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HOW TO TEACH THE CONCEPT OF HEAT OF REACTION: A STUDY OF PROSPECTIVE TEACHERS' INITIAL IDEAS

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ABSTRACT: This paper presents a study of prospective teachers' initial knowledge of how to teach the energetics of chemical reactions. The research was designed as a naturalistic case-study. Fourteen prospective chemistry teachers were invited to individually prepare the first two lessons on the heat involved in reactions in solutions. The lessons were for grade 11 classes (age 16-17) from pre-university schools. The prospective teachers were not allowed to consult any textbook, but they were asked to incorporate two specific classroom experiments in their lesson plan. During a group meeting, the lesson plans were exchanged and discussed. Research data were obtained from audiotaped semi-structured interviews with the individual prospective teachers. In addition, their written lesson plans were collected and analysed. The group discussions were also audiotaped and analysed. The results reveal a number of interesting characteristics of prospective teachers' pedagogical content knowledge. Implications of the study for science teacher preparation courses will also be presented. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 91-96]

KEY WORDS: *prospective science teachers, pedagogical content knowledge; heat of reaction; naturalistic case-study*

INTRODUCTION

Regarding the issue of the knowledge base of teachers, Shulman (1986) has introduced the concept of pedagogical content knowledge (PCK) to acknowledge the importance of the transformation of subject matter knowledge per se into "subject matter knowledge for teaching" (Shulman, 1986, p. 9). For prospective science teachers, the science content knowledge acquired during their science studies constitutes one of the main bases from which their PCK may be derived. Another important factor influencing their PCK is their personal background, especially the memories of their own experiences with science courses when they were learners at secondary schools (Huibregtse, Korthagen, & Wubbels, 1994). However, the study of an academic discipline may not provide prospective science teachers with the kind of understanding they need to effectively transform their academic knowledge into instructional activities in the classroom (Sanford, 1988). As De Jong, Acampo, and Verdonk (1995) have indicated, science teachers' subject matter knowledge can function as a source of difficulties in teaching science topics.

Science teacher preparation courses aim at promoting the development of an appropriate PCK for prospective teachers. According to a constructivist point of view, the acquisition of PCK is considered a dynamic process in which the prospective teachers actively construct meaning from their actual experiences in connection with their prior understanding. From this perspective and in the context of designing constructivist-based courses, it is important to know prospective teachers' initial PCK.

TOPIC AND RESEARCH QUESTION

In this study, the initial PCK will regard a central topic in science teaching at upper secondary school level, viz. teaching the topic of heat involved in chemical reactions. Secondary school students experience difficulties in understanding the concept of heat. Most of the studies of their difficulties deal with understanding 'heat' in a physics context. Driver, Squires, Rushworth, and Wood-Robinson (1994) give a comprehensive review of these studies. A minority of the studies deal with students' understanding of 'heat' in a chemistry context. A comprehensive review is given by Boo (1998).

College and university students' difficulties in understanding 'heat' have also been the subject of research, although the studies are much more limited in number. Research results indicate that several difficulties in understanding 'heat' in a physics context as well as in a chemistry context exhibited by secondary school students persisted in college and university students (see e.g. Cross and Maurin, 1986; Frederik, Van der Valk, Leite, & Thoren, 1999). For that reason, these difficulties may also be present in prospective science teachers.

The present study is focused on answering the following research question:

- *What initial pedagogical content knowledge do prospective teachers exhibit regarding the teaching of heat involved in chemical reactions?*

More specifically, the present study seeks to identify prospective chemistry teachers' initial PCK of how to teach the explanation of temperature changes of exothermic and endothermic reactions in solutions, to students at upper secondary school level.

DESIGN OF THE STUDY

The participants

Dutch prospective teachers wanting to become qualified teachers at secondary schools (upper level) have to take a university preservice course. This course consists of two components: a pre-degree course (2 months) and a post-degree course (one year). The pre-degree course can be considered a first orientation to secondary school education and the teaching profession. Taken from this course, fourteen prospective teachers (eleven males and three females; average age: 22) were involved in the research project.

All participants had entered the university (on average) four years before; they were still studying chemistry and had passed several examinations on thermodynamics. They entered the research project at the end of the pre-degree course. The participants had done various workshops, for instance concerning the nature of science, the chemistry curriculum, students' preconceptions and teaching and learning chemistry topics. They had also gained a two-week experience of observing and evaluating chemistry teaching in the classroom and a two-week experience of teaching chemistry by themselves. The prospective teachers were not confronted with students' preconceptions of 'heat' in a science context and had no preceding experience in observing, preparing or doing lessons on this topic.

Procedure

The participants were invited to individually prepare the first two lessons (50-minute lessons) on heat involved in reactions in solutions. These lessons would have to be suitable for a class of mixed ability students of grade 11 (age 16-17) from pre-university schools. This grade is the second year of the higher secondary level and is the third year of chemistry. The prospective teachers were told to assume that a number of specified curriculum topics had been taught beforehand, such as the qualitative meaning of exothermic and endothermic reactions (but without any explanation). They were not allowed to consult any textbook. As a substitute, they were asked to incorporate two classroom experiments taken from the (current) school textbooks and used by the prospective teachers when they themselves were schoolboys/girls. The experiments deal with the dissolving of 12 g of ammonium chloride in 100 ml of water, and the mixing of 25 ml of 1,0 *M* HCl solution with 25 ml of 1,0 *M* NaOH solution. Both reactions have to take place in an insulated container (with thermometer).

After the lesson plans had been made, during a subsequent interview, each prospective teacher was invited to explain the prepared lessons and the answers to the questionnaire. They were also asked to report their own former experiences with the topic as a learner (schoolboy/girl). All the interviews were audiotaped.

Some days later, a (regular) course meeting was organised. Because of that planned meeting, the prospective teachers were asked after each interview not to report their lesson plans to each other and not to consult any textbook. During the meeting, the prospective teachers exchanged their lesson plans and had a plenary discussion of them. The group meeting was also audiotaped.

Data analysis

All audiotaped statements were transcribed into protocols. The interview protocols served as the core data source for the study. The analysis of the data was performed using a phased procedure. In the first phase, the interview protocols of each prospective teacher were repeatedly read and analyzed in an iterative way. In the next phase, analysis results of the individuals were compared to identify common ways of explanation. The validation of the interpretations was promoted by applying the constant comparative method (Denzin, 1994). This involved the comparison of the analysis results of the interview protocols with other sources, viz. (a) the group discussion protocols, and (b) additional data, especially chemistry textbooks for school and university, to trace the possible origins of the prospective teachers' statements.

RESULTS

The prospective teachers wanted to pay attention to the classroom experiments, especially to the recorded temperature changes. They expected a temperature decrease in the case of dissolving ammonium chloride in water and a temperature increase in the case of mixing the acid solution with the base solution. They wanted to explain the semi-quantitative change of temperature by introducing a conceptual scheme involving the idea of the distinction between a system (reactants or products) and its surroundings (water). The prospective teachers indicated this basic distinction implicitly, and only described the two components themselves. The 'system' component deals with the relationship between the concepts of chemical reaction and energy (or heat), while the 'surroundings' component deals with the relationship between the concepts of energy (or heat) and temperature

In the 'system' component of their conceptual scheme, *two ways of reasoning* were distinguished, which are summarized as follows. A small majority (eight) of the prospective teachers wanted to refer to the reaction equation and used *'bond energy' as the key explanatory concept.* They wanted to point out that the breaking (or forming) of bonds requires (or releases) energy. A large minority (six) of the prospective teachers wanted to refer to an energy diagram and uses *'energy level' as the key explanatory concept.* They wanted to indicate that the difference between the level for the reactants and the level for the products reflects the requirement for (or the release of) energy. In the 'surroundings' component, only one way of reasoning is indicated. The prospective teachers wanted to point out that energy, in the form of heat, which has gone away from (or goes to) the water causes a temperature decrease (or increase).

The sequence in which both conceptual components are interconnected depends on the kind of 'system' component preferred. In the case of the 'bond energy' explanatory concept, the prospective teachers introduce the sequence: the 'system' component followed by the 'surroundings' component. In the case of the 'energy level' explanatory concept, the prospective teachers introduce the reverse sequence of the components. A summary of the proposed conceptual schemes is given in the Table.

The explanations given of nearly all prospective teachers are not quite complete. Among the teachers using the 'bond energy' concept, six out of eight only talk about the effects of bonds that have been broken, viz. in the case of NH_4Cl, or bonds that have been formed, viz. in the case of H_2O. They do not mention the forming of bonds with the surrounding water molecules in the case of NH_4^+ and Cl^-, or the preceding breaking of bonds in the case of H^+ and OH^-. They do not indicate an overall energy effect. Nevertheless, all of them have written down reaction equations including the formulas of the hydrated forms of the ions. These reaction equations are also written down by the prospective teachers using the 'energy level' concept. However, in their energy diagrams, none of them draw levels for the hydrated forms of the ionic reactants or products.

The use of the concepts of heat and energy by the prospective teachers is not always very consistent. Sometimes, both concepts are conceived as identical. For instance, the prospective

TABLE. *Summary of the proposed conceptual schemes.*

Conceptual scheme			Number of prospective teachers (N = 14)
I. Scheme involving the 'bond energy' concept			8
System component	---->	Surroundings component	
[Bond breaking/forming <--> Energy]		[Energy or Heat <--> Temperature]	
II. Scheme involving the 'energy level' concept			6
Surroundings component	---->	System component	
[Temperature <--> Heat or Energy]		[Energy <--> Energy level]	

teacher says: "The heat increases, because heat is energy, and the energy of water increases". Sometimes, the meaning of energy is varied. For instance, the prospective teacher talks about energy that becomes stored in substances or particles: "energy has gone from the water into the solid substance, into the ions"; but also talks about substances or particles that have energy: "the loose ions (. . .) together have more energy than the solid substance".

DISCUSSION AND IMPLICATIONS

The prospective teachers want to use a conceptual scheme including a system component and a surroundings component. The prospective teachers will be very familiar with this distinction because they have learnt it in thermodynamic courses and at secondary schools. This explains why they do not explicitly justify to the students the idea of constructing a system and its surroundings. However, in the case of the discussed reactions in solutions, the proposed distinction is unclear, because it suggests that water is the only substance that changes in temperature. This implies the existence of places of different temperature within the container.

The proposed distinction may cause conceptual difficulties to students, and besides, is superfluous, because the heat involved in reactions can be related to the reaction mixture as a whole. Although some prospective teachers express awareness of conceptual difficulties in distinguishing the appropriate system and its surroundings, none of the prospective teachers has pointed out that the use of the distinction is not necessary. *The influence of preceding education is probably too strong to provide them with an open mind to other views.*

Two kinds of explanatory schemes are used. Most of the prospective teachers, although the smallest majority, prefer to interpret the system from a 'reaction mechanism' point of view, by using the 'bond energy' concept. However, the largest minority prefer to interpret the system from a 'reaction composition' point of view, by using the 'energy level' concept. For that reason, the last mentioned scheme may be somewhat more closed related to the context of thermodynamics. The prospective teachers who prefer this scheme have to compare the semi-quantitative values of the energy levels for reactants and products to explain temperature changes. However, nearly all prospective teachers who prefer the 'bond energy' scheme, ignore a comparison of semi-quantitative values of the energy bond breaking and bond forming. They take into account the energetics of only the bond breaking or only the bond forming. For that reason, their proposed scheme seems to be more student-oriented than the other scheme [on condition that students understand bond energies, which is not always the case, as Boo (1998)
has pointed out]. However, this advantage is only apparent, because looking at a net energy effect is necessary as well. The incomplete reasoning of the prospective teachers may not contribute to a better understanding of heat involved in reaction. For instance, in this way, they suggest implicitly and wrongly that dissolving ionic compounds in water always is an endothermic process.

In sum, both proposed schemes have more or less the same kind of advantages and disadvantages to students. The somewhat greater popularity of the 'bond energy' scheme among the prospective teachers can be explained by their one-sided reasoning [which is not unusual among university students, as Ribeiro, Pereira, and Maskill (1990) have indicated]. This creates a model of explanation which is necessary but insufficient for developing a good understanding of the topic of heat involved in reactions.

This study has some important implications for preservice teacher education courses for science teachers. These courses should ask prospective teachers:

a) to compare thermodynamic ways of reasoning with 'school textbook' ways of reasoning;
b) to reflect on their own preferred ways of reasoning;
c) to pay attention to students' conceptual difficulties and to match these with the results of their textbook analysis;
d) to prepare lessons on heat involved in chemical reactions and to discuss these plans in small groups;
e) to carry out the lessons, to evaluate the results and to formulate intentions for future lessons.

By taking such courses, prospective science teachers could improve their pedagogical content knowledge. In order to confirm these expectations, further research in the field of science teachers' knowledge bases should be initiated.

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