis they had mainly concentrated on doing calculations. One student teacher worried that she had not had any contact with the pupils' world so that she did not know what pupils think. Another student teacher expressed the same idea by saying that her teaching experience was very small. Altogether five student teachers expressed their concern about their own development.

One student teacher was worried that she would not be able to give proper answers to pupils' questions, and the other expressed the same thing saying:

- *What worries me is that I am responsible for pupils learning.*

The student teachers were not very optimistic about what pupils would learn during the lesson. One hoped that pupils would at least remember the demonstration, another stressed that pupils should remember that electric current is needed in this phenomenon, and the third pointed out that more than one lesson is needed for pupils to learn this topic. Altogether seven student teachers expressed the need to read more about electrolysis in order to be able to teach it properly. Interestingly, only two student teachers spontaneously expressed their concerns about how to interact with pupils.

Six student teachers considered electrolysis as one of the most difficult topics in chemistry and had doubts about how to simplify the topic for pupils, for example, how to explain the reactions at the anode and cathode. Only one of the eight student teachers was not worried about teaching electrolysis and he also seemed to have the biggest deficiencies in his knowledge of this topic. In this connection one student teacher expressed her concern about pupils' attitudes towards chemistry and natural sciences. Another worried about the shortage of time for planning lessons.

- *Is there enough time to plan my teaching and will the quality of teaching suffer if I do not have enough time to plan my lessons?*

To summarise, the student teachers' concerns were directed to content knowledge, pedagogical content knowledge as well as to pedagogical knowledge, and they were partly self-oriented and partly task-oriented (Fuller & Bown, 1975). Typical concerns included lack of sufficient knowledge of the topic, how to make it understandable to pupils, failure to

demonstrate concepts or phenomena properly, insufficient knowledge of how to guide discussions, failure to plan the available time properly.

In this study, nearly all of the student teachers were concerned about their subject knowledge and they expressed their need to read more about the subject in order to be able to teach it properly. As electrolysis is a difficult and unfamiliar topic to the student teachers, it is understandable that the student teachers were more worried about their lack of sufficient content knowledge than insufficient knowledge of how to guide classroom discussions or interact with difficult pupils. It is also interesting to note that only one student teacher was particularly worried that her pupils would learn this topic. According to Fuller and Bown (1975) the main concern of experienced teachers is how pupils will learn whereas student teachers seem to worry about how they themselves will manage. However, as van der Valk *et al.* (1999) point out, concerns also depend on the context.

CONCLUDING REMARKS

According to this study there are certain aspects that should be taken into account in the basic courses for prospective chemistry teachers. We have found these exercises, which are based on student teachers' spontaneous lesson plans without textbooks or other teaching materials, very useful because they reveal both to the student teachers and to the educators many important and essential deficiencies in student teachers' knowledge. Especially the exercise of finding a good key demonstration reveals whether a student teacher looks at the exercise more from the teaching perspective or from the knowledge perspective. A good key demonstration from the knowledge point of view is connected with the logical structure of the discipline i.e. chemistry whereas a good key demonstration from the teaching point of view concentrates more on the learner's knowledge background. In chemistry studies at the university the aim is to train the students to develop new knowledge in the field whereas in teaching the main focus should be on helping pupils to understand the central concepts and ideas.

The first recommendation concerns understanding of the concepts related to the topic to be taught. In our study, student teachers were given some concepts treated in previous lessons but they seemed to assume that pupils had more or less mastered these. In order to improve pedagogical content knowledge it is important for student teachers to have practices which help them to see connections between scientific concepts. Concept mapping and V-diagramming are very useful learning techniques at all levels (Novak & Gowin, 1988). In connection with these practices student teachers will also reflect on their own conceptions. Understanding of the interconnectedness between different concepts is important as well in choosing a good key demonstration or in finding a scientific explanation for a phenomenon. These practises would be useful for all chemistry students already during their very first chemistry courses at university.

The second recommendation concerns communication related to a key demonstration. None of the student teachers suggested asking pupils to make predictions. Without making predictions the event shown in a demonstration may be remembered but the idea of what the event is supposed to mean will not be revealed to pupils. Hirn & Viennot (2000) have pointed out the same kind of unanimous absence of the idea of prediction with experienced teachers. In the connection of a demonstration pupils should be asked to make predictions, they should be asked to relate their observations and known facts to some previously introduced laws and principles. This means that student teachers should be guided to demand reasoning and explanations from pupils and not only to let pupils observe phenomena.

CORRESPONDENCE: Maija AHTEE, Department of Teacher Education, University of Jyväskylä, Seminaarinmaki, P.O.Box 35, FIN-4035,1 Jyväskylä, Finland; fax: +358 14 2601701; e-mail: ahtee@edu.jyu.fi

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