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Coteaching chemical bonding with Upper secondary senior students

A way to refine teachers' PCK

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Coteaching chemical bonding with Upper secondary senior students
- A way to refine teachers PCK

By

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ABSTRACT

The aim of this study was to investigate how an experienced chemistry teacher gains and refines her pedagogical content knowledge (PCK) by cooperating with two grade 12 students (age 18) as coteachers while teaching chemical bonding in a grade 10 Upper secondary class. The study has been conducted from a sociocultural perspective, especially Vygotsky's zone of proximal development (ZPD) (Vygotsky, 1978). Other theoretical concepts and models that has framed this study are Shulman's Pedagogical content knowledge (PCK) and Pedagogical reasoning and action model (Shulman, 1986, 1987). When analysing the data, Magnusson, Krajcik, and Borko's (1999) model of PCK and the 2017 Refined consensus model of PCK (Carlson, Daehler, et al., in press) was used. Empirical data was collected by video- and audio recorded lessons, coreflection sessions, coplanning sessions and interviews. During 10 weeks, about 28 hours of video and audio recordings was collected. Selected parts of the material were transcribed and analysed in order to answer two questions:

- (1) How can chemistry teachers refine their PCK when coteaching together with senior students in an Upper secondary science class?
- (2) How do Upper secondary senior student coteachers' conceptual knowledge of representations and chemical bonding shape a teacher's foundation of personal PCK (pPCK) when teaching chemical bonding in an Upper secondary science class?

The results relating to research question one indicates that the coteachers contributed with their own learning experiences to help the teacher understand how students perceive difficult concepts. The coteachers were mediating between the teacher and the students, thus bridging the

gap between the teacher and the students' frames of references. The experienced chemistry teacher improved her understanding of students' thinking about themselves as learners of chemical bonding. Regarding the second research question, the findings showed that the creative process of reconstructing concepts of chemical bonding in the coplanning sessions meant that these were a useful tool for developing new teaching strategies and to further develop representations such as drama to illustrate chemical bonding. Together, the teacher and student coteachers, constructed a new representation that better illustrated polar covalent bonding.

Taken together, these results provide important insights into how the chemistry teacher's pPCK was refined and how the coteachers contributed to improve instructional strategies.

Keywords: coteaching, pedagogical content knowledge, pck, chemical bonding, representations, chemistry education, chemistry didactic

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SAMMANFATTNING

Syftet med studien var att undersöka om och hur en erfaren kemilärares ämnesdidaktiska kunskap (PCK) utvecklas när två äldre elever från gymnasiets naturvetenskapliga program agerade ”coteachers” i en årskurs ett klass på samma skola. Coteaching innebär att man gemensamt ansvarar för planering, genomförande och utvärdering av lektioner.

De teoretiska ramverk som studien vilar på är dels sociokulturella perspektiv och då främst Vygotsky’s ”proximala utvecklingzon” (ZPD) (Vygotsky, 1978), samt Shulman’s ”pedagogical content knowledge” (PCK, sv. ”ämnesdidaktisk kunskap”) och ”pedagogical reasoning and action model” (Shulman, 1986, 1987). Vid analyserandet av datamaterialet har Magnusson, Krajcik, och Borko’s (1999) PCK modell samt 2017 års PCK konsensus modell använts (Carlson, Daehler, et al., in press). Data består av videofilmade lektioner samt ljudinspelningar av intervjuer, planeringar och utvärderingar. Cirka 28 timmar video och ljudupptagningar spelades in under de 10 veckor som empiriinsamlingen pågick. Delar av det empiriska materialet transkriberades och analyserades för att ge svar på två frågor: (1) Hur kan kemilärare förbättra sin ämnesdidaktiska kunskap genom att ”co-teacha” tillsammans med två äldre elever på gymnasiet? (2) Hur inverkar ”elev-coteacherna’s” kunskap om olika representationer kemilärarens personliga ämnesdidaktiska kunskap (pPCK) vid undervisning om kemisk bindning på gymnasiet?

Resultatet för forskningsfråga ett visar att elev-coteacherna bidrog med sina egna erfarenheter av hur det var att lära sig kemisk bindning. Detta hjälpte läraren att förstå hur eleverna kan uppfatta svåra begrepp. Elev-coteacherna fungerade som en förmedlande länk mellan elevernas

och lärarens olika referensramar vilket gjorde att läraren fick en större förståelse för hur elever tänker och uppfattar kemisk bindning. Forskningsfråga två visade att diskussionerna tillsammans med elev-coteacherna om olika begrepp i kemisk bindning var ett bra sätt att utveckla nya undervisningsmetoder såsom drama, för att illustrera kemisk bindning. Tillsammans utvecklade de en representation som på ett bättre sätt illustrerade polär kovalent bindning. Sammantaget så visar resultaten att läraren utvecklade sin personliga ämnesdidaktiska kunskap (pPCK) vilket ledde fram till nya undervisningsstrategier.

” To learn one has to teach /.../ and to teach one has to learn”

(Daniels, 2008 p. 113)

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Halmstad, September 2018,

Felix Schultze

List of papers

Paper I

Coteaching with senior students – a way to refine teachers' PCK for teaching chemical bonding in Upper secondary school.

Felix Schultze, Pernilla Nilsson

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Paper II

Coteaching with Upper secondary senior students as a method to refine teachers personal PCK (pPCK) when co-constructing representations in chemical bonding.

Felix Schultze, Marie-Helene Zimmerman, Pernilla Nilsson

Submitted to *Research in Science Teaching*

List of abbreviations

CHAT	Cultural historical activity theory
CK	Curriculum knowledge
FontD	The Swedish National Graduate School in Science, Mathematics and Technology Education Research
IDZ	Intermental developing zone
MPRA	Model of Pedagogical reasoning and action
PCK	Pedagogical content knowledge
ePCK	Enacted Pedagogical content knowledge
ePCK _E	Enacted Pedagogical content knowledge during evaluation
ePCK _P	Enacted Pedagogical content knowledge during planning
ePCK _T	Enacted Pedagogical content knowledge during teaching
pPCK	Personal Pedagogical content knowledge
cPCK	Collectiv Pedagogical content knowledge
QSA	Qualitative content analysis
RCM	Refined consensus model of PCK
SI	Supplementary instructions
SMK	Subject matter knowledge
TPKB	Teacher Professional knowledge bases
TSPK	Topic Specific professional knowledge
TPK&S	Teacher professional knowledge and skills
VSRD	Video stimulated reflective dialogue

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1. Introduction

1.1 Background

It is well documented that many students find it hard to learn science, especially chemistry (e.g. Abell & Lederman, 2007; Osborne, Simon, & Collins, 2003; Bennett & Hogarth, 2009). There are many reasons for this and one of them is the way that science is communicated in the classroom (Garcia-Martinez, Serrano-Torregrosa, & Atkins, 2015; Herron & Eubanks, 1996; Cassels & Johnstone, 1984). To overcome this dilemma and to assist and improve student learning in science, Supplementary instructions (SI) was implemented in the school where I teach between the years 2008 and 2011. SI is a student assistance program originally developed at University of Missouri-Kansas City (UMKC) in 1973 (Arendale, 2002). In the SI session, a senior student facilitates peer-learning between students by encouraging problem solving discussions in the group. Dawson, van der Meer, Skalicky, & Cowley (2014) concluded in a systematic review and meta-analysis of literature published between 2001 and 2010, that SI positively affected undergraduate students' academic performance. At our school, the year 10 students worked in peer assisted groups each lead by two year 11 students (SI leaders). Teachers were not allowed to participate during the SI sessions to prevent students worrying of being assessed. This arrangement worked out well according to the students themselves and the SI leaders. However, the arrangement also meant that the teachers did not get to know what and how students discussed and ex-

plained different concepts in science. When I mentioned this to my supervisor Pernilla Nilsson, she introduced me to coteaching¹. Could coteaching that involves students as coteachers be a way to solve this dilemma? The idea of having a chemistry teacher coteaching, coplanning and coevaluating lessons with Upper secondary senior students evolved and finally resulted in this research project. The overall aim of this thesis is to investigate if this coteaching method can refine a teacher's professional knowledge for teaching chemical bonding. PCK, originally introduced by Shulman (1986, 1987) has become a way of understanding the complex relationship between teaching skills and content knowledge through the use of specific teaching approaches. A teacher's PCK is also strongly dependent on the teacher's experience and reflection (Nilsson, 2008). As the aim of this thesis is to investigate if the coteaching method could enhance a teacher's professional knowledge, pedagogical content knowledge (PCK) was used both as a methodological and as a theoretical framework in this thesis.

¹ I follow Kotch-Jester (2014) argument and type coteaching as a single and not as a hyphenated word: "Using coteaching as a single and not a hyphenated word stems from the work by Tobin and Roth (2002) to distinguish the act of coteaching from the act of team teaching or other models which use division of labor between two or more persons to teach. Tobin and Roth (2006) explain that the term coteaching was constructed analogous to copiloting, a work situation in which both pilots take full responsibility for all aspects of work. In doing so, they learn from each other" (p. 3)" (Kotch-Jester, 2014, p. 9)

1.2 Coteaching

During the last two decades, coteaching has evolved as a popular teaching model in many countries, beneficial to both teachers and students (Murphy & Beggs, 2010). In Sweden, coteaching (in Swedish: “tvåläraarsystem”) is a relatively new phenomenon and practiced mainly at the elementary level. However, the concept “team teaching” was explored as early as the 1960’s as one way of improving teaching and learning in the United States (Trump, 1966). Although most research on coteaching has been done in the last 20 years (Murphy & Martin, 2015), there was research conducted as early as the late 1980’s, mostly in relation to specialized teaching, such as special needs education (Cook & Friend, 1995). Today, there are a large number of books and research papers describing coteaching. In a simple search in the UniSearch data base for the word coteaching or co-teaching in the title of published research literature, academic journals and reports resulted in 6737 hits (2018-07-23).

The coteaching team can be composed in many ways depending on the coteachers’ background, teaching purpose and student needs. For instance, the team can consist of a science teacher teaching together with a non-science teacher, or a special needs teacher with a classroom teacher. Coteaching is also often practiced with a student teacher and an experienced teacher as coteachers. Thus “Learning to teach” has become a central aspect in coteaching (Roth, Tobin, Carambo, & Dalland, 2004). The purpose of coteaching is “to reduce the theory–practice gap in teacher education, to improve reflective practice in the classroom, and to develop further teachers’ pedagogical content knowledge” (Murphy & Martin, 2015, p. 277). Important elements in coteaching are the coevaluating and

coplanning process (se figure 1). To plan, evaluate and exchange ideas for lessons is rewarding not only for the teachers involved, but also for the students.

Figure 1. The three interacting steps in coteaching

Several studies describe the impact of coteaching on students' performance (Tobin, 2006; Roth et al., 2004; Scruggs et al., 2007). In a large quantitative study between the year 2004 and 2008 in Minnesota, U.S.A., involving more than 9.800 K-6 students, Bacharach, Heck, and Dahlberg (2010) showed a statistically significant improvement of academic outcomes in reading and mathematics for student in cotaught classes compared to students in non-cotaught settings. The number one advantage that students experienced was that they got assistance when needed (Bacharach et al., 2010). Another major benefit reported in this study was that having two different teaching styles in the classroom turned out to be beneficial, both for the student teacher and the cooperating teachers (Bacharach et al., 2010). In a study of 120 primary schools in Northern Ireland, Murphy,

Beggs, Carlisle, and Greenwood (2004) showed a positive impact on the students' attitudes towards science when science student teachers, with more content knowledge in science, cotaught with an experienced classroom teacher with more pedagogical (content) knowledge. They also noted benefits for the student teachers – considering confidence and teaching practice– and for classroom teachers' professional development (Murphy & Beggs, 2010). This is also in line with Roth et al., 2004, who found that a student teacher and an experienced teacher collectively provided more resources for learning. However, the number of studies where teachers cooperate with students as coteachers are limited. In the three studies that I identified, one was performed in a 10'th grade class with special need students in science (Grimes, 2010) and two related to mathematics lessons. Jackson and Philips, (2010) study in a 7'th grade class and Woodburn's, (2010) study in a 9'th grade class involving students with different ethnic backgrounds. All three studies reported improved teaching and student performance as a result.

Searching for studies describing the impact of coteaching on teachers' PCK, resulted in 3 hits (UniSearch, 2018-07-23) in titles containing the word coteaching and pedagogical content knowledge (PCK), and coteaching and PCK in abstracts resulted in 12 hits (ERIC, 2004-2017). This simple database search should of course be interpreted carefully but might indicate a lack of research studies focusing on describing the impact of coteaching on PCK compared to the overall research performed on coteaching.

1.3 Challenges in teaching chemistry in Upper secondary school

Johnstone (1991) suggested that one reason why students find it difficult to learn chemistry is that they are presented to three different domains of meanings; the macroscopic domain (visible), the submicroscopic domain (molecules and atoms) and the symbolic domain (e.g. chemical formula) illustrated in “Triangle of meanings” (p 78). Students are often expected to handle all three domains of meaning at the same time, rather than handling one domain at a time (De Jong & Taber, 2014). The same authors suggest that to avoid student difficulties in switching mentally between the three domains, the teacher should be very explicit in specifying when shifting focus between the domains of meaning. De Jong & Taber, (2014) summarized students’ conceptual difficulties in three interrelated factors: the ‘student factor’, ‘the chemistry content factor’ and the ‘teacher/textbook factor’. The student factor, they argue, concerns students’ already existing conceptions, often deeply rooted in their everyday lives. The chemistry content factor concerns students’ lack of knowledge of models as representations and the teacher/textbook factor concerns when teachers tend to use expert language in classrooms and that textbooks authors are not always aware of students’ alternative conceptions.

One of the difficult and abstract “core” concepts in chemistry is chemical bonding. It involves making sense of different models, explaining different features of actual observable phenomena at the macroscopic level, such as melting temperature or solubility in solvents (De Jong & Taber, 2014). There is a wide range of research literature describing student learning difficulties in chemical bonding (e.g. Ünal, Çalık, Ayas, &

Coll, 2006; Taber, Tsaparlis, & Nakiboğlu, 2012; Nicoll, 2001). In addition, there are studies concerning how Swedish textbooks explain and use different models and metaphors to illustrate chemical bonding (Bergqvist, Drechsler, De Jong, & Rundgren, 2013) and concerning the teachers' pedagogical content knowledge, PCK to teach chemical bonding (Bergqvist, 2012). These studies indicate that many of the student's misunderstandings of chemical bonding are due to how it is presented in school textbooks. Bergqvist's (2012) results also show a gap between students understanding of chemical bonding and teaching practice. She found several examples of when the teachers were not able to specify students difficulties in understanding (Bergqvist, 2012, p. 40). Similar to this, Levy Nahum, Mamlok-Naaman, Hofstein, & Taber, (2010) concluded in their review:

there is a huge gap between what we know about learning the chemical bonding concept and what has been implemented in educational systems. We have shown that the traditional approach to the teaching of the concept is strongly embedded in teachers' thinking and in the various curricular approaches around the world. (p. 202)

The citation highlights a serious dilemma of the gap between what research has shown is difficult about learning the concept of chemical bonding, and what is actually taught in the classroom. It confirms the assumption by De Jong & Taber, (2014) that ideas once acquired seem to be persistent and "is in effect being taught by one generation of learners to the next when some of them become teachers themselves" (p.4)

2. Theoretical background

2.1 Sociocultural theory

The theoretical framework for this thesis is grounded in the sociocultural tradition which Daniels (2008) defines as “unified in its focus on the development of an understanding of the social formation of mind” (p. 51). The interaction observed within a group of learners working together is situated within a special historical, institutional and cultural context, commonly referred to as Cultural Historical Activity Theory (CHAT), proposed by the early twentieth century Russian psychologists’ Lev Vygotsky, Alexander Luria, A.N. Leontiev and their students (Miller & Xinuin, 2005). Human learning and thinking are parts in activities situated in social practices. In order to study human learning, one has to study these social activities of meaning making (Säljö, 2013). What makes us social beings is our ability to learn and understand how other individuals think when we interact, known as *intersubjectivity*, a kind of mutual understanding (Säljö, 2015). As opposed to a computer or a schoolbook, a teacher can establish intersubjectivity with the student, thus guiding them in the process of appropriating knowledge and skills (Säljö, 2015). Murphy, Scantlebury & Milne, (2015) argue that intersubjectivity is central in coteaching when “coteachers share expectations and feeling of a common world” (p. 285). In doing so, Murphy et al., (2015) state that language “lies at the very heart of learning through coteaching” (p. 285) which also is in line with Vygotsky (1978) who identified language as the most important mediating cultural tool. However, Vygotsky’s meaning of language should be under-

stood as a semiotic system of “signs” used as a mediating tool to understand, describe and analyse the world (Säljö, 2013). Examples of semiotic systems are e.g. metaphors and analogies. The importance of classroom dialogues and the use of language as a tool for reasoning and creating new knowledge are described by Mercer & Littleton (2007). Their research has shown that when teachers focus on children’s language it can lead to significant improvements in childrens’ problem solving and curriculum learning. They even speculate that the quality of the dialogic process between the students and teacher are more important for student success than the capability of the individual student or the skill of their teachers.

One of Vygotsky’s most widely used ideas is the Zone of Proximal Development (ZPD). ZPD is generally defined as the difference in a person’s independent problem solving and problem solving with assistance (Vygotsky, 1978). The main dimension of ZPD, Daniels (2008) argues, is the link between concepts generated spontaneously, or the everyday and the scientific concepts that develop through teaching. The ZPD brings together the progress in learning of the individual from social to individual internalization and meaning making (Mortimer & Scott, 2003). However, Wells (1999) stated that it is not always a more capable other that is required to work in the ZPD and Moll (1990) suggests that:

focus should not be on transferring skills as such, from those who know more to those who know less, but on the collaborative use of mediational means to create, obtain and communicate meaning (p.13).

Thus, ZPD can be viewed as the interaction between individuals such as e.g. the student and the teacher, but also between coteachers in coplanning, coevaluating and coteaching. ZPD is created in an activity and participants can assist each other and learn from each other in the process (Wells, 1999). Daniels (2008) interprets Holzmans' (1999) aspect of ZPD were the emphasis "is on creation and transformation rather than transmission /.../ both learner and that which is being learned are mutually transformed" (Daniels, 2008, p. 24). To better describe the dynamic dialogic development between the teacher and student, Mercer & Littleton, (2007) introduced the concept of the intermental developing zone (IDZ). IDZ represents

a continuing state of shared consciousness maintained by a teacher and learner, which is focused on the task in hand and dedicated to the objective of learning (Mercer & Littleton, 2007 p. 21)

To emphasise that it is not only a transmission of knowledge from adult to child, the authors also stress that the notion of intersubjectivity in IDZ is important. This view is also supported e.g. by Wells (1999) who stated that the dialogue is co-constructed and depends and develops on intersubjective agreement. Murphy et al., (2015) conclude that Vygotsky's theory of ZPD is an explanatory framework for understanding how and why coteaching works. In their coteaching pilot study involving pre-service teachers and in-service teachers Murphy et al., (2015) identified 6 elements of Vygotsky's ZPD that could be used to examine the development in coplanning, copractice and coevaluation, see table 1. The first Vygot-

skyan element in ZPD, the authors identified when coplanning is an “Interaction between real and ideal”, meaning that the coteachers, supported by the teacher educators, identify “ideal” practice based on theories about learning science in order to test theory in practice. Vygotsky (1978) explained the ZPD as “the functions that has not yet matured but are in process of maturation” (p.86) and named them “buds” or “flowers of development”.

COTEACHING PHASE	VYGOTSKIAN ELEMENTS
COPLANNING	<ul style="list-style-type: none"> • Interaction between real and ideal forms • Buds of development
COTEACHING	<ul style="list-style-type: none"> • Vygotskian imitation • Unity of affect and intellect
COEVALUATION	<ul style="list-style-type: none"> • Regression/recursion • Structured reflection

Table 1. Elements of Vygotsky’s ZPD in different coteaching phases.
After (Murphy et. al., 2015 p. 286)

The best learning occurs in the ZPD, and when coteachers coplan and share ideas they have to identify and develop these “buds” (Murphy et al., 2015). One coteacher can emulate the other coteacher if their teaching is nearer the ideal, thus expanding their agency, identified by Murphy et al. (2015) as the “Vygotskian imitation”. The “unity of affect and intellect” is the emotional engagement, an essential element of learning in Vygotsky’s theory. Murphy et al. (2015) propose that regression in the element of “regression/recursion” is the key element to “deep learning” and define recursion as when “the learners revert to an earlier stage and progress /.../

in effect they relearn” (p. 288). The authors stress that “Structural reflection” in the coevaluation requires that coteachers reflect how their practice was progressing towards the “ideal”. Murphy et al., (2015) found that “Interaction between real and ideal”, “Vygotskian imitation” and “Structural reflection” were the most used Vygotskian elements in their study.

2.2 Pedagogical content knowledge, PCK

What are the skills that teachers need to teach well? Nowadays, most people would agree that specific subject matter knowledge (SMK) is not enough to be an excellent teacher. In a research review by Van Driel, Berry and Meirink (2014), the authors conclude that teachers often “demonstrate misconceptions similar to those of their students” (p. 851) and that no clear relationship between SMK and other teacher characteristics such as attitude and confidence exists. However, the same authors also conclude that some studies found that SMK improves through teaching. There is a consensus that teaching requires knowledge from different sources (Fernandez, 2014) and that these knowledge sources may differ and have a variety of origins both from theoretical and on a regular teaching practice (Van Driel et al., 2014). Fenstermacher (1994) discusses the nature of teacher knowledge from the epistemological point of view by stating four questions: (1) What is known about effective teaching? (2) What do teachers know? (3) What knowledge is essential for teaching? (4) Who produces knowledge about teaching? The first questions, Fenstermacher classifies as a formal teacher knowledge, as it appears in behavioural science research. Referring to Gage (1978), Fenstermacher states that “teaching

should not be a science but that it is an art based on science” (Fenstermacher, 1994, p. 7), referring to psychology. The second question, he classifies as practical teacher knowledge with research investigating what teachers know as a result of their teaching experience. The third question addresses the work of Lee Shulman and colleague (see page 15), and the fourth question addresses knowledge produced by university-based researchers and that generated by practicing teachers (p. 6).

Fenstermacher (1994) concludes that

the critical objective of teacher knowledge research is *not* for researchers to know what teachers know but for teachers to know what they know. It is /.../ for teachers to be knowers of the known (p.50).

The purpose of educational research highlighted in this statement is that teachers should be “knowers of the known” which is line with Shulmans (1987) famous statement when defining Pedagogical content knowledge, (PCK) as “their own special form of professional understanding” (Shulman, 1987 p. 8). Since the 1980s, the emphasis has shifted from studying knowledge *for* teachers to study knowledge that teacher developed, knowledge *of* teacher (Fenstermacher, 1994). It is noteworthy that teacher knowledge is strongly interconnected with teacher beliefs e.g. personal values, attitudes and ideologies (Van Driel et al., 2014) and that “research has not found shared features of teacher knowledge valid for all teachers at a large scale” (p. 849).

The understanding of SMK was an important step for the development of PCK, (Van Driel, Verloop, & de Vos, 1998). In the late 1980s, Lee Shulman started a research program on teacher knowledge, aiming to identify knowledge essential for teaching (Fenstermacher, 1994). In two

highly influential publications, Shulman (1986, 1987) outlined a new model of knowledge base for teaching, PCK, explained as

that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding (Shulman, 1987, p.8)

According to Shulman, PCK can be understood as the knowledge the teacher will require to “grasp of both the material to be taught and the process of learning” (Shulman, 1987, p. 19). In other words, teachers’ PCK is the knowledge about students’ difficulties and misconceptions in different topics and how to prevent them, using different representations and activities (Van Driel et al., 2014). Shulman (1986) first identified three categories of content knowledge: subject matter knowledge (SMK), pedagogical content knowledge (PCK) and curriculum knowledge (CK). He later added another four categories of content knowledge: general pedagogical knowledge, knowledge of learners and their characteristics, knowledge of educational contexts and knowledge of educational purposes, values, and their philosophical and historical grounds (Shulman, 1987, p. 8). In an attempt to improve the model, several authors modified and added knowledge categories that are included in teacher knowledge e.g. Van Driel, Verloop and de Vos (1998) added the teachers “craft knowledge” as “integrated knowledge which represents the teacher’s accumulated wisdom with respect to their teaching practice” (p. 674). In 1987, Shulman also introduced the model of pedagogical reasoning and action, illustrated as a cyclic model of how the teacher and teaching are

transformed through different stages of reasoning (Shulman, 1987). See figure 2.

Figure 2. Shulman's Model of Pedagogical Reasoning and Action (MPRA)
(Adapted from Shulman, 1987, p.15 and Schultze & Nilsson, 2018)

The first stage in this model is the teacher comprehending the purposes, subject matter structures and ideas both within and outside of the discipline. This is followed by a transforming stage, allowing this knowledge to be taught by the teacher and understood by the students. Then, aspects of teaching (instruction) are evaluated and reflected upon, leading to new comprehensions of teaching and students understanding (Shulman, 1987, p. 15). Shulman's model of PCK is the foundation for research investigating teacher knowledge which also relates to the planning of lessons and instruction in the classroom (Fernandez, 2014).

Many researchers have since proposed different conceptualisations of PCK to guide their research. Grossman (1990) was the first to re-examine Shulman's idea of a knowledge base including PCK for teachers (Fernandez, 2014). In this model Grossman added "Conceptions of Purposes for teaching subject matter" and "curriculum knowledge" (Grossman, 1990, p. 5). Magnusson, Krajcik, and Borko's (1999) model, describes

PCK by its constituent parts, which they defined as: (a) orientation towards science teaching; (b) knowledge and beliefs about science curriculum; (c) knowledge and beliefs of students understanding of specific science topics; (d) knowledge and beliefs about assessment in science and knowledge and (e) beliefs about instructional strategies for teaching science (Figure 3). Magnusson's et.al (1999) model follows Grossman's model but replaces Grossman's "Conceptions of Purposes for teaching subject matter" with "Orientations to teaching science" and they also added assessment knowledge as a part of teacher knowledge.

Figure 3. Magnusson, Krajcik, and Borko (1999) model of PCK
From: (Magnusson et al., 1999, p. 99)

Magnusson's et.al model of PCK has been influential in research since 2000 (Friedrichsen, Driel, & Abell, 2011) but it has also been modified by different scholars, for example the PCK models of Park and Oliver (2008), Rollnick, Bennet, Rhemtula, Dharsey and Ndlovu (2008) and Park and Chen (2012).

Abel (2007) combined the model proposed by Grossman (1990) and the model of Magnusson, Krajcik and Borko (1999) in which the components of PCK and the knowledge base of teachers was included.

Referring to Magnusson et. al's model, the two components shown to be of most important for student learning was knowledge of student understanding and knowledge of instructional strategies and representations (Shulman, 1986; Berry, Friedrichsen, & Loughran, 2015; Nilsson & Vikström, 2015; Park & Chen, 2012).

For many years, research about PCK suffered from a lack of shared definitions and clarity about what was being studied (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015; Van Driel et al., 2014). As a consequence, researchers in the field of PCK gathered in a summit meeting in 2012 and agreed on a PCK model known as the "Consensus model of PCK" (Berry, Friedrichsen, & Loughran, 2015), see figure 4. The consensus model includes teacher professional knowledge and skills (TPK&S) and PCK (Gess-Newsome, 2015). The model is divided into canonical PCK and personal PCK, in which the former is the result from research and best practice and established by science education profession (Gess-Newsome, 2015; Rollnick & Mavhunga, 2017). Personal PCK exists within the individual and is formed through teaching, planning and reflecting on the teaching (Smith & Banilower, 2015). The canonical PCK is

further divided into Teacher Professional Knowledge Bases (TPKB) and Topic Specific Professional Knowledge (TSPK). TSPK is dependent on the topic that is being taught and includes, for instance, knowledge of instructional strategies, content representations and student understanding. Personal PCK, on the other hand, is a tacit knowledge that includes the reasoning behind and the planning for teaching “a particular topic in a particular way for a particular purpose to particular students” (Gess-Newsome, 2015, p. 36). What the student finally perceives is filtered and/or amplified through student belief, prior knowledge and behaviours.

Figure 4. Model of teacher professional knowledge and skills including PCK. (From Gess-Newsome (2015, p. 31)

One of the limitations of the 2012 consensus model was that it describes PCK in “minimal” detail, not representing the “variables, layers, and complexities of PCK” (Carlson, Daehler, et al., in press, pp. nn). The need to

further develop the 2012 model was obvious and it was reworked and upgraded in a second summit meeting in 2016 and at the ESERA conference in 2017 to the “2017 Refined Consensus Model of PCK”, (RCM) (Carlson, Daehler, et al., in press). The refined model focuses more on student learning in relation to PCK, highlighting the practice of teaching. Further, as noted by Alonzo, Berry and Nilsson (in press), compared to the earlier model, the RCM has a stronger emphasis on making explicit the different variables, layers, and complexities associated with PCK and highlighting in a clearer way the relationship between PCK and teaching practice. The revised consensus model identifies three realms of PCK – collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK), (see figure 5, p 21). The refined model illustrates a continuum with gradually increased elements of canonical PCK reaching from the highly individual ePCK in the centre to the collectively shared PCK in the outer frames of the circle. The ePCK is generated in every new moment of action, evolving in the unique classroom situation, lesson planning or lesson reflection (Alonzo, Berry & Nilsson, in press). The authors also note that the plan-teach-reflect cycle, in the centre of figure 5, occurs in two timescales, a “macro” focused in a “unit of instruction” (e.g. a lesson) and a “micro” focused “in the moment during a unit of instruction” (Alonzo, Berry & Nilsson, in press, p. nn).

Thus, the ePCK is unique to every teacher, classroom situation and teaching episode. ePCK exists in three forms: ePCK_P (for planning), ePCK_T (for teaching) and ePCK_R (for reflecting) which all both rely on as well as drive modifications to transform pPCK (Alonzo, Berry & Nilsson, in press).

Figure 5. The refined 2017 consensus model of PCK.

(After Carlson, Daehler, et al., in press)

A teachers' pPCK reflects the teacher's own entire teaching and learning experience to which others also contributed, such as colleagues, educational researchers, subject content specialist and the students (Carlson, Daehler, et al., in press). Teachers use parts of pPCK in a specific topic and classroom situation which then becomes ePCK. The exchange of knowledge between ePCK and pPCK is a dynamic flow which is filtered and/or amplified and works in both directions. This is symbolized with double arrows ($\Leftrightarrow$) in figure 5. In a lesson, teachers develop their ePCK_T

through “reflection-in-action”. Chan & Yung (2015) noted that teachers invent new instructional strategies/representations “on the spot” during the act of teaching when exposed to e.g. unexpected student responses or un-anticipated student questions. During these micro units of instruction, it is most likely that the teacher tacitly transforms the ePCK_T to pPCK (Alonzo, Berry & Nilsson, in press). However, instructional strategies created on site (in situ) may not always improve student understanding and may not be used again in the teachers’ future teaching of the topic (Chan & Yung, 2015).

The next circle reaching out from the centre is the “Learning context”. It comprises a broader educational perspective and individual student aspects such as a specific school, classroom, knowledge of students such as developmental readiness, language proficiency and motivation. The learning context separates the personal PCK from cPCK, where the latter is knowledge shared by for example educators and researchers or involve teachers at the same school that participate in lesson studies, thus transforming pPCK to cPCK. The cPCK can involve a broad range of knowledge from discipline-specific to concept-specific. The outermost circle represents the different Professional Knowledge Bases; Content Knowledge, Pedagogical Knowledge, Knowledge of Students, Curricular Knowledge and Assessment knowledge. These knowledge bases are all essential components in the teaching profession.

3. Aim and research questions

3.1 Overall aim

The aim of the study is to deepen the understanding of how coteaching with two grade 12 students (aged 18) who recently had learnt chemistry, can assist a chemistry teacher to identify students' learning difficulties and to develop teaching strategies to promote students' understanding of chemical bonding in a grade 10 (aged 16) science class.

3.2 Specific questions

Paper 1

How can chemistry teachers refine their PCK when coteaching together with senior students in an Upper Secondary science class?

Paper 2

How do the Upper Secondary senior student coteachers' conceptual knowledge of representations and chemical bonding shape the teacher's foundation of pPCK when teaching chemical bonding in an Upper secondary science class?

4. Method and research design

“The social and educational world is a messy place, full of contradictions, richness, complexity, connectedness, conjunctions and disjunctions. It is multilayered, and not easily susceptible to the atomization process inherent in much numerical research. “

(Cohen, Manion, & Morrison, 2011, p. 219)

The above citation highlights the complexity that researchers face when investigating social interaction in learning situations. Although great achievements in research have been accomplished, there is still “a lack of coherent understanding of how methodologies illuminate learning and education as a social process and how these conceptual tools work in empirical studies” (Kumpulainen, Hmelo-Silver, & César, 2009, p. 1). Therefore, the authors conclude that it is important to discuss and demonstrate how these methodologies are used.

For this study, a flexible, multiple method design was used. In a flexible design approach, the design develops during the process. Once records are collected, more specific hypothesis, or as in this study, research questions, are formed after viewing the records (Engle, Conant, & Greeno, 2007 cited in Derry et al., 2010).

4.1 Participants and settings

The study took place in a public Upper secondary school in Sweden with about 1200 students between the ages of 16 and 19. Approximately 270 of them were studying at the Natural Science Programme. The volunteering teacher Sahra (pseudonym) was an experienced chemistry- and biology teacher with 13 years of teaching experience. The participating grade 10

class (first year at the Upper secondary level) at the Natural Science programme, involved 30 students, 13 boys and 17 girls, aged 16. The two coteachers, Jenny and Tess (pseudonyms) were students from the same school who studied their third year (grade 12) at the Natural Science programme. Both coteachers had Sahra as their chemistry teacher and had completed their chemistry courses during grade 10 and 11. Jenny and Tess were highly motivated and high performing students, which also made them feel comfortable with the assignment. To facilitate their own studies, they were exempted from participating in another scheduled school project, which was mandatory for their classmates. Some minor changes in their lesson schedule was made, so that they would not miss any lessons in other subjects. Sahra, Jenny and Tess were introduced to the coteaching concept, the different roles and classrooms settings. For this purpose, a coteaching guide (Gallo-Fox, Gleason, Kotch-Jester, & Peace, n.d.) was used and partly translated to Swedish. The researcher's task was to observe, record data and not interfere during lessons, coevaluation or coplanning sessions. All students in the class agreed to participate in the study and signed (together with their parents as they were under 18) a letter of consent (see appendix 2) where the purpose and procedures of the study were fully explained. Full anonymity was guaranteed and the right to terminate their involvement at any time (without giving a reason) was explained. Sahra, Jenny and Tess also agreed to these terms.

4.2 Data collection and research design

Chemistry was taught three times a week, two 50-minute lessons and one 90-minute lesson. The 90-minute lesson was used as a laboratory practical

lesson with half the class participating at a time on three occasions during the data collection period. The topic of chemical bonding was taught for seven weeks and the topic included intra-molecular forces like ionic bonding, covalent bonding and metal bonding and intermolecular forces such as hydrogen bonding, dipole-dipole bonding and Van der Waals interaction. Data was collected from classroom practice, interviews, coreflection, and coplanning during a period of 10 weeks (October – December 2015). As illustrated in figure 6, lessons were video documented and interviews, coreflection and coplanning sessions were audio recorded.

Figure 6. A schematic overview of the research design

Video was recorded using two “compact” video cameras (Panasonic). One of the video cameras filmed in HD format and on the other, a wide-angle

lens was attached in front of the ordinary lens thus covering most parts of the classroom. The cameras were fixed on tripods in separate corners back in the classroom except when the students illustrated chemical bonding outdoors. In these instances, the activity was filmed with one handheld camera. Fixed positions of the cameras were chosen because the classroom was quite small and moving around with a camera could have been disturbing. This is in line with Heath, Hindmarsh and Luff, (2010), who stated that fixed cameras is less demanding on the students. Jenny and Tess were equipped with a small dictaphone each, which was attached to their clothes. A total of sixteen 50 minute-lessons and three 90 min lab work lessons were video-recorded and about 10 hours of coplanning and coevaluation sessions were audio recorded. The coplanning and coevaluation sessions took place directly after each lesson, and at some occasions continued the day after. In four of the coreflecting sessions, video stimulated reflective dialogue (VSRD), formed a part of the coreflection (Hargreaves et al., 2003; Schön, 2011; Calderhead, 1981). Short video clips were viewed, accompanied by discussions aimed at answering the question “what were you thinking when you did or said that?” (Rosenstein, 2002, p. 26). After each lesson, the students evaluated and reflected individually on what they had learned using their Chromebook to answer a short web-based questionnaire, 'Socrative' (n.d., <http://socrative.com/>). In 'Socrative', Sahra, Jenny and Tess created their own questions, adapted to the lesson performed. The students' reflections was used as a resource in the coevaluation discussions.

4.3 Interviews

Semi structured interviews (Cohen, Manion, & Morrison, 2011; Kvale & Brinkmann, 2014) were performed with Sahra, Jenny, Tess and the students. For practical reasons and to stimulate a discussion to generate a wider range of responses, the students in the class were group interviewed (Cohen et al., 2011). An interview protocol was constructed with the emphasis that the interviewees should speak freely as much as possible without any interruption. All interviews took place after 7 weeks, when the topic of chemical bonding was completed, but before the students received the results of their assignments. The reason for this was that we expected that a negative, or positive result on the test could influence their answers at the interview.

4.4 Selecting and analysing data

Data consist of video recordings of lessons, audio recordings of interviews, coplanning and coreflecting sessions. Short fieldnotes were taken during lessons to accompany the video recordings in order to get a brief overview of different events in the lessons. All the audio recordings of the coevaluation sessions, the coplanning sessions and interviews were transcribed in order to get an overview of the data. To limit the analysis, only relevant parts reflecting the research questions were selected and assigned to coding frames. The transcribing process was time consuming but facilitated by using 'f4transcript' software (audiotranscription.de, n.d., <https://www.audiotranskription.de/english/f4>). A transcript should not have too much information, becoming difficult to follow and assess (Ochs, 1979). The author also concludes that “a more useful transcript is a more

selective one” (p. 44). It is a matter of balance between detail and readability and thus a simplified version of Jefferson’s (2004) transcript system was used. The transcribed recordings were imported to 'f4analysis' software (audiotranscription.de, n.d., <https://www.audiotranskription.de/english/f4-analyse>) and a qualitative content analysis, QCA, was performed by assigning the material to categories of a coding frame (Schreier, 2013). The concept driven main coding frames for the first and second paper were based on two of Magnusson, Krajcik and Borko, (1999) knowledge bases: Knowledge of instructional strategies and Knowledge of students understanding. Additional coding frames for the second paper were analogies, metaphors and model-building. Text passages were underlined and assigned with a code frame, each with a different colour. An advantage of using the software was that when clicking on the coding frame, all the associated quotations was instantly retrieved.

4.5 Validity

Validity is defined as ”the degree to which what is observed or measured is the same as what was purported to be observed or measured” (Robson, 2011, p. 534). An instrument is considered valid if it captures what it is set out to capture. In this research project, validity is considered in three main areas: data collection, data analyse, and data reporting.

4.5.1 Data collection

Any study involving interviews, video recording and stimulated recall sessions has potential limitations. One potential source of bias that could affect the validity of the conclusions is when people may change their

thoughts or behaviour when being interviewed or filmed in order to present themselves in a more favourable way (Gaier, 1954 cited in Calderhead, 1981). However, camera effects are reported to be of none or low importance and this risk is often exaggerated (Heath, Hindmarsh, & Luff, 2010; Jordan & Henderson, 1995). In addition, the students' relaxed behaviour indicate that video or audio recordings did not appear to have any influence on the participants.

As Sahra was their former chemistry teacher there was a possibility that this could prevent Jenny and Tess from speaking freely. However, Sahra encouraged them to speak and discuss freely, which made them relaxed and comfortable in their roles. This was also observed through the many spontaneous comments and laughs during the video reflections.

4.5.2 Data analysing

When analysing and interpreting data, Schreier (2013) mentions two main issues of validity depending on how coding frames have been generated. If the coding frames are data driven, then validity is referred to face validity (Schreier, 2013). Neuendorf (2002) recommends using a WYSIWYG (What you see is what you get) approach to face validity, that the researcher "takes a step back and examine the measures freshly and as objective as possible" (p.115). To ensure content validity of coding frames, two other researchers in the field independently investigated parts of the coded data and any discrepancies/disagreements were negotiated between researchers until consensus was reached. To assess the reliability of the coding frames, comparisons across points in time (stability) were performed (Schreier, 2013), meaning that the coder used the same coding

frame to re-analyse the same unit after a period of time, usually 10-14 days.

To validate some of the data, a member-checking was performed by asking the participating teacher if my interpretations were correct. This also motivated the participating teacher to become more involved in the research.

4.5.3 Data reporting

External validity is a measure of how results can be generalized to the wider population, i.e. transferability of findings (Cohen et.al 2011). Schofield (1996: 200; in Cohen, 2011) suggests that generalizability is up to others to decide, and to make this possible it is important to provide a "clear, detailed and in-depth description" of the research (p. 186). Yin, (2009) argues that case studies rely on analytic generalization, not on statistical generalization. In analytical generalization, the researcher strives to generalize the results to some broader theory (Yin, 2009).

5. Summary of the papers

The overall aim of this research project was to investigate how an experienced chemistry teacher gains and refines her pedagogical content knowledge (PCK) by cooperating with two grade 12 students (age 18) as coteachers while teaching chemical bonding in an Upper secondary school. Data for the two papers was collected during 10 weeks October – December 2015.

5.1 Paper 1

The objective was to examine how the coteachers affected the chemistry teacher's knowledge of students' understanding and knowledge of instructional strategies and further, how the two knowledge bases interacted as the teacher was engaged in pedagogical reasoning during the coplanning, coteaching and coreflection on lessons on the topic chemical bonding. The teacher and the two coteachers coplanned, cotaught and coevaluated lessons in chemical bonding in a grade 10 Upper secondary class. A large amount of qualitative data was collected, consisting of interviews, video-recorded lessons and audio recordings during coevaluation and coplanning. In four of the coreflecting sessions, video stimulated reflective dialogue (VSRD) was used which means that short video clips from the lesson were viewed, accompanied by discussions. The dialogues in the coevaluation, coplanning sessions and interviews were transcribed verbatim. The transcribed dialogues were analysed and assigned using coding frames which were based on Magnusson et al's., (1999) model, knowledge of instructional strategies and knowledge of students understanding.

The findings indicate that the coteachers contributed with their own learning experiences to help the teacher understand how students perceive difficult concepts. For instance, Sahra became aware of how students might misunderstand the concept of electronegativity, where the word in itself can be a hindrance for students' understanding. With this new knowledge, Sarah developed her lesson to better meet students' understanding. Her knowledge of students' understanding was integrated with her knowledge of instructional strategies in a way that made explicit her refined PCK in an interactive manner. Also highlighted during coplanning and coreflection, was the unwillingness of students to answer questions. Students tend to believe that answering a teacher's questions carry a risk of being assessed by the teacher. The findings revealed that the students were more willing to ask questions to the student coteachers than to the teacher, probably because they did not consider the coteachers as teachers that give the grades. The coteachers shared their experience of how to answer questions from the teacher. Through the coteaching and coreflection, Sarah understood that students felt afraid of being assessed and that the use of students as coteachers could assist her in the classroom to overcome students' unwillingness to ask questions. Thus, the coteachers were mediating between the teacher and the students, bridging the gap between the teacher and the students' frames of references. The experienced chemistry teacher improved her understanding of students' thinking about themselves as learners of chemical bonding. With its particular focus on having Upper secondary school students as coteachers and "agents for change", the research project contributed with new knowledge concerning coteaching and science teacher PCK. Further, with its focus on students' reflections of what

makes science content difficult to learn, the research project strived to give a new dimension to what we know about science teacher knowledge. The coreflection and coplanning were crucial for the refinement of the teacher's PCK moving from one zone to the next in the ZPD. The results indicate that coteaching as a teaching method can be viewed as integrated in Shulman's (1987) pedagogical reasoning and action model, where comprehension and transformation of new knowledge takes place in the coevaluation and coplanning sessions. The ZPD is a useful conceptual framework to explain why coteaching works (Murphy, Scantlebury, & Milne, 2015). In this research project a model was designed to illustrate the development of PCK and how coteaching, pedagogical reasoning and action and ZPD are integrated parts (see figure 7). The ZPD in the model is illustrated as the development that occurs within the interaction between the teacher and the student coteachers in the pedagogical reasoning process.

Figure 7. An integrated model of coteaching, pedagogical reasoning and ZPD. (1) Coprehension, (2) coplan – transformation, (3) coteach – instruction, (4) coevaluate – evaluation, (5) coevaluate – reflection, and (6) new comprehension. (Schultze & Nilsson, 2018, p. 703)

As such, in this model, the ZPD is the force that drives pedagogical reasoning together with coteaching to develop PCK and meaning making which lead to new teaching strategies. To further explain the model, an analogy from physics was used where an electrical current in a wire can be generated when induced by a varying magnetic field. The ZPD is like the magnetic field, a force that drives pedagogical reasoning together with coteaching, like the 'current in the wire', to develop PCK and meaning making between the teacher and the student coteachers.

5.2 Paper 2

The focus for this study was to investigate the dynamics and transformation between an experienced teacher's enacted pedagogical content knowledge (ePCK) and personal pedagogical content knowledge (pPCK) during coplanning lessons in chemical bonding with two senior Upper secondary students.

The data collected and used in this paper was mainly audio recordings of the dialogues between the coteachers and the teacher together with parts of video recorded lesson. The concept driven main coding frames for the dialogues in this study were analogies and metaphors, model building and drama. Additional coding frames were based on two of (Magnusson, Krajcik, & Borko, 1999) knowledge bases: Knowledge of instructional strategies and Knowledge of students understanding. As such, the coding frames intended to provide evidence of the teacher's ePCK as well as her pPCK.

The results show that in the coplanning dialogues of reconstructing concepts of chemical bonding, the coteacher students revealed their understanding and misconceptions to the teacher. On the basis of this, the coteaching team selected and developed analogical dramas as a representation to illustrate chemical bonding. The dramas demonstrated chemical bonding in a better way than previous used analogical models. The results indicate that the chemistry teacher's pPCK was refined and the coteachers contributed to improve instructional strategies. The dialogue between the teacher Sahra and the coteachers Jenny and Tess is summarized in figure 2. The dynamic flow and transformations between Sahara's ePCK_p and pPCK and the knowledge exchanged between Sahra, Jenny and Tess when coplanning is illustrated with arrows (A - D). In figure 8 the ePCK is divided into ePCK_T, ePCK_E and ePCK_P, but in our example ePCK is produced in the form of ePCK_P.

Figure 8. The exchange of knowledge and interactions between the teacher and the senior student coteachers

Sahra reveals her pPCK on several occasions during the dialogue which stimulated the dialogue and ePCK_p production (A). Sahra's explanations contributed to Jenny's and Tess' subject matter knowledge (B) in order to facilitate the construction of a suitable representation. On the other hand, Jenny and Tess contributed to Sahra's knowledge of students understanding when they revealed their knowledge and misconceptions (C). This knowledge was transformed tacitly from Sahra's ePCK_p to pPCK (D). The creative process of reconstructing concepts of chemical bonding in the coplanning sessions turned out to be a useful tool to develop new teaching strategies and to further develop representations such as drama to illustrate chemical bonding. Together, they constructed a new representation that better illustrated polar covalent bonding.

6. Discussion

This study has taken a new perspective on coteaching by investigating how an experienced chemistry teacher refines her PCK by cooperating with two grades 12 students as coteachers. The findings from this study make several contributions to the current literature. First, the results show that the chemistry teacher improved her understanding of how student think about themselves as learners. Knowledge was developed in the negotiations of meaning of different scientific concepts in chemical bonding. An example of this was when Jenny and Tess tried to appropriate the concept of electronegativity and revealed that the word in itself was the source of student misunderstanding. This way of misunderstanding the electronegativity concept was new to Sahra and is not described in the literature before. Words, especially in science, are reinterpreted and understood within social practices. Wold, (1992) and Daniels (2008), stated that “there is a shared understanding in accordance both with Bakhtin and Vygotsky that meaning is dependent on the social and historical contexts in which it is made” (p 62). The electronegativity concept was created and used by scientists as a tool in another sociocultural historic context more than 200 years ago and made sense when chemical reaction was associated with substances similarities and dissimilarities and Jacob Berzelius electronegative - electropositive antagonism (Jensen, 1996). Students and teachers have different frames of references and the language to describe a scientific concept can hence be a hindrance. The example highlights the importance of teachers reflecting on the meaning of scientific concepts from different perspectives, which in this study, was facilitated by the coreflecting sessions together with the senior student coteachers. Thus, teachers

coteaching together with students facilitate new possibilities for the teacher to understand student difficulties in order to improve instructional strategies.

Second, the study revealed that the students in the class found it easier to ask questions to the senior student because they did not assess them. The coteachers acted as mediators between the teacher and the students in terms of building a shared awareness of teaching and learning chemical bonding.

Third, the senior student coteachers assisted and motivated the teacher in the ZPD when collectively reconstructing knowledge to develop representations that illustrated chemical bonding. By using the 2017 consensus model as a tool, the transformation of teacher ePCK into tacit pPCK during coplanning was illustrated. Together, Sahra, Jenny and Tess developed a representation of chemical bonding that better illustrated the concept than previous used representations. The teacher refined her pPCK in the form of instructional strategies and knowledge of students understanding.

Murphy et al., (2015) noted that the relationship issue is one of the most common problem mentioned in coteaching. The friendly and mutually respectful relationship between Sahra and the senior student coteachers was undoubtedly an important factor that made coteaching work in this study. Jenny and Tess contributed to the discussions with constructive suggestions and ideas. However, there were also occasions during the 'brainstorming' process in the coplanning and coevaluation sessions when Jenny and Tess came up with ideas or suggestions that were rejected by

Sahra. This might be due to the coteachers' lack of teaching experience, content knowledge or due to other practical reasons.

Sahra also noted that she had to think more about student learning than on her teaching during coplanning sessions. She explained: “/.../we [a colleague] think more alike (.) in a way it would have been easier but in another way maybe less creative /.../ now more time was spent to discuss concepts [in chemical bonding]”. Scientific concepts were used as a tool for communication, not as a cognitive fact to memorize, making tacit knowledge explicit. Sahra was confronted by her own practise, understanding and how she used to teach chemical bonding. She was placed in the position as a learner which provided development and change, a conclusion consistent with other research (Loughran, 2014).

Research has shown that coteaching as such is beneficial for both students and teachers (Murphy & Beggs, 2010) and the importance of reflection on teaching as an essential element for developing PCK (Schneider & Plasman, 2011). This research has focused on how *one* teacher's PCK was refined by coteaching with student coteacher. However, there is no shared features of “teacher knowledge valid for all teachers, at a large scale” because “teacher knowledge is by definition embedded in teachers' personal and professional context” (Van Driel et al., 2014, p. 849). Nevertheless, based on the findings in this research, it might be suggested that this method of coteaching could act as a teaching model for other teachers in chemistry and in other subjects to challenge taken-for-granted assumptions and for teachers to become aware of their learners' learning needs.

6.1 Implications and further research

The results presented here suggest that a coteaching model in which a teacher cooperates with senior students is a powerful way to refine a teachers PCK - not only in chemistry, but also in other subject areas. The studies showed that this teaching model could be used as an effective tool to stimulate reflection. As noted in the results, the teacher's PCK was captured and refined through her paying attention to the coteachers' views and experiences. This indicates that investigating more experienced students' reflections on teaching and learning science might improve a teacher's understanding of students' thinking about themselves as learners, as well as teachers' knowledge of how to motivate their students, represent and formulate the subject to make it comprehensible for others (i.e. their PCK).

The aim of this study was to investigate how an experienced chemistry teacher gains and refines her pedagogical content knowledge (PCK) by cooperating with two grade 12 students as coteachers, with a focus on the interaction between the teacher and the two students during the coplanning and coevaluation of lessons. Further research, expanding this study to include an analysis of the classroom interaction between the senior student coteachers, teacher and the students while teaching different chemistry topics, would be of great interest. This could also involve expanding the research questions to study how and in what way the coteachers influence teaching in class, and whether there was any difference in what kind of questions the students asked to the teacher and to the student coteacher.

In conclusion, the results support the use of coteaching as a means of improving the teaching of chemical bonding in Upper secondary schools in Sweden. Further research is needed to elucidate the mechanisms

by which coteachers influence teaching within the classroom, and to what extent these findings translate into other subject areas.

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Appendix 2 - Letter of consent

2015-09-11

Till Elever och målsmän i klass NN

En forskningsstudie i NN för att utveckla kemiundervisningen.

Den senaste tiden har svenska elevers kunskaper och möjligheter att lära sig stått i fokus och diskuterats. En av de viktigaste faktorerna för att eleverna ska få en bra utbildning och lära sig så mycket som möjligt är att de har kunniga lärare – lärare som kan sina ämnen och på ett bra sätt kan lära ut. Inom ramen för mina forskningsstudier vid Höskolan i Halmstad kommer jag att studera en undervisningsmodell där två elever från årskurs tre tillsammans med klassens kemilärare planerar, undervisar och utvärderar lektioner i kemi under några veckor med start i oktober. För eleverna i klassen innebär det i praktiken att de kommer att ha två extra lärare ("coteachers") under kemilektionerna som bl.a. kan ge ökad individuell hjälp. Genom denna metod kan de äldre eleverna (coteachers) vara en resurs för att öka förutsättningarna för de yngre elevernas lärande.

För att göra studien möjlig behöver jag göra video- och ljudinspelningar i klassrummet samt under samtal med lärare och elever relaterat till det som händer under lektionerna. Video- och ljudupptagningar kommer att ske vid några tillfällen under aktuell period och fokus kommer att vara lärarens och "coteachers" undervisning. Inspelningarna kommer att användas och analyseras i forskningssyfte för att jag i egenskap av forskare tillsammans med kemiläraren och coteacherna ska kunna utvärdera och förbättra lektionerna för eleverna. Inspelningarna kan även komma att analyseras inom forskargruppen vid Höskolan i Halmstad.

De uppgifter som samlas in kommer att behandlas enligt Vetenskapsrådets forskningsetiska principer för studier av detta slag. Vetenskapsrådets forskningsetiska principer omfattar fyra områden. Dessa områden är informationskravet, samtyckeskravet, konfidentialitetskravet samt nyttjandekravet. Informationskravet uppfylls genom den information vi ger i detta brev. Samtyckeskravet innebär att målsman till de elever som deltar i denna studie ger sitt skriftliga samtycke. Konfidentialitetskravet innebär att vi som forskare kommer att behandla uppgifter om

deltagande elever på ett sådant sätt att utomstående inte kan identifiera dessa elever. Nyttjandekravet innebär att de uppgifter som insamlats endast kommer användas för forskningsändamål. Alla deltagare i studien är garanterade anonymitet och jag kommer att byta ut namn på elever, lärare och klass. Inspelningarna kommer att förvaras oåtkomligt för obehöriga. Om du inte vill delta kan du meddela mig när som helst under studiens gång.

Vi hoppas att du/ni vill ställa upp på denna undersökning som är viktig för att ge kunskap om hur vi kan förbättra undervisningen så att fler elever finner skolarbetet roligt och värdefullt.

Det finns möjlighet att ställa frågor bl.a. i samband med föräldraträffen torsdagen den 17/9.

Ni är också välkomna att ställa frågor via mail eller telefon till mig eller någon av mina handledare (se nedan).

Vänliga hälsningar,

Felix Schultze

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Forskningsstudie om kemiundervisning med hjälp av "coteaching" på xx-gymnasiet läsåret 2015/2016

Elevens namn: _____

☐ Jag har tagit del av informationen om studien och ger mitt samtycke till att delta. Videoinspelningarna används endast inom studien och i syfte att utveckla verksamheten vid Kattegattgymnasiet.

☐ Jag har tagit del av informationen om studien men vill inte delta.

Ort datum

Elevens underskrift

Vårdnadshavarens underskrift

Appendix 3 - Skriftserielista

Studies in Science and Technology Education

ISSN 1652-5051

1. Margareta Enghag (2004): MINIPROJECTS AND CONTEXT RICH PROBLEMS – Case studies with qualitative analysis of motivation, learner ownership and competence in small group work in physics. (licentiate thesis) Linköping University
2. Carl-Johan Rundgren (2006): Meaning-Making in Molecular Life Science Education – upper secondary school students' interpretation of visualizations of proteins. (licentiate thesis) Linköping University
3. Michal Drechsler (2005): Textbooks', teachers', and students' understanding of models used to explain acid-base reactions. ISSN: 1403-8099, ISBN: 91-85335-40-1. (licentiate thesis) Karlstad University
4. Margareta Enghag (2007): Two dimensions of Student Ownership of Learning during Small-Group Work with Miniprojects and context rich Problems in Physics. ISSN: 1651-4238, ISBN: 91-85485-31-4. (Doctoral Dissertation) Mälardalen University
5. Maria Åström (2007): Integrated and Subject-specific. An empirical exploration of Science education in Swedish compulsory schools. (Licentiate thesis) Linköping university
6. Ola Magntorn (2007): Reading Nature: developing ecological literacy through teaching. (Doctoral Dissertation) Linköping University
7. Maria Andree (2007): Den levda läroplanen. En studie av naturorienterande undervisningspraktiker i grundskolan. ISSN: 1400-478X, HLS Förlag: ISBN 978-91-7656-632-9 (Doctoral Dissertation, LHS)
8. Mattias Lundin (2007): Students' participation in the realization of school science activities.(Doctoral Dissertation) Linköping University
9. Michal Drechsler (2007): Models in chemistry education. A study of teaching and learning acids and bases in Swedish upper secondary schools ISBN 978-91-7063-112-2 (Doctoral Dissertation) Karlstad University
10. Proceedings from FontD Vadstena-meeting, April 2006.
11. Eva Blomdahl (2007): Teknik i skolan. En studie av teknikundervisning för yngre skolbarn. ISSN: 1400-478X, HLS Förlag: ISBN 978-91-7656-635-0 (Doctoral Dissertation, LHS)
12. Iann Lundegård (2007): På väg mot pluralism. Elever i situerade samtal kring hållbar utveckling. ISSN:1400-478X, HLS Förlag: ISBN 978-91-7656-642-8 (Doctoral Dissertation, LHS)

13. Lena Hansson (2007): "Enligt fysiken eller enligt mig själv?" – Gymnasieelever, fysiken och grundantaganden om världen. (Doctoral Dissertation) Linköping University.
14. Christel Persson (2008): Sfärernas symfoni i förändring? Lärande i miljö för hållbar utveckling med naturvetenskaplig utgångspunkt. En longitudinell studie i grundskolans tidigare årskurser. (Doctoral Dissertation) Linköping University
15. Eva Davidsson (2008): Different Images of Science – a study of how science is constituted in exhibitions. ISBN: 978-91-977100-1-5 (Doctoral Dissertation) Malmö University
16. Magnus Hultén (2008): Naturens kanon. Formering och förändring av innehållet i folkskolans och grundskolans naturvetenskap 1842-2007. ISBN: 978-91-7155-612-7 (Doctoral Dissertation) Stockholm University
17. Lars-Erik Björklund (2008): Från Novis till Expert: Förtrogenhetskunskap i kognitiv och didaktisk belysning. (Doctoral Dissertation) Linköping University.
18. Anders Jönsson (2008): Educative assessment for/of teacher competency. A study of assessment and learning in the "Interactive examination" for student teachers. ISBN: 978-91-977100-3-9 (Doctoral Dissertation) Malmö University
19. Pernilla Nilsson (2008): Learning to teach and teaching to learn - primary science student teachers' complex journey from learners to teachers. (Doctoral Dissertation) Linköping University
20. Carl-Johan Rundgren (2008): VISUAL THINKING, VISUAL SPEECH - a Semiotic Perspective on Meaning-Making in Molecular Life Science. (Doctoral Dissertation) Linköping University
21. Per Sund (2008): Att urskilja selektiva traditioner i miljöundervisningens socialisationsinnehåll – implikationer för undervisning för hållbar utveckling. ISBN: 978-91-85485-88-8 (Doctoral Dissertation) Mälardalen University
22. Susanne Engström (2008): Fysiken spelar roll! I undervisning om hållbara energisystem - fokus på gymnasiekursen Fysik A. ISBN: 978-91-85485-96-3 (Licentiate thesis) Mälardalen University
23. Britt Jakobsson (2008): Learning science through aesthetic experience in elementary school science. Aesthetic judgement, metaphor and art. ISBN: 978-91-7155-654-7. (Doctoral Dissertation) Stockholm university
24. Gunilla Gunnarsson (2008): Den laborativa klassrumsverksamhetens interaktioner - En studie om vilket meningsskapande år 7-elever kan erbjudas i möten med den laborativa verksamhetens instruktioner, artefakter och språk inom elementär ellära, samt om lärares didaktiska

- handlingsmönster i dessa möten. (Doctoral Dissertation) Linköping University
25. Pernilla Granklint Enochson (2008): Elevernars föreställningar om kroppens organ och kroppens hälsa utifrån ett skolsammanhang. (Licentiate thesis) Linköping University
 26. Maria Åström (2008): Defining Integrated Science Education and putting it to test (Doctoral Dissertation) Linköping University
 27. Niklas Gericke (2009): Science versus School-science. Multiple models in genetics – The depiction of gene function in upper secondary textbooks and its influence on students' understanding. ISBN 978-91-7063-205-1 (Doctoral Dissertation) Karlstad University
 28. Per Högström (2009): Laborativt arbete i grundskolans senare år - lärares mål och hur de implementeras. ISBN 978-91-7264-755-8 (Doctoral Dissertation) Umeå University
 29. Annette Johnsson (2009): Dialogues on the Net. Power structures in asynchronous discussions in the context of a web based teacher training course. ISBN 978-91-977100-9-1 (Doctoral Dissertation) Malmö University
 30. Elisabet M. Nilsson (2010): Simulated "real" worlds: Actions mediated through computer game play in science education. ISBN 978-91-86295-02-8 (Doctoral Dissertation) Malmö University
 31. Lise-Lotte Österlund (2010): Redox models in chemistry: A depiction of the conceptions held by upper secondary school students of redox reactions. ISBN 978-91-7459-053-1 (Doctoral Dissertation) Umeå University
 32. Claes Klasander (2010): Talet om tekniska system – förväntningar, traditioner och skolverkligheter. ISBN 978-91-7393-332-2 (Doctoral Dissertation) Linköping University
 33. Maria Svensson (2011): Att urskilja tekniska system – didaktiska dimensioner i grundskolan. ISBN 978-91-7393-250-9 (Doctoral Dissertation) Linköping University
 34. Nina Christenson (2011): Knowledge, Value and Personal experience – Upper secondary students' use of supporting reasons when arguing socioscientific issues. ISBN 978-91-7063-340-9 (Licentiate thesis) Karlstad University
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