Exploring chemistry teachers' perspectives on questioning and providing a new way of analyzing teacher questions in science classrooms

Festo Kayima

Thesis for the Degree of Philosophiae Doctor (PhD)
University of Bergen, Norway
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Preface

This dissertation is submitted as part of the fulfilment for the degree of Philosophiae Doctor at the University of Bergen. The research work has been carried out at the Department of Chemistry under the supervision of Matthias G. Stadler and Erik C. Fooladi from January 2013 until October 2017. In one of the papers that form the present thesis, I collaborated with Prof. Arne Jakobsen at the Department of Elementary school teacher education at University of Stavanger.

The main concern of this thesis is to explore how chemistry teachers conceptualize the nature of oral questions used in teaching, and how their understanding influences their questioning practice. Also, the aim is to develop and advance an alternative method for studying and evaluating teacher questions in context.

The methodological orientation for the present thesis work was qualitative, involving the analysis of transcribed teacher talks, analysis of recorded video lessons, and a narrative review analysis. The teachers who took part in one part of the project, were recruited from within the Bergen area of Norway, and the interview sessions were conducted at the respective participants' schools. The interview data collection guide used in the part of the project that involved interviewing teachers were first submitted for approval by NSD –National centre for research, Norway.

Acknowledgements

First, with great pleasure, I would like to thank my supervisors, Mathias G. Stadler and Erik C. Fooladi. There are not enough words to use for appreciating Matthias' excellent help and guidance from the beginning to the final end of the study program. Thanks Matthias for your patience and for having always kept the door open for me. Thanks to Erik for always being there to advise especially in critical times when the best choices needed to be made. I want to thank Prof. Arne Jakobsen for offering to work with me on the part of the project.

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During my doctoral studies, I have had the opportunity to be a part of the NATED research school, where I have also received guidance and support from various experts in the field of teacher education and research, and also from other PhD students who are part of NATED. I want to thank you all. In particular I thank Prof. Kirsti Klette and Prof. Arne Jakobsen for their constructive and professional input towards my work throughout all NATED gatherings that I had a chance to be a part of.

My warmest thanks go to my mother Margret Nanozi for her patience and prayers.

I want to express my deepest gratitude to my wife, Wilter Nabankema and our two sons Ethan Elijah Kayima and Alexander Samuel Kayima for their encouragement, patience and prayers during the working years.

Finally, and of great importance, I thank the Almighty God, without whom I would not stand a chance even to write the above note of thanks to those that have positively

impacted on my reaching this far. Only one that has the power to create life and maintain it can doubt your existence. Thanks a million, and more times.

Abstract

The goals of this dissertation were, to examine how chemistry teachers conceptualize the nature of questions used in teaching, as well as how their understanding influences their questioning practice, and to explore a new way of studying and evaluating teachers' questions within the contexts in which the questions occur. The overall research work is reported in three papers which form this dissertation.

Paper I explores how chemistry teachers construe the practice of questioning and the nature of questions they use in their own teaching, and how the teachers have developed their knowledge about questioning. The aims in paper I were achieved by analyzing semi-structured interviews of eleven secondary chemistry teachers from the city of Bergen in Norway. The analysis and interpretation process was informed by Gadamer's philosophical hermeneutics (Gadamer, 2004). The results reveal that the teachers hold a dichotomous system of question types that they apply in whole-class situations. This system is simpler than most of the question classification systems used in research, and the two types, "facts"-questions and "thinking"-questions, are used flexibly in different situations for different purposes. By facts-questions teachers implied questions that request students for information that they (students) had learnt from before, whereas by thinking-questions, the teachers implied a kind of questions that ask students for their experiences (thinking, opinions or views) about a chemical phenomenon under consideration. From paper I analysis results, conflicting purposes with asking a question seem to be an important reason for why teachers ask many facts questions. The wish for communicating with their students during the lesson wins over the initiation of students' thinking.

In paper II, five out of 41 question classification taxonomies developed by different educational researchers since 1956 are analyzed. The taxonomies were developed either for use in research as systematic observation instruments, or for classroom teaching purposes. The aim of the analysis was to examine the extent to which the taxonomies could be used by chemistry teachers as a guide to formulating and using

questions as desired to achieve target objectives. The conclusions were that the taxonomies were complex and seemed inconsistent with how teachers think about questioning as established in paper I. As a result, in paper II, an alternative framework is proposed as a guide to teachers for developing and using classroom questions.

Paper III suggests an alternative methodological approach that could be used in the study and evaluation of teachers' questions based on their situational adequacy. The development process follows a review of relevant methodological approaches and frameworks for analyzing teacher discourse, along with a review of how teacher questions have been conceptualized by researchers from both the process-product and sociolinguistic (interpretive) paradigms. The resulting product is a three-step methodological approach for studying and evaluating teacher questions. It comprises three theoretical frameworks, each employed in one of the three analysis steps. The first step uses the Identification, Interpretation—Evaluation, Response (IIER) framework by Louca, Zacharia, and Tzialli (2012) to characterize the context of questions, the second step consist of a designed protocol to evaluate the questions' adequacy, and the third step utilizes a classification scheme by Anderson et al. (2001) to determine the cognitive level of questions. Results from applying the approach to teachers' questions in eight science lessons from the 1999 TIMSS-video study indicate that the approach offers a meaningful way of studying and evaluating teacher questions that opens up for new perspectives regarding, the nature of classroom aspects addressed by a teacher's questions, the moment by moment distribution of questions along different classroom aspects (content of questions), how students' reactions and needs influence the teachers' use of certain questions, and the overall value of teacher questions in a given teaching context.

List of publications

Paper I: Stadler, Matthias G. & **Kayima, Festo.** The practice of questioning in science classrooms: Perspectives from chemistry teachers. *Manuscript to be submitted to International Journal of Science Education.*

Paper II: **Kayima, Festo.** (2016). Question classification taxonomies as guides to formulating questions for use in chemistry classrooms. *European Journal of Science and Mathematics Education, 4*(3), 353-364.

Paper III: **Kayima, Festo** and Jakobsen, Arne. Exploring the situational adequacy of teacher questions in science classrooms. *Submitted to Research in Science Education.*

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1. Introduction

1.1 The conception of the topic of study

Interest in exploring teachers' questioning practices came out of my own experience as a chemistry teacher and some knowledge about questioning from education research that the practice should be conducted in a different way. Classroom teachers had been labelled "poor questioners" as from education research reports, with claims that teachers are unable to exploit the full potential of questions in teaching. Reflecting about my own teaching, I had never been concerned about the questions I ask my students, for everything seemed normal concerning asking questions and getting responses that aid to progress the lesson. It was interesting to realize that for the years I had been teaching, I had not thought about the nature of questions that I pose during my lessons, their quality and neither the rate at which I asked the questions. When I talked to some experienced teacher educators at the faculty about using questions in teaching, I noted that there were some differences in how they claimed to question their students compared to my own practice. This raised my curiosity for wanting to know about my own questioning practice as well as that of other teachers, what influences questions cause to students learning as well as the kind of ideal practice that is recommended in research.

In addition, research reports questioning teachers' questioning behaviors and claims about teachers resisting to take up research-recommended questioning techniques and advice, also made me to wonder why teachers would stick to their ways of questioning despite being regarded ineffective. I became curious as to why teachers would not take up research-generated interventions or questioning strategies in their teaching as was being claimed by researchers. There seemed to be a discrepancy between how classroom teachers construe their questioning practice vs. how questions and questioning are conceptualized in research. I thus became interested in exploring the reasons that might be behind the teachers' consistently reported ways of using questions in teaching. This was the point of departure for all the research work that was performed and which is presented in this thesis.

1.2 Teacher questioning in teaching

Asking questions during lessons occurs in almost every context where a teaching activity ensues. Teachers often use questions as tools to initiate, review and summarize lessons, motivate students and develop their interests, evaluate students' preparation for learning, nurture students' insights, and assess achievement of instructional goals and objectives (Blosser, 2000; Chin & Langsford, 2004; Christenbury & Kelly, 1983; Hargie, 1978; Tofade, Elsner, & Haines, 2013; Vogler, 2005; Wilen, 1991). As revealed in research spanning several decades (e.g.; Alison, 1994; Andersson-Bakken & Klette, 2016; Carlsen, 1993; Gall, 1970; Roth, 1996; Smith, Blakeslee, & Anderson, 1993; Stevens, 1912), teachers' classroom questions have not only defined the traditional teaching for many years (Gall, 1970), but they continue to be an important component of child-centered approaches to teaching (Chin, 2007; Roth, 1996).

From my review of the research studies conducted on the topic of questioning over the last decades (a period spanning a century), the studies could be grouped into four categories. The first category of studies are those which focused on investigating teachers' classroom questioning behaviours and the types of questions teachers use in their classrooms (e.g., Stevens, 1912). The second category includes studies that came up with several techniques for effective questioning and intervention studies aimed at training teachers on effective questioning (Wilen, 1987, 1991). The third category of studies were mainly theoretical studies, and these focused on developing systematic observation instruments for use in the study of teachers' questioning practices as one component of teachers' classroom practices (see reviews by; Gall, 1970; Riegle, 1976; Wilen, 1986), whereas the fourth category of studies were those that investigated the relationship between the types of questions teachers ask and students' achievement (see meta-studies by; Gayle, Preiss, & Allen, 2006; Redfield & Rousseau, 1981; Samson, Strykowski, Weinstein, & Walberg, 1987; Winne, 1979).

The findings and conclusions from the first category of studies are that teachers ask many questions in a typical lesson, of which the majority of the questions are of a lower-cognitive level (e.g.; Eshach, Dor-Ziderman, & Yefroimsky, 2014; Gall, 1970; Stevens, 1912). For instance, the first formal investigation about teachers' questioning practices that I found had been conducted by Stevens (1912). Stevens took stenographic accounts of 100 lessons in six subjects and followed ten different classes for a whole school day. Observation of the ten classes yielded an average of 395 questions within six to seven 45-minutes lessons which amounts to up to two questions and answers per minute over the whole school day. Although there was some variance in the frequency of questions in the individual lessons, the great majority of the 100 lessons had well over one question per minute with a maximum of almost five in one English lesson. Stevens compared teacher's and students' oral classroom activity in a set of lessons and found it to be at the ratio of 64% to 36% respectively suggesting that teachers do most of the work in classes instead of the students. These large numbers of questions per lesson indicated according to Stevens that only verbal memory and superficial judgments could be reckoned as educational assets in such a class. In addition, individual students' needs could not be catered for and learners could not become independent thinkers in such lessons. Stevens also claimed that "teachers do use the question as a means to bridge gaps and kill time during a class hour, thus perverting its legitimate and valuable function as an educational agent" (p. 2).

Several of the empirical studies conducted after Steven's work including even the most recent ones reported similar findings as those of Stevens (1912). For example, that teachers ask many questions at a low cognitive level (Andersson-Bakken & Klette, 2016; Carlsen & Hall, 1997; Dillon, 1988; Eshach et al., 2014; Gall, 1970; Graesser & Person, 1994; Lee, Kinzie, & Whittaker, 2012; Levin & Long, 1981; Redfield & Rousseau, 1981), that teachers lack skills about question asking (Anderson & Burns, 1989; Dantonio, 1990; Graesser & Person, 1994; Seymour & Osana, 2003), and that teachers' lack an awareness of research-suggested questioning techniques and question sequencing (Barnes, 1979; Brophy & Good, 2000; Lucking, 1978; Rice, 1977; Vogler, 2005; Wilen, 2001).

Research studies in the second category in which several effective questioning techniques were recommended along with a series of trainings in effective questioning, emerged as a response to the findings reported in studies in category one. From the first category of studies, researchers had concluded that teachers lack knowledge about existing questioning taxonomies that would guide them into effective use of questions, and that teachers also lack knowledge about questioning sequencing that is essential for productive questioning (Barnes, 1979; Lucking, 1978; Rice, 1977). The researchers' reasoning was that teachers could be asking questions at only one or two levels due to a lack of an understanding of the different cognitive levels of questions (Vogler, 2005). Also, a lack of an understanding of sequencing questions and techniques of delivering questions such as the use of wait time, prompting, probing, and refocusing, makes the teachers' questioning less effective (Good & Brophy, 2008). These conclusions led researchers to search for ways to improve teachers' questioning practices and hence the second category of studies.

With the assumption that teachers could improve their questioning practices if they were trained in the use of question taxonomies, efforts were made to train both pre-service and in-service teachers in the skill of questioning (Lucking, 1978; Rice, 1977; Wilen, 1984). The training programs focused mainly on raising the level of teacher questions and implementing a variety of questioning techniques (Wilen, 1984), as well as extending wait-time and reducing the number of questions asked in a unit (Rice, 1977). In Rice's (1977) study, she concluded that teachers showed significant improvements in their questioning after receiving instruction on specific question-asking strategies. A similar conclusion was made by other researchers who conducted related programs (Wilen, 1987, 1991). However, though these reports showed that teachers changed their questioning practices after undergoing training, there were no follow-up studies reported as to whether teachers continue to apply the learned skills after training. Based on a qualitative interview with teachers on why they make little use of Bloom's taxonomy in their teaching, Anderson (1994) reports that teachers claim to find the taxonomy complex and that the teachers' beliefs about teaching and learning are inconsistent with using the taxonomy. Indeed, Sanders (1972, pp. 268-269) argued that the "teachers trained in the taxonomy of questions often fail to implement the questioning skills in their classrooms in a pervasive and continuous way. The problem is not that they reject the merit of asking a variety of questions; rather, they find it difficult to put into practice."

Research studies in the third category which focus on developing systematic observation instruments to study teachers' questioning practices were influenced by the findings from Stevens (1912) empirical study as according to reports by Clegg (1987); Wilen (1985, 1987) and Wilen (1991). Around the 1950s, Bloom and his colleagues proposed the well-known "taxonomy of educational objectives" — the cognitive domain, comprising six levels:— knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). At the same time, Guilford (1956) developed a three-dimensional model of intellectual processes for classifying mental abilities. Gallagher and Aschner (1963) adopted Guilford's categories classifying abilities underlying a person's performance to devise a question category system of six question types — cognitive, memory, convergent, divergent, evaluative, and routine questions. Bloom's cognitive domain categories and Gallagher & Aschner's question category system became the major question classification frameworks that were employed over several decades in the study of teacher questioning practices. Indeed, the two frameworks are the basis upon which the rest of other question classification schemes that emerged later were developed.

The fourth category of studies are those in which teachers' questions were characterized and then a relationship investigated between the types of questions asked by the teacher and students' achievement (e.g.; Aagaard, 1973; Bedwell, 1975; Beseda, 1981; Gall et al., 1976; Gall et al., 1978; Land, 1980; Lynch et al., 1973; Martikean, 1973; Mills, Rice, Berliner, Rosseau, & Rousseau, 1980; Rogers & David, 1970; Sahin, 2008; Salenger, 1981; Savage, 1972). Overall, the findings from these studies as summarized in a few available meta-analytic studies (e.g.; Gayle et al., 2006; Redfield & Rousseau, 1981; Samson et al., 1987; Winne, 1979) give an inconclusive picture about this relationship. For example, in a meta-analytic study by Gayle et al, (2006), there are inconsistences pointed out with regards to earlier studies exploring the effects of the cognitive level of questions on students' achievement. Overall, they find a moderate positive effect of higher cognitive-level questions, but the large range of effects between -.54 and .92 suggests moderating variables. In studies exploring the link between the cognitive level of teacher questions and the cognitive level of student responses they found a moderate positive effect. These results suggest that higher cognitive-level questions are beneficial for students' learning, but the big variance in the observed effects remains unaccounted for.

1.3 Gaps in earlier research about teachers' questioning practices

My review of earlier studies on questioning in general resulted in three gaps, which I identified as warranting a further investigation. First, the study reports over several years consistently indicated that teachers continue to dominate their classes and pose many questions in a typical lesson, of which the majority are low-level questions. In addition, the reports also indicate that teachers had not taken up research recommendations and suggested techniques. Even those teachers that underwent training in questioning techniques (Lucking, 1978; Rice, 1977; Wilen, 1984), could not pervasively and continuously implement the learned techniques (Sanders, 1972). This consistent finding over several years raises the question of why teachers seem persistent with their ways of asking questions despite calls for change. Consequently, reasons for why teachers continue to execute their questioning practices as consistently reported are unknown from a research perspective. Further still, earlier research studies do not indicate having taken into account teachers' own knowledge and perceptions about question asking, or how teachers themselves conceptualize the questions they use in their teaching. Thus, a teacher's perspective with regard to classroom questioning in general is missing in prior research about questioning.

Teacher education research in the past focused mostly on what teachers need to know and how they can be trained into doing it (Carter, 1990; Richardson, 1990). What teachers actually know about teaching and how they acquired what they know, received less attention. Consequently, teachers' own contributions to the knowledge base of teaching had for long been missing in research (Cochran-Smith & Lytle, 1990). The same happened in the study of teacher questioning practices. Cochran-Smith and Lytle (1990) argue that important teacher perspectives concerning the nature of "questions teachers ask, the ways teachers use writing and intentional talk in their work lives, and the interpretive frames teachers use to understand and improve their own classroom practices" (p. 2) need to be explored from a teacher's perspective as well as a researcher's perspective. They express that limiting the knowledge base for teaching to what academics have recommended has resulted into problems such as discontinuity between what is taught in universities and what exactly happens in classrooms. In regard to questioning in science classrooms for example, Eshach et al. (2014) pointed to a gap between how science researchers and teachers view the role of teacher questions. They report that while teachers consider the affective domain, science education researchers focus on the cognitive dimension of teacher questions. Putnam and Borko (2000) also report about research knowledge being inconsistent with how teachers think and view the reality of teaching. They note that "teachers, both experienced and novice often complain that learning experiences outside classroom are too removed from the day-to-day work of teaching to have a meaningful impact" (p. 6).

The implication is that not only teachers' experiential knowledge has a substantial effect on the actual practice of teaching, but also on the extent to which teachers take up and apply educational research knowledge. Teachers' experiential knowledge, their beliefs and perceptions about teaching serve as a core reference for teachers as they process new information, and strongly influence how teachers approach their teaching

(Golombek, 1998; Hampton, 1994; Pajares, 1992; Tabacbnick & Zeichner, 1984). To be able to improve teaching, there is need for a sufficient understanding of "how teachers cope with the complexities of their work" (Freeman, 1996, p. 95). Thus, reasons why teachers employ a large percentage of lower-level questions could be well established if it was known how teachers conceptualize the questions they use, their knowledge about questioning and the types of classroom questions in general. Without establishing teachers' knowledge and thinking about the questions they ask, it is difficult to validate researcher claims about teachers' lack of knowledge about questioning, since there are likely conceptual differences in regard to what forms of knowledge about questioning are being considered between the researcher and the teacher. In addition, it is also difficult to ascertain the exact problems teachers face when using questions, as well as suitable forms of interventions that would contribute to developing teachers' questioning practices.

Second, most research studies on teacher questioning employed question classification schemes (taxonomies) based either on Bloom's cognitive domain, e.g., Sanders' (1966) question classification scheme, or on Gallagher & Aschner's (1963) question category system, to study and report about teacher questioning. With such pre-established frameworks, a researcher would categorize a teacher's questions and then count the number of questions coded at a particular cognitive level along the used question classification scheme. The results would show how many of a teacher's questions were lower-level questions and how many were higher-level questions if Bloom's cognitive levels are used, or, how many questions were convergent or divergent in that respect if s/he used Gallagher & Aschner's (1963) question category system.

In her reviews of the use of teacher questions, Gall points out the insufficiency of available taxonomies in classifying teacher questions as they are not fully grounded in a theory of instruction and learning and thus fail on providing a basis for deciding the various levels of questions asked and their respective answers (Gall, 1970; Gall, Gall, & Borg, 1996). She further mentions that these systems were formulated to explain the questions teachers ask rather than those questions which teachers should ask in a classroom situation and thus are not suitable for use in question framing. In a similar vein, Furst (1981) reviewing the application of Bloom's taxonomy in questioning noted that "the scheme is aimed more at the outcomes of instruction than at the language moves a teacher might undertake to probe meanings, opinions, and preferences and otherwise to facilitate discussion" (p. 33).

Several other researchers expressed similar concerns about using pre-defined category systems to study teacher questioning practices. Farrar (1986) noted that using question classification frameworks in the study of teacher questions could not allow for accounting for all the functions of teacher questions which are both social and cognitive. Others also pointed to a lack of fine-grained analyses in earlier studies on teacher questioning to uncover all the details around questioning (e.g.; Andre, 1979; Chin, 2007; Dunkin & Biddle, 1974; Heritage & Heritage, 2013; Ho, 2005; Roth, 1996). For example, Ho (2005) expressed that the question-answer exchanges are not isolated activities but rather influenced by other factors within the teaching context, and such exchanges are open to varied interpretations. Roth (1996) noted that using pre-determined frameworks to measure and collapse scores across students, situations or social and physical settings does not allow a sufficient understanding of teachers' practice of questioning. Andre (1979) also expressed that the question taxonomies being used often fail to capture the details in the teacher's questioning. He added that some researchers might have difficulties using some question classification taxonomies, while others might be influenced by their own perceptions and understanding of the topic of questioning. He thus like Dunkin and Biddle (1974, p. 8) concluded that the reliabilities with which teacher questions could be classified using pre-determined schemes can at best be moderate.

Further still, research on teacher questioning that focused on the relationship between discrete observable teacher questioning practices and students' outcomes or students' achievement in particular (Carlsen, 1991; Chin, 2007; Roth, 1996), seem to have paid little attention to the interactional nature of classroom discourse. This can be thought to be one of the reasons why research on whether certain questions lead to more students' learning gains than others remain inconclusive (Brophy, 1986). Review studies on this aspect of questioning indicate that whereas some researchers found higher level questions to lead to higher students' achievement (Gayle et al., 2006; Mills et al., 1980), some studies (Dunkin & Biddle, 1974; Gall, 1970) concluded that the use of higher level questions demonstrated little relationship to student achievement. Therefore, it is likely that such inconsistences are a result of the inadequacy of the methods that were employed in the study of teachers' questions, which only account for the cognitive functions of questions, leaving out the social function or the interactional nature of classroom discourse. Like Farrar (1986) advised, there is need for approaches that allow for examining questions and responses in context before any valid judgments can be made about the values of classroom questions.

The third gap identified as warranting an exploration concerns the fact that despite a large body of research on teacher questioning in science classrooms, research studies focusing on questioning in chemistry classrooms were scarce especially at the conception of the current study. Indeed, by the time of conception of the present study topic in the spring of 2013, there were challenges finding reliable sources of information concerning teachers' questioning behaviors in chemistry classrooms. This picture has not changed much as of 2017. Only a few studies addressing teachers' questioning in chemistry classrooms have emerged (e.g.; Kira, Komba, Kafanabo, & Tilya, 2013; Li & Arshad, 2014; Nehring, Päßler, & Tiemann, 2017). Further still, the first two issues that I noted as missing from previous research studies are not addressed in these recent studies.

1.4 Scope and objectives of the thesis

Following the above cited gaps (section 1.3), in this dissertation three objectives were pursued, each in one of the three independent research papers that comprise the thesis.

In paper I, the objective was to unfold classroom teachers' knowledge and perceptions about questioning. Whereas questioning is a topic that touches all subjects (arts and sciences), focus was on chemistry teachers in particular. The goal was to explore how chemistry teachers conceptualize the oral questions they use in their teaching and how their knowledge of questioning had been shaped over the years. This study was motivated by the need to understand main reasons behind the science teachers' continued use of mainly lower-level questions. In addition, the findings from this study were expected to provide insights into possible directions for consideration by educators and researchers in efforts to contribute to the transformation of teachers' questioning practices. The research performed in paper I was guided by three research questions:

1. How do chemistry teachers conceptualize questioning in classrooms?
2. Which taxonomic heuristics are used, if any, by teachers in terms of questions and questioning?
3. Which factors do teachers perceive as contributing to their use of questions over time?

In paper II, the extent to which question classification taxonomies could be used by chemistry teachers in teaching was examined. The underlying objective in paper II was to explore how consistent the conceptualization of teacher questions in respective taxonomies and teachers' thinking and perceptions are as reported in paper I. This was to allow for either recommending or suggesting a new framework that is more in line with the teachers' thinking, which teachers could use as a guide in their questioning practice. The underlying research question was;

> To what extent can the existing question classification taxonomies guide chemistry teachers in formulating and using classroom questions?

Paper III was aimed at developing a research approach for studying and evaluating teachers' questions in science classrooms. This undertaking was in response to the insufficiency of the available frameworks to account for both social and cognitive functions of teachers' questions, whereby questions are evaluated based on their situational adequacy. After its proposition, the approach was tested for its feasibility and applicability through analyzing eight science lessons from two countries, four lessons from the USA and four lessons from Australia. Paper (study) III was guided by the question;

> What alternative approach(es) could be employed in the study and evaluation of teacher questions, while taking into account the contexts in which the questions are asked?

2. What role do teachers' classroom questions play in teaching?

2.1 Role of teacher questions in science teaching

Several science education researchers share in a social constructivist view that learners socially construct knowledge (Duit & Treagust, 1998; Vygotsky, 1978). They thus contend that the teaching and learning of science is a collective activity, whose success relies to a larger extent on the nature of teacher talk, and the teacher-student interactions enacted during instruction (e.g.; Chin, 2007; Tobin, 2012). Tobin (2012) argues for example that, for science teachers to support students' construction of new forms of knowledge, they have to enact and maintain successful chains of interactions with students. Teacher questions, a component of teacher classroom talk, are considered to have a substantial role in determining the nature of discourse during science teaching and learning. Thus, a growing body of research, e.g.; Andersson-Bakken & Klette (2016); Chen, Hand, and Norton-Meier (2016); Chin (2006, 2007); Oliveira (2010); Roth (1996); Smart and Marshall (2013); van Zee and Minstrell (1997a, 1997b); and Yip (2004), indicates that the nature of questions teachers ask and how teachers approach their questioning, not only has an influence on the type of cognitive processes students engage in as they learn science, but also on what to learn and how to learn it.

For instance, Chin (2007) argues that teacher questions are a psychological tool with the potential of mediating students' knowledge construction (p. 816). She maintains that teachers' questioning can guide a meaningful discourse that supports students learning. She describes a case of one of her study subjects, who displayed what Chin referred to as purposeful or productive questioning. According to Chin, this teacher's questions were built around various forms of thinking, and the teacher was keen on following up on students' preceding contributions (p. 837). Some of the questions posed "were aimed at recall of information, others were process-oriented, stimulating students to generate ideas, apply concepts, make comparisons, formulate hypotheses, predict outcomes, give explanations, analyze data, make inferences, evaluate information, and make connections between ideas" (p. 837). To Chin, this teacher's questioning enabled learners to gradually ascend to higher levels of knowledge and understanding because the teacher elicited students' participation using questions, and was able to use students' responses for further inquiry.

Other scholars have emphasized the role of teacher questions in guiding students' thinking and in scaffolding students' discursive activity resulting in student-centered discussions during science instruction (Kawalkar & Vijapurkar, 2013; Oliveira, 2010; Smart & Marshall, 2013; van Zee & Minstrell, 1997b; Yip, 2004). For example, van Zee and Minstrell (1997b) describe a sequence consisting of a student statement, teacher question, and additional student statements as "reflective toss" (p. 227). The teacher question in the sequence throws the responsibility for thinking back to the student, eliciting an elaboration of the original statement. During the teacher-student exchange, both teacher and students work together to re-construct their understandings of scientific concepts, and the teacher's questions "help clarify meanings, examine a variety of views, and monitor the discussion process" (p. 259), and facilitate students own thinking during the learning process.

Kawalkar and Vijapurkar (2013) emphasize that "teachers' questions in the inquiry classroom not only explore and make student thinking explicit in the class but also serve to guide and scaffold it" (p. 2004). They describe several broad categories of teachers' questions they found to serve these roles. These questions include those that elicit students' personal experiences, setting the stage for the class and igniting discussions, questions that support students' in generating ideas and explanations through stimulating interest and provoking thought, questions that probe further responses such as reflective tosses, and questions that were aimed at redefining students' conceptions and explanations.

Yip (2004) also concluded from his study that teacher questions exhibit the potential to cause conceptual change in students learning science. Drawing on the model of conceptual change (Posner, Strike, Hewson, & Gertzog, 1982), Yip characterized "conceptual change" questions as those that could probe students' preconceptions or alternative conceptions, or challenge students to review and resolve inconsistent views. "Conceptual change" questions could also be questions that extend students' knowledge base, thereby enabling students to establish links and relationships between existing knowledge and experiences, resulting in development of new understandings, or questions leading students to apply the learned concepts (pp. 77-78).

Some other scholars have emphasized the pivotal role of teacher questions in promoting dialogic interaction in argumentative practice (Chen et al., 2016). The growing consensus among science educators to focus science learners towards authentic scientific practices other than simply memorizing facts, underscores the importance of argumentation in science teaching (Cavagnetto, 2010; Manz, 2014; Osborne & Wittrock, 1983). The introduction of argumentative practices in science classrooms sees learners actively constructing own claims supported by relevant, sufficient, and coherent evidence either as individuals or within a group. They search for information in support of scientific claims and publicly present their thinking, seek critique, and also react to varying views as they improve on their individual arguments (Andersson-Bakken & Klette, 2016; Chen et al., 2016; Ford, 2012). Argumentation in science classrooms thus enables the teacher and students to work together to search for deficiencies and errors in their arguments thereby solving cognitive conflict (Ford, 2012). Central to the success of a fruitful argumentative practice is the way a teacher uses questions to moderate and maintain a science discussion. The teacher uses questions to elicit students' ideas, to clarify students' ideas and to scaffold students to develop acceptable scientific knowledge (Andersson-Bakken & Klette, 2016; McNeill & Pimentel, 2010; Oliveira, 2010).

Andersson-Bakken and Klette (2016) for example, compare how teacher questions as an instructional tool are used in science and language arts classrooms. They report that science teachers use open questions with no pre-specified answers, drawing different interpretations and responses to explore students' understanding and interpretations (p.

73). The authors also note that science teachers use questions to give students cues to guide them in the direction the respective teachers want their students to go (p. 74). The teachers' open questions serve to elicit what students think, provoke students to give their explanations or predictions, and to make known their understanding of the scientific concepts being studied.

What is revealed in the existing literature as reviewed above is that, by using questions, science teachers provide a forum for students' development of conceptual understanding of science. Teacher questions can challenge students to think, give and elaborate on their ideas, they can provide a forum for strengthening students' ways of presenting scientific arguments, and they are key instruments to inducing students' conceptual change, among other functions related to classroom management. Thus, teacher questions are a key instructional tool with the potential to support students' learning, and improve their performance in science.

2.2 Role of teacher questions in chemistry teaching

Chemistry as a subject is conceptualized as mainly comprising three levels of chemical knowledge (content and concepts); the macroscopic (tangible, visual, experiential-mostly practically based), the molecular (submicroscopic), and the symbolic (calculations, symbols, graphical representations and equations). The learning process thus requires students to establish conceptual relationships among the macroscopic, microscopic, and symbolic representations (Wu, 2003).

Having students involved in a multilevel thought during instruction makes chemistry learning difficult (Johnstone, 1991). Indeed, several study reports show that students have difficulties understanding and interpreting microscopic chemical representations (Ben-Zvi, Eylon, & Silberstein, 1986, 1987; Kozma & Russell, 1997; Nakhleh, 1992). Students are also challenged when it comes to providing verbal explanations of chemical processes and making translations (Kjærnsli, Lie, Olsen, & Roe, 2007; Kozma & Russell, 1997). Due to the microscopic nature of chemistry, teachers have to present a learning environment that demonstrates conceptual relationships among levels of chemical knowledge, that is, relationships among representations at the macroscopic, molecular, and symbolic levels in a learning context (Wu, 2003). In addition, chemistry teachers need to link information that is used to develop students' conceptual understanding with students' existing knowledge and further science concepts (Nehring et al., 2017).

Teacher questioning is one discourse strategy that can affect students' learning of chemistry. Drawing on Osborne & Wittrock's (1983) Generative Learning Model, teachers through classroom discourse and in particular questioning, can assist students in the active construction of meaning, thereby supporting students in generating links between new information and existing schema. Through questioning, teachers can guide students towards conceptual understanding, where students can engage in cognitive organization of chemical knowledge by making of connections between new and prior knowledge (Nakiboglu & Yildirir, 2011; Smart & Marshall, 2013).

Several scholars have explored the role of teacher questions in chemistry teaching and learning. Ray (1979) investigated the effect of lower and higher-level questions on students' abstract reasoning and critical thinking during chemistry instruction. Using a definition by Andre (1979, p. 282) a "level-of-question" implies the nature of cognitive processing required to answer a question. As such, a lower-level question is that which asks a learner to repeat or recognize information as it was presented during instruction, whereas a higher-level question will require more than direct memory of facts — usually above the knowledge level of Bloom's taxonomy (Andre, 1979). According to Ray (1979), the results of analysis of covariance indicated significantly higher performances on critical thinking and abstract reasoning tests for classes taught with higher-level questions. Depending on the nature of questions a teacher chooses to ask, the used questions will have an impact on students' learning of chemistry in general. Ray's findings were in line with Aagaard's (1973) conclusions that teacher oral questions, in particular higher-level questions have a positive influence on students' achievement in chemistry classrooms.

Wu (2003) describes how teachers applied several discursive strategies to scaffold students' construction of links between abstract chemical representations and observable phenomena. The teachers used a series of oral questions which supported students' conceptions to move beyond the perceptual experiences (p. 887). He concludes that the teachers' explicit instruction and guidance through dialogic interaction and questioning were particularly crucial to students' creation of conceptual links. That is, "the teachers' questions contained important conceptual information and implied possible relationships among chemical representations that became a linguistic scaffold to support the meaning making process" (p. 887).

In a more recent example, Becker, Stanford, Towns, and Cole (2015) underscore the criticality of mathematical and graphical representations as tools for reasoning about chemical phenomena in physical chemistry classrooms. They however note that understanding complex thermodynamics topics requires students to go beyond rote mathematical problem solving, and be able to connect their understanding of mathematical and graphical representations to macroscopic as well as the submicroscopic phenomena they represent (p. 769). They thus emphasize the importance of teacher guided classroom discussions in supporting students' reasoning. In their study, Becker et al. (2015) describe how a teacher's facilitation strategies promoted students' reasoning with macroscopic, submicroscopic, and symbolic levels of chemical representation. They report that the teacher used questioning strategies extensively to initiate and sustain classroom discourse, following an elicitation-response-elaboration (ERE) pattern (Bowers & Nickerson, 2001) during the whole-class discussions. They observed that the teacher elicited students' reasoning and supported student elaboration of ideas through revoicing (O'Connor & Michaels, 1993). The teacher's questions involved those directly evaluating students' knowledge claims, questions for clarifying students' knowledge claims, those for probing explanations and those requesting for justifications for ideas stated by students. According to the authors, teacher questions were generally aimed at eliciting increasingly more complex information, moving students from declarative to conceptual knowledge (Becker et al., 2015, p. 774).

Other researchers have also reported on the central role of teacher questions in facilitating students' active learning (Obenland, Munson, & Hutchinson, 2013; Taber, 2014), and for motivating students in cooperative learning chemistry classes (Sisovic & Bojovic, 2000; Tastan & Boz, 2012). Teacher questions are also considered a vital tool in chemistry classes where problem-based learning approaches are used (Gunter & Alpat, 2017). In organic chemistry and chemistry laboratory classes, teacher questions have been used as key instruments to facilitate students' conceptual understanding (Flynn, 2014; Högström, Ottander, & Benckert, 2010).

In general, teacher questions are a key instructional tool that serves a variety of both social (and class management) and cognitive functions aimed at facilitating students' learning. In view of the role of teacher questions in science classrooms in general (section 2.1) and their role in chemistry classrooms (section 2.2), chemistry as a subject seems not to be different from other science subjects when it comes to questioning. Nevertheless, the subject orientation, nature of content or chemical processes involved could influence the way questions are formulated and presented in chemistry classrooms.

2.3 What research says about science/chemistry teachers' practice of questioning

Whereas a wide agreement exists among science education researchers about the important role of teacher questions in instruction (Treagust & Tsui, 2014), a body of research on teachers' questioning practices continues to indicate that the potential of teacher questions is not fully exploited. Research over several decades has shown that productive questioning resulting in better meaning making has to go beyond the triadic dialogue — initiation-response-evaluation/feedback (IRE/F) pattern, where a teacher asks questions, calls students to respond and then teacher evaluates students' answers or comments on them (Chin, 2006; Lemke, 1990; Mercer & Littleton, 2007). In a productive questioning environment, a teacher asks questions to elicit students' ideas and facilitate productive thinking, s/he invites and welcomes students' responses, encourages multiple responses and questions, responds to students' responses and questions, and also provides an on-going assessment (Chin, 2007). Such questioning provides opportunities to students to state their thinking — explanations and predictions, and to elaborate on their previous answers and ideas, which altogether contribute to knowledge construction (Roth, 1996; van Zee & Minstrell, 1997b).

Whereas the IRE/F discourse pattern still seems to dominate science classrooms, Nassaji and Wells (2000) argues that the IRE/F pattern is not in itself effective or ineffective as a discourse practice. Rather, it is the content of each turn in the sequence and the nature of the exchange that follows that determine whether or not the pattern facilitates students' deeper understanding of the topic. Accordingly, if teacher questions ''introduce issues as for negotiation,'' then this is more likely ''to elicit substantive student contributions'' (Nassaji & Wells, 2000, p. 400), and if the response/follow-up turns ''requests justifications, connections or counter-arguments,'' then the dialogue adopts ''a more conversation-like genre'' (p. 401). Nevertheless, several research reports indicate that the IRE/F pattern that is dominant in science classrooms offers minimal opportunities for students' active engagement, as teacher questions are mainly of a closed type aimed at evaluating what students know (Kira et al., 2013; McNeill & Pimentel, 2010). That is, teachers often seek for predetermined short answers, and the questions asked mainly require students to recall previously studied knowledge. Such a questioning practice is seen to discourage students from sharing their different ideas and depriving them of opportunities to engage in an interactive discourse (Andersson-Bakken & Klette, 2016; Chin, 2007; and McNeill & Pimentel, 2010).

Researchers who have studied science teachers' use of questions in teaching, have concluded their reports with indications that certain questioning behaviours exhibited by teachers tend to deprive students of learning opportunities. In a study by Andersson-

Bakken and Klette (2016) in which they explored teachers' use of questions as an instructional tool in science and language arts classrooms, they report that science teachers spent more time on sequences of repeated questions than language teachers. They add that these science teachers were more concerned with getting correct answers from students than eliciting students' explanations. The teachers in this study also spent more time on cued elicitations in pursuance of the desired correct answers. The authors noted that the science teachers' practice of questioning in the observed lessons did not support students' development of critical reflection and argumentation skills, as the questions were more focused on checking students' knowledge and mastery of specific conceptual terms.

Eshach et al. (2014) upon exploring the practice of nine science teachers from different public schools in south Israel, found the total number of questions that teachers asked to be twice the number that the students afforded in a typical lesson on average. In addition, of the total teacher's questions asked in a typical lesson, 84.5 % were facts requiring questions that only invited students to reproduce previously learned concepts. Goossen (2002) also reported after observing teachers' questioning and response strategies in twenty-four middle-school science lessons that the teachers did not use higher-level cognitive questions.

Studies taken in chemistry classroom settings also do not give a different picture. Gabel and Bunce (1994) noted that students should be able to make connections among various chemical concepts in order to solve chemical problems. Studies on problem solving (e.g., BouJaoude, Salloum, & Abd-El-Khalick, 2004; Nakhleh & Mitchell, 1993; and Tsaparlis & Zoller, 2003) found that chemistry students, despite being able to use algorithmic equations to solve chemical problems, showed little understanding of the concepts described in the equations that they solved. Whereas teacher questions should support students' conceptual understanding and making of connections, teachers are reported to use mainly recall and algorithmic type questions (Nurrenbern & Robinson, 1998), which majorly promote the reproduction of definitions and the calculation of values following pre-established algorithms (Nakiboglu & Yildirir, 2011).

For instance, DeCarlo and Rubba (1994) sought to establish and understand what teachers do during high school laboratory sessions. They observed that their teachers focused on helping students conduct the experiment, but did not require their students to think what or why they were trying to achieve by performing the experiment (p. 41 & 46). In a comparable and more recent study, Li and Arshad (2014) investigated teacher's questions in chemistry's laboratory and theory lessons. They report that the teacher during laboratory work sessions attempted questions that addressed process skills learning, but that most of the questions posed in theory lessons were content questions. The authors further noted that IRE was dominant in the observed chemistry lessons, and the teacher did not try to invoke curiosity among students through questions. Though not explicating how, Li and Arshad (2014) concluded that systematic planning of the nature of inquiry activities and appropriate questions is needed to improve the teaching practice in chemistry classrooms.

Bleicher, Tobin, and McRobbie (2003) explored discourse strategies employed by students and a chemistry teacher to support or constrain opportunities to engage in experimentation and making sense of new experiences. They report that, "students were not given opportunities to do more than passively listen to teacher talk, and occasionally deliver one or two message units of discourse, almost always supplying simple factual information to the on-going teacher discourse" (p. 334). The authors also noted that the teacher did not present opportunities for students to present alternative hypotheses to explain the phenomenon under discussion. Accordingly, the questions asked by the chemistry teacher throughout the discourse were merely requiring factual answers from the students, and the teacher missed on questions to probe students' understanding. The teacher's questions were designed to elicit quick, correct answers from students to help move the lesson along (p. 328). Bleicher et al. (2003, p. 331) concluded from their study that owing to the discourse strategies displayed by the teacher, “the metaphor of science as argument or students engaging in scientific thinking as argument” was far from reach in such a classroom.

In short, research reports about how science/chemistry teachers use questions in their teaching suggest that many teachers fail to make the best out of their questioning. They dominate their questioning with simple facts-requiring questions. Accordingly, such questions do not elicit higher-order thinking other than students reproducing that which they have been taught in previous lessons. What remains to be answered is whether the teachers’ reported practice of questioning is attributed to a lack of knowledge and skills about questioning, or there are other factors influencing the practice in the reported direction.

2.4 Analyzing teacher questioning practices: Towards interpretive approaches

By an interpretive methodology, the researcher explores and makes sense of elements of the study. S/he assumes a position where meaning or understanding is gained through social constructions –language, consciousness, shared meanings, and instruments. With an interpretive approach, the researcher thus does not start with concepts determined a priori, but rather s/he seeks to allow these to emerge from the elements that s/he investigates (Prasad, 2005; Yanow & Schwartz-Shea, 2006). Following Carlsen’s (1991) sociolinguistic perspective on teacher questioning, where he argued for conceptualizing questions within contexts where such questions occur, interpretive approaches to studying classroom questioning have been employed in several studies. Interesting about studies that have employed interpretive approaches is the possibility to analyze both the cognitive and social functions of a question in a given teaching context.

For example, Chin (2007) interpretively analyzed science video clips, lesson handouts and students’ written work in a study where she reports on teacher questioning approaches that stimulate productive thinking. Through a multiple reading of transcripts of classroom discourse, she made sense of teachers' questions and how they served their roles in specific teaching contexts. Roth (1996) also interpretively characterized the nature of questions asked by a teacher in his study in which he explored teacher questioning in open-inquiry science classrooms. Other examples include; Chen et al. (2016) who employed qualitative analysis methods to explore the pattern in teachers' development of questioning roles elementary teachers adopt to scaffold students' cognitive responses over time, and McAninch (2015) who also analyzed teachers' questioning, responses, and perceived influences in mathematics classrooms. These studies unlike those that solely relied on question taxonomies, have attempted to conceptualize the context in which a question is being used, in order to evaluate the question in terms of how well the question served its intended function.

While analyzing classroom teacher discourse and questioning in particular, most researchers draw on the Initiation-Response-Feedback/Evaluation — IRF/E (Lemke, 1990; Mehan, 1979; Sinclair & Coulthard, 1975), or the Initiation-Response-Feedback-Response-Feedback — IRFRF (Mortimer & Scott, 2003) patterns/frameworks. However these frameworks fail to capture all the details about questioning (Louca et al., 2012). Louca et al. (2012) expressed for example that, the IRF/E or the IRFRF frameworks "fail to address issues related to teacher's minute-by-minute decisions, specifically regarding how to respond to students' ideas and thinking" (p. 1828). They argued that because classroom discourse takes several forms, describing it requires taking into account more discourse features than teacher questions and feedback alone.

The three-fold structure – Identification, Interpretation-evaluation, and Response (IIER) framework proposed by Louca et al. (2012) in response to the inadequacies with using the IRF/E or the IRFRF frameworks, takes the perspective of the teacher when it comes to analyzing discourse. The IIER framework comprises the identification part which concerns what the teacher responds to (that is, students' discourse contributions), the interpretation-evaluation part which concerns how a teacher interprets and evaluates students' contributions, and the response part which concerns how a teacher responds to students' contributions. Though the IIER framework allows for exploring a teacher’s minute by minute decisions about how to respond to student discourse, and in particular teacher questions and students’ responses, the framework does not provide for exploring and evaluating the usefulness or suitability of questions in specific contexts. This makes the IIER framework inadequate as a tool that could be employed in the study and evaluation of teachers’ questions within their contexts.

Consequently, the interpretive approach to studying teacher questioning still suffers from a lack of a systematic framework for use in evaluating the usefulness of a teacher’s question in a given context. In studies where analyses have been done interpretively, individual researchers stipulate their own guidelines or interpretive frames which differ from one study to another. At best, only a moderate reliability can be expected if each individual researcher has to stipulate own guidelines within which to judge the usefulness of a teacher’s question in a given context. This is because the outcomes of the analysis are very much influenced by the researcher’s perceptions, beliefs, and competencies in regard to “good questioning”.

3. Methods

This chapter describes the research design, data collection procedures, and the analysis processes used in the study. The first part of this chapter (section 3.1) gives a descriptive overview of data selection and collection procedures, and analytic methods and procedures employed in each of the papers, I, II and III. In the same section, I also briefly describe the theoretical conceptions that informed the interpretive work performed in each respective paper. In section 3.2, the research credibility of the study, pertaining issues of validity, reliability, transferability, as well as ethical concerns is discussed.

3.1 Data collection, analytic methods and procedures

The data collection tools and analytic procedures were chosen according to the nature of research problems in the respective papers.

3.1.1 Paper I: The practice of questioning in science classrooms: Perspectives from chemistry teachers

In paper I, the aim was to establish how chemistry teachers conceptualize the nature of oral questions they each use in their teaching. This was to open up for understanding the reasons for the teachers' persistent use of mainly simple recall (facts) questions as reported in research and to suggest possible interventions towards transforming the practice.

From a sociolinguistic perspective, teacher oral questions are not isolated activities, but rather mutual constructions between teacher and students (Carlsen, 1991). Thus studying teacher oral questioning is more about analyzing teacher and students' communication exchanges. Wittgenstein (2009) provides conceptual ideas that are helpful to analyzing communication. He introduces the construct of "language-game" as a specific way by which a community talks and acts. He denies the existence of a fixed relation between language and objects and perceives language not to be an objective mediator between human beings and the objects. According to him, words have neither a consistent nor an objective meaning. In different language games various meanings of a word can occur and consequently, there is no direct transformation from a word to its meaning. Wittgenstein argued that we can use a word or sentences in multitudes of ways and what makes us pick one way over another is related to our "form of life", the way that we have experienced the world. "The meaning of a word is its use in the language game" (Wittgenstein, 2009, p. 25). Wittgenstein argued that language is woven into the activity and without knowing how people in a community complete the activities, we cannot realize the meaning of the words they use.

Based on Wittgenstein's conception, questioning as part of classroom discourse, can be regarded a language game for which both teacher and students are competent players in the game – or in the family of different but interconnected games, and who know the rules of this game. Being competent players of this game implies that teachers can describe what they do in certain situations, how they perceive the interaction with their students, and why they are acting as they do. This claim is also supported by recent work by Kunter and Voss (2013) who report about teachers being able to give useful information concerning teaching activities such as classroom management, teaching purposes and instruction. It is thus possible that we can learn about and establish how science (chemistry) teachers construe their use of questions, and how their questioning is shaped over time. This was achieved through engaging in dialogue with these teachers where they described their views regarding how they execute their practice of questioning and the nature of questions they use.

Data sources and participants

An invitation to science teachers to participate in the study was sent out to different schools across the city of Bergen in Norway. Participation was voluntary and the invitation specifically targeted science teachers with chemistry as one of the teaching subjects. Altogether, 11 teachers accepted to take part in the study. Interviewing was the main data collection instrument. A questionnaire was also prepared in advance and administered to individual teachers before the interview. This was used to capture individual teachers' background information regarding their education and training, teaching subjects, teaching experiences, school grades taught in during their respective years of teaching, age, and gender. All the teachers who took part in the study were qualified science teachers with teaching experience between 1 and 36 years. Table 1 shows a summary of each teacher's background information. The names used for teachers in Table 1 are pseudonyms.

Table 1 Participant teachers' profiles

Age range	Tr	Teaching experience (years)	Qualification & training	Yr. attained	Teaching subjects	level taught: upper/ lower
20–30	Emy	0 – 5	Masters + 1 yr (TE)	2012	Chem.	Upper
	Flora		5yrs Integrated TE	2012	Chem., Science, Math	Upper
	John		Masters + 1 yr (TE)	2011	Chem. & Science	Upper
	Kari		Masters + 1 yr (TE)	2011	Chem., Bio., & Science	Upper
31–40	Charles	5 –15	Masters + 1 yr (TE)	2007	Science & Math	Lower
	Darby		Masters + 1 yr (TE)	2006	Chem, Science, & Math	Upper
	Grace		Masters + ½ yr (TE)	2009	Chem., Science, & Math	Upper
41–50	—	—	–	–	–	–
51–60	Anet	>15	Masters + ½ yr (TE)	2002	Chem, Math, Psychology	Upper
	Hope		Masters + ½ yr (TE)	1988	Chem., Science, Math	Upper
	Ian		3yrs degree + TE	1978	Science & Math	Lower
> 60	Ben		Masters + ½ yr (TE)	1979	Chem., Bio., & math	Upper

***Notes**: — Tr –shows teachers' pseudonyms, TE –teacher education training, Math – mathematics, Chem –chemistry, Bio-biology, Classes taught —These are classes participants have taught in since their graduation as teachers. Norwegian lower secondary school lasts three years. It starts at the age of 12 or 13 and covers the 8th to the 10th grade. Upper secondary school also lasts three years and starts at the age of 16. It covers the 11^{th} to the 13^{th} grade.*

After filling in the questionnaire and prior to interviewing, the teachers were showed two short video clips selected from the[1]TIMSS Video study. The two video clips were

[1] TIMSS- Trends in International Mathematics and Science Study: The TIMSS 1999 video study was a study of eighth-grade mathematics and science teaching in seven countries. The study involved videotaping and analyzing teaching practices in more than one thousand classrooms; http://www.timssvideo.com/timss-video-study

meant to elicit participants' perspectives, to make it easier for the participants to relate to the topic, and to produce more concrete responses. The participants had to observe teaching situations in the two videos, and thereafter comment on the teachers' respective use of questions. Accordingly, doing so would expectedly trigger the participants' reflections about the topic, thereby enabling them to disclose their implicit knowledge (Bromme & Ben-Peretz, 1990) regarding their individual use of oral questions in teaching.

Questions in the semi-structured interview guide addressed five themes. It included a question inviting the teacher to comment on the observed video clips, questions about the teacher's own use of questions in teaching, and how the teacher deals with students' responses to posed questions. The guide also included questions about the types of questions the teacher asks as well as how the teacher in question developed his/her displayed knowledge or conceptions about questioning (see Appendix II). Therefore, during the interview session, teachers talked about their own questioning practice, the different types of questions that they ask their students as well as the reasons exhibited for using particular kinds of questions. They were probed for clarifications and further explanation of their respective ideas and arguments as was deemed necessary by the interviewer. All interviews were audio recorded and transcribed verbatim. On average, each interview lasted about 40 minutes. English was used as the main language of communication during data collection because it was the only language that I as the main interviewer could understand and use, given that my understanding of Norwegian was low.

About the used TIMSS video clips and their selection

TIMSS video study was a study in which teaching practices in more than one thousand science and mathematics classrooms in seven countries were videotaped and analyzed. The countries included; Australia, Czech Republic, Hong Kong, Netherlands, Japan, Switzerland, and the United States. The analyzed lessons were from eighth-grade mathematics and science teaching. The study which started from May, 1998 through 1999, was conducted by the National Center for Education Statistics, U.S. Department of Education under a contract with LessonLab, Inc. of Los Angeles, California, in conjunction with the International Association of the Evaluation of Education Achievement (IEA) ("The TIMSS Video Study," 1999). For science in particular, the study was conducted in five countries – Australia, Czech Republic, Japan, Netherlands, and United States (http://www.timssvideo.com/timss-video-study). About 54 of the recorded lessons were made available for public use. These lessons of which 25 are from science classrooms can be found on the website; http://www.timssvideo.com/videos/Science. The lessons have been also transcribed and the transcripts made available on the same website.

The selection of the video clips for this study (paper I) was based on the following criteria. First the lessons had to be addressing chemistry content, the aspects familiar to what the participant teachers work with in their respective teaching. Second the content or topic of the target lesson had to be a simple chemistry topic/content to allow a good start for the participants to comment on the observed themes without the need to make prior preparations. Third, whereas English transcripts are provided as mentioned above, it was necessary to have both the video and audio information. This would enable participants to both observe and listen to what the teachers in the videos were doing, how they acted both verbally and non-verbally. It was noted for example that some of teachers' questions are only recognizable by listening to the teacher, how s/he raises or lowers the voice. Therefore, as a third criterion, the target videos lessons had to be one of those lessons conducted in English, to enable both the participants and the interviewer to follow the observed lesson videos and all the activities performed during instruction.

Following the above criteria, 10 science video lessons were available for consideration for the study, five lessons from Australia and five from the United States. From the lessons from the United States, only one directly addressed chemistry content, where the theme was "Polymers" (http://www.timssvideo.com/91), whereas of the videos from Australia, there were two that directly addressed chemistry content, with study themes; metals and non-metals (http://www.timssvideo.com/31), and energy transfer (http://www.timssvideo.com/93).

On comparing the level of difficulty of the three themes – polymers, metals and non-metals, and energy transfer, it was decided that the latter two themes would be more familiar to teacher participants. This assumption was indeed confirmed during a pilot study that was conducted to check the appropriateness and feasibility of the interview approach that had been decided upon. In addition, the introduction parts of the two video lessons – metals and non-metals, and energy transfer were different in the way each teacher started their lessons and showed two different forms of questioning. The teacher in the video about metals and non-metals (excerpt 1, AU2: Metals and non-metals, 00:00:55-00:02:08) started the lesson by reviewing what was discussed in the previous lesson. He drew diagrams on the chalkboard containing parts of information about atoms, molecules, and chemical bonds, and requested students to verbally produce the missing information. On the other hand, the teacher in the video about energy transfer (excerpt 2, AU4: Energy transfer, 00:02:46-00:04:17) seemed to be starting on a new topic and she introduced the lesson by relating to the students' own experiences with heat transfer away from their feet to the bathroom floor. These two varying teaching situations were thought to allow for a broader discussion regarding the role of teacher questions in specific contexts.

Excerpt 1: AU2: metals and non-metals — teacher's and students' utterances (double slash (//) indicates overlapping speech)

1 Teacher: Come on, come on. Right; ladies and gents! Let's go back over yesterday. We talked about elements in the Periodic Table. We said that elements are matter.
2 Teacher: They are therefore composed of- they're therefore composed //of? Of particles.
3 Students: //Particles.
4 Teacher: These particles are called?
5 Students: Molecules.
6 Teacher: These particles are called molecules.
7 Teacher: These molecules are made of?

8 Students: Atoms.
9 Teacher: Okay. Joined together by?
10 Students: By chemical bonds
11 Teacher: By chemical bonds. Okay. Because they're- because elements are a pure substance.
12 Students: The same.
13 Teacher: All molecules are?
14 Students: The same.
15 Teacher: Are the same. We said yesterday in elements, what are the particles inside the molecules?

Almost all the teacher's questions in excerpt 1 are sentences that are recognized as questions through the teacher raising his voice and waiting on students to answer (lines 2, 7 and 9). There is only one utterance with the grammatical form of a question in line 15. The situation is different in excerpt 2. Here the teacher provides a background for questioning and goes ahead to solicit ideas from students (excerpt 2, lines 1-2). Individual students are given a chance to give their responses. When students give the answer that the teacher desired, she repeats the students' answer with a rhetorical question "isn't it?" (line 14).

Excerpt 2: AU4: energy transfer — teacher's and students' utterances

1 Teacher: I don't think she'll fit in there mate, you'll be all right. Okay, ready? Good, so let's talk about something. Imagine, in the mornings, it's a bit cold like in the mornings, isn't it?
2 Teacher: And you have a shower, you get out the shower, and you put your foot on the cold bathroom tiles. What do you notice?
3 Student 1: Ground's a bit colder.
4 Teacher: Sorry?
5 Student 2: Water mark?
6 Teacher: All right, you leave a water mark. Karla?
7 Student 3: Condensation.
8 Teacher: Condensation. Yeah, what else? The first thing you'd notice when you put your foot on that floor?
9 Students: Cold.
10 Teacher: Well, hands up.
11 Student 4: Reflex action.
12 Teacher: No.
13 Student 5: It's cold.
14 Teacher: It's cold, isn't it?

Analysis and interpretation of data transcripts

Analysis and interpretation of interview transcripts was informed by Gadamer's philosophical hermeneutics (Gadamer, 2004), which take into account the nature of conditions in which understanding itself takes place. According to Gadamer; "Hermeneutics must start from the position that a person seeking to understand something has a bond to the subject matter that comes into language through the traditionary text and has, or acquires, a connection with the tradition from which it speaks " (p. 306). In other words, the researcher goes with preconceived ideas into the process of interpretation. Gadamer believes that it is only through our prejudices that he calls "fore-structure" that we can begin to understand. These prejudices are the very source of our knowledge, and determine the nature of perspectives and our judgement about the world (Gadamer, 2004).

Having an awareness of our prejudices enables us to take account of them in the effort to hear what the text or the told stories say to us (Koch, 1999). However, as Gadamer cautions, the interpreter ought to remain neutral. That is, "The important thing is to be aware of one's own bias, so that the text can present itself in all its otherness and thus assert its own truth against one's own fore-meanings" (Gadamer, 2004, p. 271).

Following Gadamer's hermeneutical position, Koch (1999) explains that when participants give their stories, we as researchers accept the stories as the participants' individual realities. The participants' stories are their constructions of the situation, the ways in which they make sense of the world. In the process, we then start to construct our own understanding of the participants' stories. For example, we consider what the participants words, sentences or storyline mean, or what the participants or their texts are telling us. That is, "this is what I believe the person or text is getting at (pp. 26-27)". Finally a consensus can be reached about the construction that makes the most sense.

Guided by Gadamer's conceptualizations, transcribed teachers' expressions and descriptions were read, and interpretations started to develop through a back and forth reading process. We were two coders/researchers performing the analysis and the interpretive work, myself and another person with whom paper I is authored. Drawing on our "fore-structure" or our experiences for that matter, we constructed an understanding of what teachers implied by their expressions and explanations concerning how they question their students. This understanding was gained through considering the particular parts of the individual texts, recognizing the consistence of the whole, and realizing the contribution of each of the different parts of the teachers' utterances. Finally, we derived at an understanding that satisfies our experiences, a position where we were able to understand what it is like for the participants to be practicing the way they do, and what influences their practices.

3.1.2 Paper II: Question classification taxonomies as guides to formulating questions for use in chemistry classrooms

Paper II is an interpretive-analysis review study in which five question classification taxonomies were examined out of 41 taxonomies developed by different educational researchers since 1956. The aim was to examine the extent to which the taxonomies can be used by chemistry teachers as guiding frameworks in their questioning.

Data sources

The studies that were examined were obtained from a search of three electronic databases; ERIC- *the Education Resource Information Center*, the Web of Science, and Google scholar. The used search terms included; *"question taxonomies", "question classification", "classroom questions", "oral questions", "classifying questions" and "teacher questions".* These search terms were used in both the *title* and *abstract* fields of the electronic databases respectively. The research studies considered for this study were selected for inclusion or exclusion depending on whether or not they belonged to any of the following descriptions;

(i) Empirical studies on classroom teacher questions where the authors devised a question classification framework for studying teacher questions

(ii) Theoretical studies with a focus on developing a framework or taxonomy for characterizing, classifying, or explaining classroom questions

(iii) Review studies where question classification taxonomies or frameworks are addressed

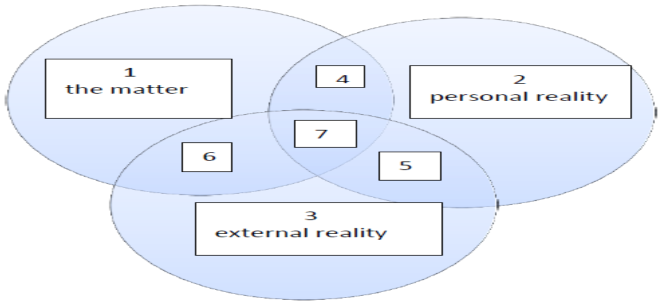
(iv) Taxonomies of educational objectives with a close relation to classroom assessment

A preliminary search resulted in four review studies conducted before the 1990s by Crump (1970); Gall (1970); Riegle (1976); and Wilen (1986). Three of these authors Crump, Riegle and Wilen, in addition to proposing alternative taxonomies, reviewed taxonomies developed before. For example, Crump (1970) reviewed eight question classification taxonomies before suggesting his own, Riegle (1976) reviewed 21 classification taxonomies, while Wilen (1986) reviewed 22 question taxonomies including those reviewed by Riegle (1976). Gall (1970) examined 11 taxonomies. Together, the four studies yielded 23 question classification taxonomies. The search in the data bases resulted in 18 additional question taxonomies including those developed before and after the 1990s. The 41 question category systems are summarized in Table 2 below. Notice that Guilford's (1956) categories classifying mental abilities underlying a person's performance are also included in Table 2, since it is based on these categories that Gallagher and Aschner (1963) devised their question category system for questions that occur in classrooms (see Table 2).

[2]Table 2 Summaries of Question Classification systems by different authors

Author	Category/Level/Classes
Adams (1964)	(i) Memory, (ii) Ratiocinative (logical reasoning), (iii) Evaluative, (iv) Associative, (v) Clarifying, (vi) Neutral
Anderson et al. (2001)	i. Remember- retrieve relevant information from long term memory; Recognize (identify, locate), Recall (retrieve) ii. Understand- construct meaning from instructional messages, including oral, written, and graphic communication; interpret (clarify, paraphrase, represent, translate), Exemplify (illustrate, instantiate), Classify (categorize, subsume), Summarize (abstract, generalize), Infer (conclude, extrapolate, interpolate, predict), Explain (construct models) iii. Apply- carry out or use a procedure in a given situation; Execute (carry out, apply), Implement (use) iv. Analyze- Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose; Differentiate (discriminate, distinguish, focus, select), Organize (find coherence, integrate, outline, parse, structure), Attribute (deconstruct) v. Evaluate- make judgements based on criteria and standards; Check (coordinate, detect, monitor, test), Critique (judge) vi. Create- puts elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure; Generate (Hypothesize, synthesize) Plan (design, devise) Produce (construct, invent).
Aschner (1961)	(i) Remembering, (ii) Reasoning, (iii) Evaluating or judging, (iv) Creative thinking
Barnes (1969)	Distinguished four question types*;* *1. Factual questions, 2. Reasoning questions, 3. Open questions and 4. Social questions*
Biber, Johansson, Leech, Conrad, and Finegan (1999)	They suggested a question classification system for teacher questions that include: (1) *Yes/no questions,* *(2) Wh- questions,* *(3) Tag questions and* *(4) Alternative questions.*
Bloom et al. (1956)	Cognitive domain consists of; **i.** Knowledge –recall or recognition of terms, ideas, procedure, theories, etc.) **ii.** Comprehension –translate, interpret, extrapolate **iii.** Application –apply abstractions, general principles, or methods to specific concrete situations **iv.** Analysis –separation of a complex idea into its constituent parts and an understanding of organization & relationship between parts. **v.** Synthesis –creative, mental construction of ideas and concepts from multiple sources to form complex ideas into a new, integrated, meaningful pattern subject to given constraints

[2] The table is organized in alphabetical order following Authors' names

	vi. Evaluation –make judgment of ideas or methods using external evidence or self-selected criteria substantiated by observations or informed rationalizations
Blosser (1973)	(i) Managerial: - keep the classroom operations moving. (ii) Rhetorical: - Emphasize a point, to reinforce an idea or statement. (iii) Closed questions: - check the retention of previously learned information, to focus thinking on a particular point or commonly- held set of ideas. Are those with a limited number of acceptable responses or right answers (iv) Open questions: - to promote discussion or student interaction, to stimulate student thinking, to allow freedom to hypothesize, speculate, share ideas about possible activities, etc. Anticipate a wide range of acceptable responses rather than one.
Carner (1963)	1. Concrete level: questions elicit responses which are characteristic of concrete, tangible or obtainable details. One is dealing with relatively simple ideas, objects, or concepts which most often do not require evaluation, judgment or drawing conclusions. 2. Abstract level: questions aid in the development of abstract thinking skills and require pupils to go beyond the specifics or detail level of comprehension in order to generate, classify or relate these specifics into meaningful patterns. Such questions should lead pupils to explore the "hows" and "whys" of the problem as well as the "whats". 3. Creative level: questions require answers which are more creative by nature and may demand both concrete and abstract thinking.
Chinn, Anderson, and Waggoner (2001)	Classified questions into; *1. Assessment questions,* *2. Genuine information questions,* *3. Open- ended questions, and* *4. Challenge questions*
Christenbury and Kelly (1983)	They depicted different areas of questioning in the form of overlapping circles which represent different domains of cognition and they overlap and not hierarchical. 1. *The matter- the subject of discussion (issue, problem, topic). 2. The personal reality- students' relationship with the subject, and 3. The external reality- the broader perspective of the subject.* According to the Christenbury-Kelly model, the most significant questions are higher-order and are developed from areas where the circles overlap. Bringing the student's personal perspective into the questioning schema begins to introduce a Constructivist view towards question generation. 

	Example 1. The *Matter* – What does Huck say when he decides not to turn Jim in to the authorities? 2. *Personal Reality* – When would you support a friend when everyone else thought he or she was wrong? 3. *External Reality* – What was the responsibility of persons finding runaway slaves? 4. *The Matter/Personal Reality* – In what situations might someone be less than willing to take the consequences of his or her actions? 5. *Personal Reality/External Reality* – Given the social and political circumstances, to what extent would you have done as Huck did? 6. *The Matter/External Reality* – What were the issues during the time which caused both Huck's and Jim's actions to be viewed as wrong? 7. *The Matter/Personal Reality/External Reality* – When is it right to go against social and/or political structures of the time as Huck did when he refused to turn Jim into the authorities?"
Clements (1964)	**(a)** Questions asked during Motivation: i. *Past experience qns.* Student tells relates himself to the topic by telling his own experience. Present experience qns. They call for immediate visual or emotional experiencing followed by the representation of the experience. ii. *Rule questions.* Used for the reiteration of previously learned techniques, rules, and maxims. They enforce the methods which the teacher feels are proper. iii. *Planning questions*. Require students to think of future actions and results, clarify in the student's mind his intent regarding both his process and product. **(b)** Questions asked during Working period: iv. Opening questions. Used by teacher as he first approaches the student at work. v. Identification questions. Determine what and where represented objects are. vi. Suggestion order qns. Suggestions and orders are often disguised as questions. vii. Acceptance qns. Students' acceptance signifies some combination of understanding, belief and future action. **(c)** Questions asked during Evaluation: viii. Process-recall questions; ask students to recall his creative process, to verbalize the intuitive feelings and decisions experienced while creating a picture. ix. Product judgment questions; Ask students to evaluate his picture or aspects of his picture.
Clements, Fielder, and Tabachnick (1966)	(i) Questions with no answers, (ii) Questions with many acceptable answers, (iii)Questions with one acceptable answer
Crump (1970)	(i) Convergent question category – comprising reproduction and translation questions (ii) Divergent category –comprising reflection and evaluation questions
	(i) Memory- recalls or recognizes information (facts, generalizations, etc.); (ii) Interpretation- states relationships between various types of data;

<table>
<tr><td>Davis and Tinsley (1967)</td><td>(iii) Translation- changes information into a different form (linguistic, symbolic, image, etc.);
(iv) Application- solves a realistic problem requiring the identification of the crucial issue or points and the selection and use of appropriate knowledge and skills;
(v) Analysis- Breaks into parts a complex idea and creates an understanding of organization & relationships
(vi) Synthesis- suggests answers to a problem that is original, speculative, or creative;
(vii) Evaluation- makes a judgment according to explicit criteria (external or internal);
(viii) Affectivity- responds with a statement of feeling, emotion, or opinion without a standard of appraisal;
(ix) Procedure- relates to classroom organization, student behavior, or instructional management.</td></tr>
<tr><td>Douglass (1967)</td><td>(i) Problems to be discovered, (ii) Problems in reasoning, (iv) Problems of retrieval</td></tr>
<tr><td>Elstgeest (1985)</td><td>He argues the use of productive questions, which he divides into various sorts
1. Attention-focusing questions; - these fix attention to some significant detail which might easily be overlooked. Eg, have you seen?, or do you notice?
2. Measuring and counting questions; -Eg How many? How long? The students can check answers themselves, learn new skills and use new instruments and feel confident.
3. Comparison questions; - these bring about sharper observation. Eg in how many ways are your seeds alike and how do they differ? Carefully phrased questions help children to bring order into chaos and unity in variety.
4. Action questions; - e.g. what happens if? They entail simple experimentation and never fail to provide a result. Children are bound to discover some form of relationship between what they do and the reaction of the thing they handle. This adds to the store of experiences which young children require.</td></tr>
<tr><td>Enokson (1973)</td><td>(i) Convergent –low level of cognition — Recall of given or remembered data
(ii) Convergent –high level of cognition— Integration of processing of given or remembered data
(iii) Divergent –low level of cognition— Recall of given or remembered data
(iv) Divergent –high level of cognition — Integration of processing of given or remembered data</td></tr>
<tr><td>Fraenkel (1966)</td><td><table>
<tr><td>Purpose of question</td><td>Type of question</td><td>Student action desired</td></tr>
<tr><td>Knowledge acquisition</td><td>Factual (key words; who, what, when)</td><td>Remembering</td></tr>
<tr><td>Knowledge synthesis</td><td>Descriptive (key word; how)</td><td>Remembering</td></tr>
<tr><td>Knowledge analysis</td><td>Explanatory (key word; why)</td><td>Reasoning/exercising Judgement</td></tr>
<tr><td>Creative thought</td><td>Heuristic (no answers are more acceptable than others)</td><td>Divergent thinking</td></tr>
</table></td></tr>
<tr><td>Gallagher and Aschner (1963)</td><td>1. Cognitive memory: simple reproduction of facts, formulae, or other items of remembered content through use of such processes as recognition, rote memory and selective recall.
2. Convergent thinking: analysis and integration of given or remembered data.</td></tr>
</table>

	3. Divergent thinking: intellectual operations wherein the individual is free to generate independently his own data within a data poor situation or take a new direction or perspective on a given topic. 4. Evaluative thinking: deals with matters of judgment, value and choice and is characterized by its judgmental quality. 5. Routine: contains a large number of miscellaneous classroom activities i.e. dimensions of praise and censure of others and self, dimensions of structuring, classroom management etc.
Galton, Simon, and Croll (1980)	In their ORACLE project (1975-1980), categorized questions based on the teacher's reaction to students' answers. They have five types. 1. Of fact: any question which requires academic information, e.g. what is? What is the capital of? Numerical (3x5 or 5+1) 2. Closed solutions. Teacher accepted on answer 3. Open solutions, teacher accepted more than one answer 4. Task supervision. Eg. How are going to measure that? 5. Routine. Eg. Why are you out of your place? Questions not related to the aims of the lesson
Graesser, Person, and Huber (1992)	(i) Verification –is a fact true? (ii) Comparison –how is x different from y? (iii) Disjunctive –is x or y the case? (iv) Concept completion –who? What? Where? (v) Definition –what does x mean? (vi) Example –what is an example of y? (vii) Interpretation –how is a particular event interpreted? (viii) Feature specification –what qualitative attributes does entity x have? (ix) Quantification –what is the value of a quantitative variable? (x) Casual antecedent –what caused some event to occur? (xi) Casual consequence –what are the consequences of an event? (xii) Goal orientation –what is the motive behind an agent's actions? (xiii) Enablement –what object or resource enables an agent to perform an action? (xiv) Instrumental/procedural –how does an agent accomplish a goal? (xv) Expectational –why did some expected event not occur? (xvi) Judgmental –the questioner wants the answerer to judge an idea (xvii) Assertion –speaker expresses that s/he is missing some information ((xviii) Request/Directive –speaker directly requests that the listener supply some information.
Guilford (1956)	Guilford's structure of the intellect theory comprises intellectual factors divided into two groups; memory and thinking 1. Memory factors Ability to learn & remember 2. Thinking factors, divided into; i. Cognition/discover factors; becoming aware of mental items or constructs of one kind or another. Under here, something must be, comprehended, recognized or discovered ii. Production factors; the production of some end result. It has two categories **(a)** Convergent thinking; usually has one answer that is regarded as unique & thinking is channeled or controlled in the direction of that answer. E.g. multiple choice tests. **(b)** Divergent thinking; there is much more searching or going off in various directions, no unique conclusion. iii. Evaluation factors; have to do with decisions concerning the goodness, suitability or effectiveness of the results of thinking. It calls for a judgment of some kind
Guszak (1967)	i. Recognition- calls students to utilize their literal comprehension skills in the task of locating information from reading context. ii. Recall- recall factual material previously read.

	iii. Translation- require student to render an objective, part-for-part rendering of s communication. Conjecture- calls for a cognitive leap on the part of the student as to what will happen or might happen. iv. Explanation- inferential in nature, it calls students to supply a rationale which must be inferred by the student from the context developed. v. Evaluation – deal with matters of value rather than matters of fact or inference & thus characterized by their judgmental quality
Herber (1978)	The question categories hierarchically are; 1. *Literal comprehension questions, 2. Interpretative comprehension questions, 3. Applied comprehension questions*
Hunkins (1972)	(i) Centering questions –converging students' thinking on a topic (ii) Expanding questions – raising thinking to a higher level (iii) Distributing questions –involving students in working with data (iv) Ordering questions – classroom management questions
Hyman (1979)	His nonhierarchical classification of questions includes; *1. Definitional, 2. Empirical 2. Evaluative and 4. Metaphysical*
Kaiser (1979)	Classified questions into; *1. Open, 2. Closed, 3. Suggestive, and 4. Rhetorical questions*
Long and Sato (1983)	Analyzed questions in two different categories; 1. *Epistemic questions* and *2. Echoic questions* Epistemic questions • Referential: questions to which the teacher does not already know the answer. Eg have you finished? • Display: questions to which the teacher knows the answer e.g. what is the opposite of up in English? • Expressive: e.g. its interesting the different pronunciations we have now, but isn't it? • Rhetorical: asked for effect only, no answer is expected from listeners, e.g. why do I do that? Because I …. Echoic questions • Comprehension checks (All right?, ok? Does every one understand?) • Clarification requests (what do you mean?, what?, I don't understand) • Confirmation checks (Carefully? Did you say he..?
Marzano (2001)	• Self-system – beliefs about the importance of knowledge, Beliefs about Efficacy, Emotions associated with knowledge • Metacognitive system –Specifying learning goals, monitoring the execution of knowledge, Monitoring clarity, Monitoring accuracy • Cognitive system – Knowledge retrieval- recall, execution, Comprehension- synthesis, representation, Analysis- matching, classifying, error analysis, generalizing, specifying, Knowledge utilization- decision making, problem solving, experimental inquiry, investigation • Knowledge domain –information, mental procedures and physical procedures
Minor (1966)	(i) synthetic questions – answer known, testing students' store of fact (ii) Real questions –questions with specified answers
Moyer (1965)	(i) Primary questions; solicits responses in terms of factual information, reasons, and explanations

	(ii) Secondary questions; declarative statements, sentence fragments, and single words intoned as questions
Nystrand and Gamoran (1997)	They group teacher questions into two; Authentic and test questions Authentic questions are those where the asker has not pre-specified the answer; include requests for information as well as open-ended questions with indeterminate answers. Test questions; - review basic information which has generally only one correct answer
Parsons (1968)	(i) Other: Questions about classroom management or questions unrelated to the learning. (ii) Rhetorical: Questions for which no answer is expected. Set direction of daily lesson. (iii) Informational: Questions asking for recall or observation of bits of information (attributes of a concept which the teacher anticipates will contribute to developing a concept needed to form the generalization. (iv) Leading: Questions asked about responses to informational questions. Teacher focuses attention by giving a clue, mentioning in- formation discovered or means for student to organize information (relate, cite, similarities, classify, or sort objects, reorder). (v) Synthesizing: Questions asked which include reference to relevant concepts developed in the lesson. Questions require relating concepts to form one meaningful idea or generalization.
Pate and Bremer (1967)	Convergent questions- call for a particular response and are designed to evoke one possible answer. Eg. *(i) Simple-recall-* one item, child asked to recall one item of information *(ii) Recall-* choice of multiple items- the learner recalls several items *(iii) Determination of skills abilities-* learner demonstrates his skill, knowledge or proficiency in the area of demonstration *(iv) Skills demonstration-* calls for a verbal demonstration of skills in some area, higher level of thought than above categories Divergent questions- call for a response that has several facets or involve more than one possible answer. E.g. (i) *Example- singular-* higher degree of assimilation and analysis (ii*) Example- multiple-* level of thought more demanding, capable of illustrating with more than one example. (*iii) Principle involved-* gives the child opportunity to see r/ships in the area, compare one principle with another and discuss potential relationships. *(iv) Concept analysis-* thought that involves maximum divergence, draw inferences *(v) Inquiry for opinion-* involves many pupils in a discussion.
Riegle (1976)	Interrogative questions (request for information) i. Empirical- give information about the world based on our experience ii. Analytic- information about r/ships between verbal, logical or mathematical symbols & verified by law of language iii. Value- judge some thing or someone as good or bad iv. Preference- questions about dislikes & likes v. Meta physical- qns about supernatural beings, events, etc. with no agreed upon method of arriving at the answer. Rhetorical questions (do not request for information) vi. Imperative- sentences with an interrogative form but an imperative function. Eg will you open the window please? vii. Declarative- sentences with an interrogative form but declarative function. Eg. Is that any way to treat a law abiding citizen?

	viii. Exclamatory- sentences with an interrogative form but an exclamatory function. Eg. What the hell's going on?! Ambiguous questions (that are functionally or semantically ambiguous) ix. Functional- qns that can be interpreted in two or more ways functionally. Eg. Why don't you do it this way? x. Semantic- qns that can be interpreted in two or more ways semantically. Eg. Explain the civil war.
Ruddell (1974)	(i) factual questions, (ii) interpretive questions, and (iii) Applicative questions
Sanders (1966)	(i) Memory- Recall or recognition of factual or conceptual information. (ii) Translation- Translating ideas from one communication to another, words to pictures etc. (iii) Interpretation- Relating facts, generalizations, definitions, values, skills (iv) Application- presenting problems that approximate the form and context in which they would be encountered in life. (v) Analysis- student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, conclusions, and structure of a statement or a question with an awareness of the thought processes he is using. (vi) Synthesis- students allowed great freedom in seeking solutions. (v) Evaluation- the process of making a judgment about the value of an idea, a solution, a method, using criteria developed by the individual himself.
Schreiber (1967a)	i. Recall of facts, arranging facts in sequential order ii. Making comparisons, identifying supporting facts, drawing conclusions iii. Speculating on outcomes iv. Identifying main part & important parts, stating moral judgment, judgment based on personal experience. Evaluating quality of source material, evaluating adequacy of data v. Describing situations, defining & clarifying information, using globes, maps, uncovering information & raising questions for study
Smith (1969)	Divided questions into; *1. Convergent and 2. Divergent questions*
Smith, Meux, and Coombs (1962)	(a). Defining - ask for meaning of term, identification of a proper noun or symbol (b). Describing -many kinds but does not include value judgements (c). Designing -ask for examples or a classification. (d). Stating -ask for rules, reasons, arguments, beliefs, conclusions, criticisms & recommendations (e). Reporting -asks specifically for what the text or source states about something. (f). Substituting - ask/direct student to substitute, simplify an expression (g). Evaluating -ask for judgment of good or bad, right or wrong etc. (h). Opining -ask for an opinion, but do not include value judgment. (i). Classifying -name class from given example. (j). Comparing & contrasting -ask about r/ship between two or more things (k). Conditional inferring -ask question in form of a conditional (l). Explaining -different kinds exist depending on what kind of explanation is asked (m). Directing & managing classroom - keep the classroom activities moving along.
Taba (1967)	Classified questions hierarchically into; *1. Form concept, 2. Interpret concept and 3. Apply concept*

Wilen (1985)	(i) Low Order Convergent; - questions require students to engage in reproductive thinking. Teacher's intention is to have students recall or recognize information. Responses can be anticipated since emphasis is on memorization and observation (ii) High Order convergent; - questions require students to engage in the first levels of thinking. The Teacher's intentions to have students go beyond recall and demonstrate understanding of information organizing material mentally. Although more thinking is involved at this level, students responses can be generally anticipated (iii) Low Order Divergent; - questions require students to think critically about information. Teacher's intention is to have students analyze information to discover reasons or causes, draw conclusions or generalizations, or support opinions. Students' responses may not be anticipated since higher-level thinking is involved. (iv) High Order Divergent; - Higher order questions require students to perform original and evaluative thinking. Teacher's intention is to have students make predictions, solve lifelike problems, produce original communications, and judge ideas, information, actions and aesthetic expressions based on internal and external criteria. Students' responses cannot be anticipated since the level represents the highest level of productive thinking.

Examining the taxonomies: the interpretive-analysis procedure

Analysis implied breaking the topic, concept, and themes or the terms of a given taxonomy into parts, in order to inspect, understand and or restructure them in a way that makes sense.

The individual question classification taxonomies were analyzed interpretively. Focus was on what the individual authors implied by the several terms and descriptions they each used to characterize the questions into categories. My own preconceived knowledge (experiential knowledge) on matters of teaching was central to understanding the feasibility of examined taxonomies. In critiquing and assessing the taxonomies, a personal reaction was made. It involved exploring the author's way of conceptualizing questions and question categories, compared to how I do or would conceptualize the same questions, procedures, or question categories. In addition, the analysis procedure was informed by the preliminary findings on how teachers conceptualize the nature of questions and questioning (paper I). The process of examination was followed by envisioning how the proposed schemes could be used in teaching situations with respect to how teachers view the nature of questions and questioning. Overall, the analysis involved two important steps;

(i) Reading the article as a whole and determining the purpose, structure, and the direction of the paper

(ii) Critiquing, assessing and evaluating the article's content/themes/terms or taxonomies with respect to the aim of the analysis

A preliminary analysis of the 41 question classification taxonomies revealed that the conceptual ideas behind all taxonomies reflected the earlier work of either Bloom et al. (1956) or Gallagher and Aschner (1963), or a combination of both. I thus grouped the 41 question classification taxonomies into two groups. The first group are a non-hierarchical form of questions reflecting general descriptions of questions as convergent or divergent, originally from Gallagher and Aschner (1963), though some reflect Bloom's ideas as well. This group comprises of taxonomies by authors, e.g., Barnes (1969); Biber et al. (1999); Chinn et al. (2001); Christenbury and Kelly (1983); Clements et al. (1966); Clements (1964); Douglass (1967); Elstgeest (1985); Galton et al. (1980); Graesser et al. (1992); Hyman (1979); Kaiser (1979); Long and Sato (1983); Minor (1966); Moyer (1965); Parsons (1968); Riegle (1976); and Taba (1967). Other non-hierarchical forms of classifying questions included using terms such as, open and closed (Blosser, 1973), real and synthetic (Minor, 1966), authentic and test questions (Nystrand & Gamoran, 1997).

The second group are question category systems that reflect Bloom's hierarchical cognitive levels (Bloom et al., 1956). Examples in this group include question categories by Anderson et al. (2001); Aschner (1961); Blosser (1973); Davis and Tinsley (1967); Fraenkel (1966); Guszak (1967); Marzano (2001); Ruddell (1974); Sanders (1966); Schreiber (1967b); Smith, Meux, and Coombs (1960); and Wilen (1985) (see Table 2 for question categories stipulated by the individual authors). For the final analysis work in paper II (Kayima, 2016), five question classification taxonomies from the two groups were selected based on how best they included the features of the group they belonged to. These included Sanders (1966), Fraenkel (1966), Minor (1966), Blosser (1973), and Nystrand and Gamoran's (1997) question category system (Table 3).

Sanders' (1966) taxonomy is an adaptation of Bloom's cognitive categories and its selection was to represent all the other taxonomies which classify questions based on the complexity of cognitive levels. Fraenkel (1966) devised a taxonomy of questions based on the purpose of the question, and his taxonomy was selected for analysis because of this feature which is not common to most other taxonomies. Minor (1966) and Nystrand and Gamoran's (1997) question categories were selected because the authors introduce unique terms; —'real and synthetic' and 'authentic and test' respectively to characterize questions. This way of categorizing questions is not common with the other taxonomies. Blosser's (1973) question category system was selected for those category systems which distinguish questions into "closed and open" categories. The analysis was followed by a proposition of an alternative framework for use as a guide to chemistry teachers in their questioning practice.

Table 3 Summary of question categories by selected authors

Authors	Question categories				
Sanders (1966)	(i) Memory, (ii) Translation, (iii) Interpretation, (iv) Application, (v) Analysis, (vi) Synthesis, (vii) Evaluation				
Fraenkel (1966)	Purpose	Knowledge acquisition	Knowledge synthesis	Knowledge synthesis	Creative thought
	Type of question	Factual	Descriptive	Explanatory	Heuristic
	Student action desired	Remember-ing	Remember-ing	Reasoning/-exercising judgement	Divergent thinking
Minor (1966)	(i) Real questions and (ii) Synthetic questions				
Blosser (1973)	(i) Managerial questions, (ii) Rhetorical questions, (iii) Closed and (iv) Open questions				
Nystrand and Gamoran (1997)	(i) Authentic questions and (ii) Test questions				

Choosing which schemes to be further examined in paper II

Through a preliminary examination of all literature on the topic of questioning (both recent and old) that I managed to retrieve and to which I had access, I came to a conclusion that there were no new developments in terms of how classroom questions have been conceptualized in recent years that are qualitatively different from the way questions were characterized in much older studies. Instead, I noted a large extent of replication of question categories and an introduction of new terms to describe the same kinds of question categories or types that were originally identified. Though some authors introduced new terms to describe questions that occur in specific subjects, the descriptions accompanying those new terms implied similar meanings as those attached to related/similar question categories in earlier studies. As an example, in Table 4, I show four question category systems describing the nature of questions asked in chemistry classrooms by Nurrenbern and Robinson (1998); Smith, Nakhleh, and Bretz (2010); Zoller, Lubezky, Nakhleh, Tessier, and Dori (1995); and Stamovlasis, Tsaparlis, Kamilatos, Papaoikonomou, and Zarotiadou (2004). These are more recently proposed question category systems compared to those in Table 3. However, a closer examination of the descriptions accompanying the respective category systems reveals that these respective categories are reflected in earlier categories in Table 3. Moreover, these systems were suggested more for written exam tasks than for oral questions. For my further work therefore in paper II, I did not consider these four category systems. This is not to undermine their importance and use in chemistry or science classrooms, but because the question categories in these four taxonomies had been captured in those category systems developed by earlier authors. It was important to focus on original frameworks as much as possible in order to explicate the conceptual ideas behind the development of several existing taxonomies. There are also other recent classification frameworks that I did not consider for analysis or inclusion for a similar reason, such as; Chin's (2007) framework that describes the nature of questioning and teacher questions in science classrooms (e.g., socratic questioning; verbal jigsaw; semantic tapestry; and framing), and the SOLO taxonomy proposed for assessment purposes (Biggs, 1989).

Generally, the authors in Table 4 describe three categories of questions; recall, algorithmic, and conceptual questions. The recall-type and algorithmic questions are those questions at the level of Sanders' (1966) question category system (memory through application levels), which Fraenkel (1966) calls “factual” questions – questions with known/pre-specified answer, Minor (1966) conceptualizes as “synthetic” questions – questions to which the teacher knows the answer, Blosser (1973) calls “closed” questions – questions with pre-specified answers, and Nystrand and Gamoran (1997) characterize as “test” questions – questions to which the questioner has pre-specified answers. The conceptual questions on the other hand are conceptualized as those which require students to do more than reproduction of factual concepts. With conceptual questions, students have to use the acquired factual knowledge to translate information, interpret ideas, extrapolate, and to apply their thinking to new situations. These questions are characterized as higher-order questions (Nurrenbern & Robinson, 1998; Sanders, 1966), open questions (Blosser, 1973), open-ended, real or authentic questions (Minor, 1966; Nystrand & Gamoran, 1997).

Table 4 Examples of more recent question category systems not considered for analysis in paper II

Smith et al. (2010)

1. Definition questions –
    a. Recall, understand, or apply a definition: —open-ended and require the recall, understanding, and/or application of a definition.
    b. Recognize a definition; —multiple-choice and require the recognition of a definition.
2. Algorithmic questions –
    a. Macroscopic-microscopic conversion questions:—require conversions between moles and macroscopic quantities (volumes or masses).
    b. Macroscopic-dimensional analysis questions:—require conversions between units of macroscopic quantities.
    c. Microscopic-symbolic conversion questions: —require stoichiometric conversions of particle or mole quantities of substances, usually based on chemical formulas or equations.
    d. Multi-step questions –Involve multiple steps, frequently based on the use or algebraic manipulation of mathematical formulas.
3. Conceptual questions:
    a. Involve explanation of underlying ideas behind chemical phenomena.
    b. Involve analysis of pictorial representations of chemical symbols or equations.
    c. Involve analysis or interpretation of data. Involve prediction of outcomes.

Zoller et al. (1995)

1. Lower-order cognitive skills (LOCS) –knowledge questions that require simple recall information or a simple application of known theory or knowledge to familiar situations and context; they can also be problems solvable by means of algorithmic processes that are already known to the solver through specific directions or practice.
2. Higher-order cognitive skills (HOCS) –problems unfamiliar to the student that require, for their solution, mare than knowledge application, analysis, and synthesis capabilities, as well as making connections and evaluative thinking on the part of the solver; this includes the application of known theory or knowledge to unfamiliar situations.
3. Algorithmic –questions that require the use of *a* memorized set of procedures for their solutions.
4. Conceptual –questions that may be text-based or diagrammatic and require students to invoke underlying concepts of the basic theories of science in order to answer the question

Nurrenbern and Robinson (1998)

1. Recall questions – ask students to recall facts, equations, or explanations
2. Algorithmic questions – ask students to use information or processes in a familiar way.
3. Higher-order questions – require some combination of the following:
    a. Translation of information from words to symbols or from symbols to words.
    b. Interpretation of information in order to select relevant data or to determine the interrelation among parts.
    c. Extrapolation in order to infer consequences.
    d. Application of principles to new problems or situations that is, to problems or situations that contain some elements of newness or unfamiliarity.
    e. Analysis of information for underlying principles and relationships or for clues to information needed to address a problem or question.
    f. Synthesis of a logical hypothesis, experiment, or model from a collection of inputs.
    g. Evaluation of new information, experiment, or model.

Stamovlasis et al. (2004)
1. Knowledge recall questions 2. Simple algorithmic 3. Demanding algorithmic 4. Conceptual questions

Considering Bloom's (1956) cognitive domain categories, or Anderson et al.'s Bloom revised taxonomy (2001) or Sanders' (1966) question categories with the four question categories in Table 4 (see Table 5 for a summary), for example, the 'remember' category captures part of the lower-order cognitive skills category of Zoller et al. (1995), the recall category of Nurrenbern and Robinson (1998), the 'knowledge-recall' category of Stamovlasis et al. (2004), as well as the definition category of Smith et al. (2010). The 'apply' category captures processes of the algorithmic, conceptual, a part of lower-order and higher-order cognitive skills categories of Zoller et al. (1995), part of the higher order category and the algorithmic category of Nurrenbern and Robinson (1998), the simple algorithmic and conceptual categories of Stamovlasis et al. (2004), as well as the algorithmic and conceptual parts of Smith et al. (2010). The other Anderson et al.'s Bloom revised taxonomy (2001) categories; 'analyze, evaluate, and create' also match with the conceptual and higher-order cognitive skills categories of Zoller et al. (1995), the higher order category of Nurrenbern and Robinson (1998), the demanding algorithmic and conceptual categories of Stamovlasis et al. (2004), as well as Smith et al.'s (2010) conceptual categories.

Table 5 Comparing question categorizations by authors in table 4 with earlier categorizations of levels of thinking by Bloom et al., (1956), Sanders (1966) and Anderson et al., (2001)

Authors	**Levels of thinking**						
Anderson et al. (2001)	Remember	Understand	Apply	Analyze	—	Evaluate	Create
Sanders (1966)	Memory	Interpretatio-n Translation	Application	Analysis	Synthesis	Evaluati-on	—
Bloom et al. (1956)	Knowledge	Comprehensi on	Application	Analysis	Synthesis	Evaluati-on	—
Zoller et al. (1995)	Lower-order cognitive skills	Lower-order cognitive skills, Part of Higher-order cognitive skills Algorithmic Conceptual		Conceptual Higher-order cognitive skills			
Nurrenbern and Robinson (1998)	Recall	Algorithmic Part of Higher-order		Higher-order			
Stamovlasis et al. (2004)	Knowledge-recall	Simple algorithmic Conceptual		Demanding algorithmic Conceptual			
Smith et al. (2010)	Definition	Algorithmic Part of Conceptual category		Conceptual			

What recent question classification framework developers did was mainly to expand the question categories so as to account for most of the questions that are possible in classrooms, and also to account for the cognitive demands of the questions at each level. Recent question classification developers make clear the existing variations in the cognitive demand of questions regardless of the questions being classified in the same group. For example in Table 4, Smith et al. (2010) stipulates different types of questions falling in the definition category of questions. Nevertheless, this was also done in some of the earlier frameworks, for example, in Table 2, Enokson (1973) and Wilen (1985) distinguished between lower-order convergent and lower-order divergent questions and higher-order convergent and higher-order divergent questions.

Drawing on the conclusion that later question classification frameworks are a modification of earlier frameworks, and some a reproduction with minor changes in the terms used to characterize questions, I deemed it reasonable to consider the earlier schemes for further examination. This would provide for exploring original ideas, the meanings and descriptions attached to different terms of questions, as well as the perceived cognitive demands of particular questions and questioning situations.

3.1.3 Paper III: Exploring the situational adequacy of teacher questions in science classrooms

Paper III is a methodological study in which a three-step approach for studying and evaluating teachers' questions is suggested and advanced. The development was as a result of my finding out that there was not a known systematic method that could be used to study and evaluate teacher questions in context.

The proposition of the approach followed a detailed examination of available frameworks to analyze their ability to characterize teacher discourse. Also, a review of literature was made concerning how teachers' questioning had been conceptualized in research. This was done to ensure that the proposed methodology is consistent with how questioning practice is conceptualized by a community of education researchers. The proposed approach was tested for its applicability and feasibility by analyzing the teachers' questions in eight science lessons from the 1999 TIMSS- study.

The development of a conceptual framework for analysis of teacher questions based on their situational adequacy

Step I: Characterizing the context in which questions occur

From a sociolinguistic perspective, teachers' questions are not simply teacher behaviors but mutual constructions of both teachers and students (Carlsen, 1991). This implies that meaning or the question's value is dependent on the teaching context where it is used. Thus, the first step to understanding a teacher's question would be to characterize the context within which such a question occurs (Farrar, 1986; Roth, 1996). The context in which questions occur is described by sociolinguists as the setting as the speaker (teacher) finds it and the conversational situation as actively modified by the teacher and students (Carlsen, 1991). The context is considered to encompass the constructions of the historical, physical, and social aspects of the setting along with the past, present, and future verbal and nonverbal actions (Ochs, 1979, p. 5).

In addition to questions classification frameworks examined in paper II (Kayima, 2016), there are three theoretical frameworks that have been suggested in the past for analyzing teacher classroom discourse. These are the Initiation—Response—Feedback/Evaluation (IRF/E) (Lemke, 1990; Mehan, 1979; Sinclair & Coulthard, 1975), the Initiation—Response—Feedback—Response—Feedback (IRFRF) (Mortimer & Scott, 2003) and the Identification, Interpretation—Evaluation, Response (IIER) framework by Louca et al. (2012). As described by their respective authors, the IRF/E and IRFRF are conceptualization of patterns where the teacher initiates the talk, students respond and then the teacher provides feedback or follow-ups. On the other hand, according to the authors of the IIER framework, it focuses on what the teacher identifies as important to respond to, how s/he perceives students' contributions during the science conversation, how s/he evaluates those contributions, and how s/he responds to them (Louca et al., 2012).

To establish a method for characterizing the context in which teacher questions occur, the above three theoretical frameworks were also examined. The focus of the examination was on the ability of a given framework to allow for the exploration of the discourse leading to a teacher's question, the nature of the question itself, how the student responds to the question, and how the teacher deals with the questioning situations before going over to another activity. In other words, characterizing the context implied examining the teacher's and students' minute by minute activities, which included questions and responses from both sides, and nature of actions taken by the teacher as s/he reacts to particular situations during the interaction. Earlier research critiques of the existing frameworks analyzing teacher discourse, most of which are discussed by Louca et al. (2012), were also taken into account. From an examination of the three frameworks, Louca et al.'s (2012) IIER framework qualified as one that would allow for a proper characterization of the context in which a question occurs. The way the IIER framework is conceptualized by its authors aligned with our interest in examining the teacher's minute by minute teaching decisions. The parts in Louca et al.'s IIER framework that were considered as relevant to characterizing the context are the "identification" and "response" parts. The identification part according to the authors (Louca et al., 2012), is concerned with "identifying what the teacher responds to in terms of students' discourse contributions", whereas the "response part concerns how the teacher responds to such students' discourse contributions" (p. 1829). These two parts were considered as making it possible to analyze the discourse leading to the question; an analysis that would enable an understanding of what is happening in a particular context, why it happens, how it happens, and how the teacher addresses it.

When considering what should comprise the identification part of their IIER framework, Louca et al. (2012) revisited earlier studies on science classroom practices by Chin (2006); Roth (1996); and van Zee and Minstrell (1997b). From reviewing the work of the above three authors, Louca and colleagues came up with different aspects and situations constituting what a teacher would respond to during science instruction. These include, students' correct and incorrect knowledge claims, students' questions and comments, students' experiences, as well as the teacher's own reactions to students' reactions in a given teaching situation (Louca et al., 2012, p. 1831). They thus summarized five categories of students' activities or actions (verbal and non-verbal) and situations that they considered to account for what the teacher would respond to in the identification part of the IIER framework. These have been summarized in Table 6.

[3]Table 6 A summary of what a teacher responds to in the Identification part of the IIER framework

Aspects of what teacher responds to in the identification part of the IIER framework
Students' knowledge claims • ***Scientifically accepted knowledge claim:*** The teacher identifies that a student states a scientifically accurate knowledge claim • ***Non-scientifically accepted knowledge claim:*** The teacher identifies that a student states a non-scientifically accurate knowledge claim • ***A student changes her knowledge claim:*** The teacher identifies that a student states a knowledge claim, that is, different from a knowledge claim she stated before in the conversation about the same topic • ***Student question about a knowledge claim:*** The teacher identifies that a student is posing a question about a stated knowledge claim • ***Different students present different knowledge claims in the conversation:*** The teacher identifies that different students in the conversation stated different knowledge claims about the same topic
Logic and reasoning • ***Hidden assumption:*** The teacher identifies that a student's knowledge claim has an underlying assumption that the students in the conversation neither have addressed nor realized • ***Correct analogy:*** The teacher identifies that a student draws a correct analogy about how different objects/situations/phenomena share similar behavior/characteristics etc. in some respects • ***Incorrect analogy:*** The teacher identifies that a student draws an analogy about how different objects/situations/phenomena share similar behavior/characteristics etc. in some respects that is not valid • ***Claims for a dependency:*** The teacher identifies that a student claims that there is a dependency between different things/factors • ***Grounds for a dependency:*** The teacher identifies that a student provides evidence in support of a claim about a dependency between different things/factors • ***Grounds for a knowledge claim:*** The teacher identifies that a student provides evidence in support of a knowledge claim
Students' experiences • ***Experience from everyday life related to the phenomenon under study:*** The teacher identifies that a student states everyday life experiences related to the phenomenon under study • ***Lack of experience (examples) related to the phenomenon under study:*** The teacher identifies that students in the conversation have failed to use experiences they have related to the phenomenon under study to support their ideas
Conversation • ***A student changes the direction of the conversation:*** The teacher identifies that a student's conversational contribution is on a topic different from the topic of the conversation so far (off-track)

[3] Taken from Louca et al.'s (2012) work on pages 1832-1933

• ***The teacher begins a conversation about a new topic:*** The teacher begins a conversation about a new topic • ***A student asks a question related to the topic of the conversation:*** The teacher identifies that a student poses a clarification question about the topic of the conversation
<u>Epistemology</u> • ***A student asks a question about the kind/ form of the answer that the teacher expected:*** The teacher identifies a student poses a clarification question about the teacher's expectations on the kind/form of the answer that students should provide after a teacher's question (i.e. an example, a theory, a numerical example) • ***Lack of understanding the differences/ similarities among contradicting knowledge claims offered in the conversation:*** The teacher identifies that students in the conversation fail to understand the differences or similarities between different knowledge claims offered in the conversation

In Table 7, a representation of how the IIER framework could be used in characterizing the context is shown. The process starts with identifying what the teacher is responding to, and how he responds. The five descriptive categories of the identification part of the IIER framework (Table 6) are followed. This enables understanding what is happening in a particular teaching situation or context.

However, on applying the framework to the actual analysis process as described in the later section, I realized that the IIER framework does not throw light on how the researcher characterizing the observed context comes to construct his/her own understanding of the context which s/he studies. This is where I considered Davidson's conceptualizations regarding the interpretation of verbal behavior (Davidson, 1973; Klaassen & Lijnse, 1996) to be useful.

Davidson (1973) explains that there are two problems in interpreting verbal behavior. The interpreter does not know what the speaker's sentences mean, and neither does s/he have direct access to the contents of his/her propositional attitudes, beliefs or desires (p. 18). These problems are solved by the interpreter performing his/her own thought experiment. S/he projects him/herself into the speaker's shoes and assumes that s/he does or would believe what the speaker would believe or believes, given that s/he were in the speaker's shoes. To achieve this, the interpreter must believe that the speaker holds true the sentences s/he speaks. In addition, the interpreter also takes into account the times (conditions) at which the speaker's sentences are held true. This implies that whatever a speaker's sentence means is something that the speaker believes, that is, the interpreter can assume that the meanings of the speaker's sentences must be truths. With both a list of the speaker's sentences and a list of the true propositions which might be their meanings, the interpreter then starts to give a theory of meaning for the sentences by matching up the truths with the sentences. That is, "detect circumstances under which the speaker selectively holds true her sentences, match the speaker's expressions to expressions of your own, assign such meanings to a speaker's expressions that she comes out as consistent and a believer of truths" (Klaassen & Lijnse, 1996, p. 129). What the interpreter constructs or reconstructs are the meanings that s/he assigns to a speaker's expressions or transcribed behavior.

Table 7 The IIER framework for characterizing questioning situations

Transcript:		**Identification part:** What did the teacher respond to?	**Response part:** How did the teacher respond?
00:00:15	Teacher: Okay. Now let's just look at where we're at. Yesterday you know very well what we did. Okay, Liam, how about you telling me what we did- what we finished off doing yesterday.	***Conversation:-*** Teacher begins and directs a conversation. He calls on the class to recall what was done a day before. The context is about reviewing what was done in the previous lesson.	Teacher clarifies the topic of the initial talk/conversation. He tells students that they indeed know what they did in previous lesson, and asks a recall question to a single student.
00:00:25	Student: Um yesterday we were examining the hairs, but today we prepared- oh-	***Student's knowledge claim*** Teacher pays attention as a student states what was done in the previous lesson. Context remains unchanged, it is about recalling what was done in a previous lesson	Pauses for seven seconds
00:00:32	Teacher: Keep going.	***Student's knowledge claim:*** Teacher recognizes that a student is not making clear his claim of what was done yesterday and he encourages the student for further elaboration	***Prompting for knowledge claims:*** Teacher tells student to keep going

00:00:33	Student: And we were doing, last lesson we were studying the layers of paint.	***Student's knowledge claim*** Teacher pays attention as the student continues to elaborate about what was exactly done in the previous lesson	***Prompting for student's knowledge claims***. Teacher waits for five seconds
00:00:38	Teacher: Okay.	***Student's knowledge claim*** Teacher identifies that the student rightly what was covered in the previous lesson.	Gives an evaluation remark

Step II: Identifying and evaluating the questions: A protocol to evaluate questions based on their situational adequacy

Though the IIER framework provides for conceptualizing the context leading to the teacher's questions, it does not evaluate the suitability of the questions themselves. There was thus the requirement for a criterion that could be used to make a statement about the question's suitability after characterizing the context. Thus the work towards developing what was termed as a "protocol" for evaluating a question's suitability started. To design this protocol, a recapitulation of what other researchers had found about questioning (the nature of teacher questions) was first performed, as well as a review of how questions have been conceptualized in research.

First, a criterion was needed that would allow for judging a teacher's question as relevant or inappropriate in a teaching situation. The term "relevant" is used here to imply that the content of a teacher's question is the very content or part of the topic/aspects being addressed by both the teacher and students in a particular teaching situation. In other words, the question is suited for a particular purpose that concerns the subject matter under consideration. We drew on Sanders' (1993) characterization of a good question to formulate a criterion to qualify a teacher's question as relevant or not. Sanders notes that not only should the teacher's question be clearly stated, easily understood, and unambiguous, it should focus on the major components of the lesson (pp. 19-20). With these descriptive features we formulated our first criterion for considering the suitability and thus the relevance of the teacher's question. Accordingly, a teacher's question in a given teaching situation would be considered a relevant question if such a question focuses on the salient elements in the lesson, which are linked to the learning goal. It should align with the content and the current context of the discourse, clear, easily understood by students, and unambiguous.

There are two other forms of questions important for classroom operations and thus relevant, regardless of whether they are linked to the topic of study or not. These two forms of questions are described by Blosser (1973) as managerial and rhetorical questions in her question category system (see Table 2). Other authors also recognize these questions in their respective question classification frameworks, For example, Gallagher and Aschner (1963) categorized them as routine questions, Davis and Tinsley (1967) characterized them as procedure questions, while Hunkins (1972) referred to them as ordering questions (Table 2). Managerial questions can be either structural questions that keep the classroom operating, move activities and pupils toward the desired goals, or can be affective questions that elicit expressions of attitudes, values or feelings of students. Rhetorical questions serve to reinforce a point, and no students' responses to these questions are expected. Therefore, as part of our first criterion for identifying a relevant question, a teacher's question aimed at keeping classroom activities moving in a direction desired by the teacher, and that which addresses a student's particular need (affective) in a given situation, would be considered relevant questions.

Second, having established a criterion to inform on whether a certain teacher's question is relevant, it was needed to explore what kind of question that question is. We needed to develop a set of characteristic features that describe certain kinds of questions that teachers ask. These would allow for aggregating questions with similar features together for further exploration. By reviewing literature accounts, we found that several scholars have attempted to describe the several forms of classroom discourse, to which questioning is a part. These scholars e.g. Edwards and Mercer (2012); Orsolini and Pontecorvo (1992); van Zee (2000); van Zee, Iwasyk, Kurose, Simpson, and Wild (2001) and van Zee and Minstrell (1997b), explored and characterized the nature of questions teachers often use in science instruction. For instance, van Zee et al. (2001)

identified in their multiple studies of science instruction by different teachers, that the teachers evaluated student thinking by asking students to clarify their ideas, to explore various points of views, and to monitor the discussion and students' own thinking. van Zee and Minstrell (1997b) noted that there are teacher questions that emerge as a response to a student statement, and such questions seek to help students to articulate their ideas, beliefs and conceptions in a better and productive way. Orsolini and Pontecorvo (1992) reported that most frequent categories of teacher discourse were rephrasing, requests for clarifications and explanations from students. What the review of literature revealed is that teacher questions not only involve evaluating students, but also include prompts, clarifications and restatements.

Drawing on the above literature accounts, we further broke down a relevant teacher's question by the characteristic features that would describe that specific question. That is, a relevant teacher's question could be, (i) a teacher's prompt of students' ideas, (ii) a clarification of a previously stated idea, (iii) a question that seeks to evaluate students' contributions in the conversation, (iv) that seeks to draw connections among different students' contributions, (v) that engages students in arguments about a phenomenon under study, (vi) a question to develop explanations about a previously stated idea or reasoning, (vii) a prompt for students experiences supporting ideas about a phenomenon or their reasoning, (viii) a question that seeks clarification about students' knowledge claims (content), (ix) that seeks clarification about similarities or differences among knowledge claims, (x) a question that seeks to refocus students on the lesson's salient features, or (xi) question that evaluates, reviews, or restates factual knowledge, and or summarizes what is important. A relevant teacher's question could also be an affective or managerial question. All of these features including the criterion for qualifying a teacher's question as relevant are summarized in Table 8.

An obvious but also important aspect realized after deciding on the criterion that would inform on the relevancy of a teacher's question was that a teacher's question being relevant alone is not enough to tell whether the question adequately served its intended aim. In other words, a teacher's question could satisfy our criterion set for being considered a relevant question, but this does not necessarily mean that the question adequately served its intended purpose. Indeed as Fraenkel (1966) put it, a right question is one that will serve a teacher's desired intention or purpose in a given teaching situation. Our conviction was that most of a teacher's questions would be questions that are linked to the content or topic of study, but not all of them would satisfactorily serve their intended purposes. There was thus the need to develop features that would allow for qualifying a question in terms of whether it adequately served its intended purpose or not. Thus, we developed two subcategories of a relevant teacher's question, that is, relevant-adequate and relevant-convenient. It was decided as working definitions that, a teacher's question would be qualified as "relevant—adequate" if it satisfies the requirements of being relevant, and satisfactorily addresses what it is intended to address as according to the analyst's judgement. Also, that a question be judged "relevant—convenient" if it qualifies to be relevant but does not satisfactorily address the student's current response, reaction, or problem situation, it is an affective, rhetorical or structuring question that is unnecessarily posed, or it is a dead-end question terminating a current talk. The two categories relevant-adequate and relevant-convenient with their accompanying descriptive features are also summarized in Table 8.

Finally, it is obvious that if a teacher's question does not fulfill the described criterion for being relevant, then it's considered irrelevant. Here we chose to use the term "inappropriate" to refer to those questions that fail to satisfy the criterion for being relevant. The term inappropriate is used in the sense that the analyst finds a teacher's question not suitable in the context in which it has been applied, or it is not proper in its formulation to be able to serve its intended purpose. The following features were identified to inform on the inappropriateness of a question. That is, the question is vague or unclearly stated by the teacher for it to be understood by the students, they are multiple questions at the same time thereby confusing students on what to respond to first, it is a question for which its answer is implied in the very question (catch question), the question is a biased one presented in a way that a particular answer is favored over others, or it is a question about extraneous matters not focused on the salient elements in a lesson. These features are also summarized in Table 8.

Table 8 Protocol for evaluating the question's adequacy in a context

A: QUESTION IS RELEVANT	B: RELEVANT –ADEQUATE	C: RELEVANT – CONVINIENT	D: INAPPROPRIATE
• The question focuses on the salient elements in the lesson – linked to the learning goal, and aligns with content and current context of discourse and; A1: i. Prompting students' ideas about a situation or phenomenon ii. Prompting for clarifications of a previously stated idea or question from the teacher or student iii. Seeks to evaluate students contributions in the conversation iv. Seeks to draw connections among different students contributions v. Engage students in arguments about a phenomenon under study vi. For development of explanations about a previously stated idea or reasoning vii. Prompting for students experiences supporting ideas about a phenomenon or their reasoning viii. Seeks clarification about students' knowledge claims (content) ix. Seeks clarification about similarities or differences among knowledge claims x. Refocusing questions – clarifications about the direction of the conversation xi. Evaluate, review, or restate factual knowledge and or summarize what is important A2: Affective question deemed necessary A3: Dead-end question deemed necessary	Belongs to A and satisfactorily addresses what its intended to address	1. Belongs to **A1** but does not satisfactorily address the student's current response, reaction, or problem situation 2. **A2** – Affective question – unnecessarily posed 3. **A3** –Dead-end question –can be yes/no question or just a word or phrase – terminating any further pursuance of the matter 4. **A4** –Rhetoric question- teacher answers the question himself 5. **A5** – Structuring question – unnecessarily posed	1. Vague – unclear, students are not really sure what it is the teacher is asking 2. Multiple questions – students confused on what to respond to first 3. A catch question –the answer to the question is implied in the question itself 4. Bias question – the question dictates only one side of the answer 5. Questions students about extraneous matters

A4: Rhetoric question deemed necessary A5: structuring question deemed necessary	

Step III: Categorizing questions according to level of thinking they elicit
In agreement with conclusions by earlier researchers (e.g.; Gall, 1970; Marzano, 2001; Riegle, 1976), it is difficult to directly measure or observe cognitive behaviors in regard to determining the level of thinking a given question can cause. Nevertheless, question classification taxonomies have been continuously employed in classifying teacher questions based on the level of thinking the questions are perceived to cause in students (Kayima, 2016). The observable features with which the analyst can inform about the cognitive demands of a question, range from having a knowledge about the quantity of work needed (e.g., short answer, long answer, computations involved, etc.), the time needed to arrive at the answer, as well as the resources a student requires to finish the task. However, findings about the cognitive correspondence between a teacher's question and a student's response remain inconclusive (Brophy, 1986; Dillon, 1982; Mills et al., 1980). Yet, this topic seem to have had little attention in the recent years. Researchers seem to literally agree that questions characterized as higher-order questions tend to elicit higher-order thinking and responses from students.

In step III, the analyst can go ahead to qualify a teacher's question by the level of thinking the questions are perceived to elicit in students. S/he could employ a suitable scheme from a number of existing question classification frameworks (Kayima, 2016). I use the word "perceive" here on grounds that it is difficult to directly observe the level of cognition a student subjected to a given question is performing at (Gall, 1970). Different authors have characterized questions using different terms. For example, some authors distinguish questions into divergent and convergent (Gallagher & Aschner, 1963), authentic and test questions (Nystrand & Gamoran, 1997), real and synthetic questions (Minor, 1966), while others modified cognitive categories of Bloom et al. (1956) to develop alternative question categories, e.g. Sanders (1966);

Smith et al. (1962) and Anderson et al. (2001) (see Table 2 for a summary of each of these question categories).

A revised form of Bloom's cognitive domain categories would be suitable for classifying questions based on levels of thinking the questions are perceived to elicit in students. Anderson et al. (2001) modified Bloom's cognitive domain categories into six levels of thinking: remembering, understanding, applying, analyzing, evaluating, and creating (Table 2). Their framework can be applied in the third step of our methodological approach.

Finally, the three steps described above form a complete three-step methodological approach that can be used to explore teacher questions and also be able to examine their respective contributions within the contexts or teaching situations in which they are used. In summary, the three steps involve, (i) characterizing the context in which questions occur, this can be achieved by employing the IIER framework by Louca et al. (2012), that provides the possibility to analyze minute by minute teacher discourse, (ii) identifying and evaluating the questions, this can be achieved by using the designed protocol in Table 8, to be able to judge the question's value within a specific teaching situation, and (iii) determining the cognitive level of questions, this can be achieved by the use of Bloom's revised cognitive domain categories by Anderson et al. (2001). These three steps are summarized in Figure 1 below.

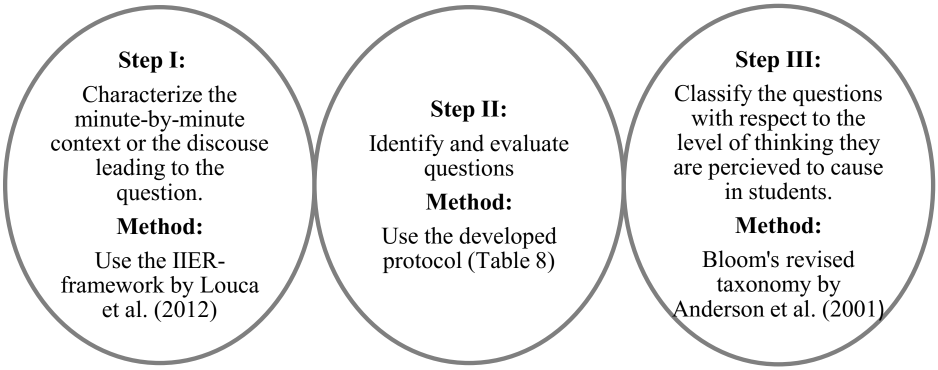


Figure 1: Conceptual framework for exploring the situational adequacy of teacher questions

Applying the approach to the study of teacher questions

Data sources and selection

The proposed three-step methodological approach to studying and evaluating teacher questions was tested by analyzing eight science lessons from the 1999 TIMSS-video study. The purpose for the analysis was to establish whether the proposed method is applicable and feasible. In addition, the aim was also to explore the results that can be generated by the approach. These videos are freely accessible. The videos from Australia and the United States were chosen mainly because English was the medium of instruction in these lessons as opposed to the lessons that were recorded by the TIMSS group from other countries. Having English as a medium of instruction in the analyzed lessons was crucial for the analysis process, since it was a language the analysts could also follow properly.

The TIMSS website provides free access to both lesson videos and their accompanying English transcripts. This means that even when one cannot follow the teaching in a language other than English, one could read the transcripts and be able to understand what is happening during the instruction. As analysts, we had an awareness of this reasoning which we to some extent agree to. Nevertheless, for the work of analyzing and interpreting the minute by minute classroom activities, relying on transcriptions alone is insufficient. Classroom activities are not only limited to what the teacher or student say out loudly (verbal behavior), but also includes how s/he says it, the tone of the sound, the expressions accompanying the words, teacher movements in the classroom, and classroom interruptions or noise (unwanted activities). All these contribute to an understanding of the discourse leading to a teacher's question. Relying only on a transcript would deprive the analyst of access to some of the classroom activities as needed to derive a sufficient understanding of the context, since s/he is not able to follow the lesson.

Further still, Gadamer (2004) puts forward some philosophical arguments about the need for a shared language in interpreting verbal or non-verbal behavior, that also informed our position on selecting the videos to be analyzed. He maintains that; "all understanding is interpretation, and all interpretation takes place in the medium of a language that allows the object to come into words and yet is at the same time the interpreter's own language" (p. 390). Gadamer argues that;

> "Every conversation presupposes a common language, or, it creates a common language. Something is placed in the center, as the Greeks said, which the partners to the dialogue both share, and concerning which they can exchange ideas with one another. Hence agreement concerning the object, which it is the purpose of the conversation to bring about, necessarily means that a common language must first be worked out in the conversation. This is not an external matter of simply adjusting our tools, nor is it even right to say that the partners adapt themselves to one another but, rather, in the successful conversation they both come under the influence of the truth of the object and are thus bound to one another in a new community. To reach an understanding with one's partner in a dialogue is not a matter of putting oneself forward and successfully asserting one's own point of view, but being transformed into a communion, in which we do not remain what we were" (Gadamer, 2004, p. 371).

Though Davidson (2005) refutes the idea of a common language in interpreting behavior (verbal or non-verbal), by arguing that understanding "is always a matter not only of interpretation but of translation, since we can never assume we mean the same thing by our words that our partners in discussion mean", that, "it is only in the presence of shared objects that understanding can come about" (pp. 274-275), it was our conviction that having a common language with teachers in the videos would provide the needed access into the worlds of these teachers.

Information on the eight selected science video lessons

The eight lessons from the two countries where English was used as the medium of instruction were chosen. They were all eighth-grade science lessons, each addressing a different science topic. The topics cut across all science subject disciplines, such as chemistry, physics, biology, and earth science. In Table 9, a summary of the respective topics handled in each lesson and the length of each lesson are given, as well as the codes used on the TIMSS website for each lesson video. In a report by Roth et al. (2006) they state that "the average eighth-grade science lesson in each of the five countries was taught by a teacher with, at minimum, postsecondary education or science education and a certification to teach eighth-grade science" (p. 16). To be more specific on the lessons conducted in the countries Australia and USA, which were of interest to the work done in paper III, only 4 % of teachers in science lessons from the USA had a qualification below undergraduate, 85 % of the teachers had an undergraduate degree and 11% teachers had a graduate degree. On the other hand, 61 % of teachers in Australian lessons had an undergraduate degree qualification, with the rest each having a graduate degree, and non below undergraduate (Roth et al., 2006, p. 16). This picture shows that the teachers who conducted the science lessons that were selected for our analysis were both qualified and certified to teach eighth-grade science in their respective countries.

Table 9 A summary of information about the lessons analyzed in paper III

Country	Lesson no ¥	Online (web) code ¥¥	Lesson topic	Duration (minutes)
Au*	1	AU1 Finger prints	Making fingerprints on different surfaces	44
Au	2	AU2 Metals and non-metals	About the chemical properties of metals and non-metals	33
Au	3	AU3 Kidney dissection	Dissecting kidneys	34
Au	4	AU4 Energy transfer	Energy transfer and energy transformation	74
USA**	5	US1 Weather	Weather maps	56
USA	6	US2 Sunspots pulleys	About sunspots and pulleys	51
USA	7	US4 Rocks	Rocks	41
USA	8	US5 Blood	About the heart	45
				378 min.

* Australia
** United States of America
¥ The corresponding lesson number was used as the entry code for respective lessons in tables of results
¥¥ Online (web) codes can be used to locate the videos at http://www.timssvideo.com/videos/Science

Prior to analyzing and evaluating the questions used by each teacher in the eight selected lessons, we explored how each of the selected lessons was instructionally organized. This information was expected to inform our understanding of the analyzed classroom contexts. For example, the information would provide clues into why teachers employed the different forms of questions in particular classroom settings. Roth et al.'s (2006) descriptions of different classroom activities were adopted in identifying and classifying classroom activities in each of the eight lessons. Each of the eight selected lessons comprised at least one of the following activities, (i) review of previous lesson, (ii) independent practical activity, (iii) independent seatwork activity, (iv) whole-class practical activity, and or (v) whole-class seatwork activity. According to Roth et al. (2006), independent practical activities include hands-on work such as students conducting a laboratory experiment, students working either individually or in small groups on tasks that involve observing, handling, or manipulating objects, or materials, whereas whole-class practical activities involve teacher demonstrations ranging from simple displays of science-related objects to displays of objects with related phenomena to demonstrations of experiments. Independent seatwork activities include students working individually or in small groups on student assignments, copying notes, or reading silently, while whole-class seatwork activities take the form of oral lectures or discussions (p. 40). Table 10 shows the main classroom activities involved in each of the selected lessons.

Table 10 Classroom activities involved in each of the eight lessons

Classroom	Lessons							
Main class activities	1	2	3	4	5	6	7	8
Independent practical	yes	yes	yes	yes	yes	yes	–	–
Independent seatwork	yes	yes	yes	–	–	–	–	–
Review-activity	yes	yes	yes	–	yes	–	yes	yes
Whole-class practical	–	yes	yes	yes	–	yes	yes	–
Whole-class seatwork	–	–	yes	yes	yes	–	–	yes

The analysis process: characterizing the context leading to a teacher's question and evaluating the question's adequacy in that specific context

The analysis started by exploring the discourse leading to a teacher's question. The IIER framework was employed at this stage to illuminate what takes place minute by minute and turn by turn. Exchanges between the teacher and his/her students were examined by analyzing what is being talked about, the relationship between what is being talked about and what was talked about before, as well as how what is being talked about leads to what happens next. All visual (video), audio (teacher and students' talk), and written (transcribed data) were followed and studied as we sought to ascertain what exactly happened as the context was being modified by both teacher and students in the respective lessons.

The eight written transcripts of the individual lessons were imported into Nvivo-11 analysis software. We created nodes in Nvivo-11 to qualify questions as relevant or inappropriate, relevant-adequate or relevant-convenient (Table 8). The six levels of thinking by Anderson et al. (2001) were also used as nodes in Nvivo-11 software, to allow for aggregating questions in the different group categories based on the level of cognition the questions were conceptualized to elicit in students. Below[4], an illustration is shown about how we worked through the process of conceptualizing the context leading to a teacher's question, and identifying and then judging the question's suitability within the characterized context.

1. Teacher: Okay. Now let's just look at where we're at. Yesterday you know very well what we did. Okay, Liam, how about you telling me what we did- what we finished off doing yesterday?
2. *Student: Um yesterday we were examining the hairs, but today we prepared- oh-*
3. Teacher: Keep going.
4. *Student: And we were doing, last lesson we were studying the layers of paint.*
5. Teacher: Okay.
6. *Student: Different colors and pigments.*
7. Teacher: And so what did you learn- what did you learn from that? Karen.
8. *Student: I don't know- [other students in the background mention] "colors"*
9. Teacher: Sorry?
10. Teacher: Lots of different colors.
11. Teacher: Oh, okay, fine. Lots of different colors. All right. Do you agree Daniel?
12. Student: Yes, I agree.

The teacher starts the lesson by reviewing what was learnt a day before. He directly tells students that they know what was done in the previous lesson (line 1). Picking on one student, the teacher requests him to remind the class what was covered a day before. The context is about reminding themselves about previous work before commencing with the current topic. We found this teacher's question to the student in

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[4] Excerpt taken from lesson 1 —AU1 –finger prints (Table 9)

line 1 to be adequate since it addressed the teacher's intention at that particular class situation, and it was clearly understood by the student who started to answer immediately in line 2. The teacher follows up the student's response in line 3. He encourages the student by telling him to keep going. The teacher seems satisfied with the content and direction of the student's response to the initial question in line 1.

In line 7, the teacher poses another question indicating that he concurs with what the student has given as response, but he would like to know what the student himself learnt from what he just described. However without waiting, the teacher chooses another student Karen to respond to the asked question in line 7. Karen's response is "I don't know" (line 8). There are however other students' voices that come up with a response "colors" (line 8), which the teacher immediately picks up and amplifies in line 10. Our conclusion here is that the teacher overlooks Karen's submission that "I don't know". We noted that the teacher takes on others' students' responses and either ignores or forgets to attend to Karen's response. By saying that "I don't know" (line 8), this would warrant a teacher's attention as to why a student would respond in that way, also given that the talk was about a review of previous work. Nevertheless, Karen's voice was suppressed by other students who were in a better state to remember. Therefore, the question in line 7 according to our assessment is "relevant-convenient". The teacher asks another question in line 11, "do you agree Daniel?" Daniel responds; "yes" (line 12). According to our protocol (Table 8), this a typical yes/no question that we also characterized as a "dead-end" question because it limits students to only saying either yes or no, without further expressing their positions/thinking. It was nevertheless realized that the question suits in the context of the talk and is thus relevant in that respect. The question is however "relevant-convenient" because of the described limitation.

Inter-rater reliability

After I had coded all of the eight lessons, one of the lessons was randomly chosen for coding by another rater with whom I co-author study (paper) III. The results of the two raters were compared for 96 questions that were coded from the selected lesson.

Cohen's kappa (κ) was calculated to determine the level of agreement between the two raters. Calculation of the inter-rater reliability, Cohen's κ, was only possible for the categories that fulfilled the condition for being mutually exclusive, for example the categories with which no overlaps were noticeable or possible (Cohen, 1960, p. 38). Thus, Cohen's κ was run to determine the level of agreement between the two raters, first, on whether a teacher's question was relevant or inappropriate, and second, on whether a teacher's question was relevant-adequate or relevant convenient. The results of the inter-rater reliability calculation are shown in the Tables 11 and 12 respectively.

From Table 11, the resulting Cohen's kappa (κ) of 0.708 indicates that the proportion of agreement between the two raters on whether a teacher's question was relevant or inappropriate is a substantial one as from the scale described by Landis and Koch (1977). Further still, since $p = 0.000$ (implying that $p < 0.0005$), the calculated kappa coefficient is statistically significant. By using the expression, Estimate ± 1.96SE, where SE is the standard error, also given in Table 12 as part of symmetric measures, a 95 % confidence interval was obtained. Therefore, from Table 11 there was a substantial agreement (good agreement) between our two judgements in regard to whether a teacher's question was relevant or inappropriate, $\kappa = 0.708$ (95 % CI, 0.467 to 0.949), $p < 0.0005$.

This substantial level of agreement could further be seen by looking at the cross tabulation results in Table 11, and by considering both the sensitivity and specificity of the performance of the task. For example, out of the 86 questions classified by rater 1 (Festo) as relevant questions, 84 (97.7 %) questions were also classified by rater 2 (Arne) as relevant questions. Still in Table 11, of the 10 questions classified by rater 1(Festo) as inappropriate questions, 7 (70 %) questions were also classified by rater 2 (Arne) as inappropriate questions.

The results in Table 12 also indicate that there was a good agreement between our two independent judgements of a teacher's questions either being relevant-adequate or relevant-convenient, Cohen's $\kappa = 0.735$ (95 % CI, 0.563 to 0.907), $p < 0.0005$.

Table 11 Results for calculation of inter-rater reliability Cohen's Kappa (κ): Variables: a teacher's question is relevant or inappropriate

Rater 2-Arne * Rater 1-Festo Cross tabulation					
			Rater 1-Festo		Total
			Inappropriate question	Relevant question	
Rater 2-Arne	Inappropriate question	Count	7	2	9
		% within Rater 2-Arne	77,8%	22,2%	100,0%
		% within Rater 1-Festo	70,0%	2,3%	9,4%
		% of Total	7,3%	2,1%	9,4%
	Relevant question	Count	3	84	87
		% within Rater 2-Arne	3,4%	96,6%	100,0%
		% within Rater 1-Festo	30,0%	97,7%	90,6%
		% of Total	3,1%	87,5%	90,6%
Total		Count	10	86	96
		% within Rater 2-Arne	10,4%	89,6%	100,0%
		% within Rater 1-Festo	100,0%	100,0%	100,0%
		% of Total	10,4%	89,6%	100,0%

Symmetric Measures					
		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	,708	,123	6,949	,000
N of Valid Cases		96			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					

Table 12 Results for calculation of inter-rater reliability Cohen's Kappa (κ): Variables: a teacher's question is relevant-adequate or relevant-convenient

Rater 4-arne * Rater 3-festo Cross tabulation					
			Rater 3-festo		Total
			Relevant-Convenient question	Relevant-Adequate question	
Rater 4-arne	Relevant-Convenient question	Count	15	4	19
		% within Rater 4-arne	78,9%	21,1%	100,0%
		% within Rater 3-festo	78,9%	5,5%	20,7%
		% of Total	16,3%	4,3%	20,7%
	Relevant-Adequate question	Count	4	69	73
		% within Rater 4-arne	5,5%	94,5%	100,0%
		% within Rater 3-festo	21,1%	94,5%	79,3%
		% of Total	4,3%	75,0%	79,3%
Total		Count	19	73	92
		% within Rater 4-arne	20,7%	79,3%	100,0%
		% within Rater 3-festo	100,0%	100,0%	100,0%
		% of Total	20,7%	79,3%	100,0%

Symmetric Measures				
	Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.

Measure of Agreement	Kappa	,735	,088	7,047	,000
N of Valid Cases		92			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					

An inter-rater reliability statistic Cohen's kappa was not computed to determine the level of agreement between the raters in regard to characterizing teacher questions based on the features described in the first column of Table 8, which describe the specific areas addressed by a teacher's question. It was also not possible to compute a reliability statistic to inform on the level of agreement when we classified questions based on the cognitive categories by Anderson et al. (2001). The reason was because the respective categories were not mutually exclusive or exhaustive (Cohen, 1960). We noted during analysis that, a teacher's question categorized at Anderson et al.'s (2001) lowest level – "remember", could also be classified at the "understand" level, depending on how the evaluator conceptualizes the level of cognition demanded by the question. Thus there was this recurring overlap in the categories that would not allow for a clear decision regarding to which level a question actually belonged. The same was observed when analyzing the nature of content areas or features addressed by a teacher's question using the features stipulated in the first column of Table 8. Whereas a teacher's question could be one prompting students to give their experiences supporting the ideas being discussed in a lesson, the same question could also be a question that engages students in arguments about a topic. Thus, the variables were not exhaustive and tended to overlap.

Nevertheless, to ensure reliability in terms of our coding, it was resolved that each of the raters' results for the two parts be shared to another, in order to identify the differences in the coding. This was followed by a thorough discussion to allow each rater to give a justification of his choice regarding those areas where disagreements existed. Each rater (analyst) explained the reasons for classifying a question in a given category, which ended with a reconciling of the disagreements based on satisfying reasons. For example, of the 96 questions that were coded by both raters (me and the second author), in regard to the nature of areas addressed by each teacher's question, 90 questions were coded at the same node by both of us, and disagreement was with only 6 questions, which each rater coded at a different node. We thus discussed the reasons for our choices and reconciled accordingly.

3.2 Research credibility

3.2.1 Validity and reliability

Validity in qualitative research is concerned with the integrity and application of the methods used and the precision with which the findings reflect the data, while reliability describes the consistency within the employed analytical procedures (Long & Johnson, 2000). The research credibility for the present study concerns the verification strategies that were employed in the process of inquiry to ensure reliability and validity (Morse, Barret, & Mayan, 2002; Noble & Smith, 2015), and thus the rigor of the study. First was the issue of methodological coherence as was needed to ensure congruence between the research questions and the components of the method. This required a careful review of the aims of the study as well as the research questions in the respective papers to determine the appropriate data collection methods for the project.

In paper I, the goal was to explore how chemistry teachers conceptualize the oral questions they use in their teaching. This demanded talking to teachers rather than observing them. The use of interviews was thus an appropriate data collection tool. There was nevertheless the awareness from prior research, about the challenges associated with interviewing (Nunkoosing, 2005). For example, the potential differences between what teachers actually do in teaching and what they say they do in teaching. That is, the use of interviews is susceptible to a social desirability bias (Grimm, 2010; Rubin & Babbie, 2010). To minimize such bias, an observation activity was introduced before the interview session. Participants were made to observe a teacher using questions in an actual teaching situation, and then asked to describe in their own understanding the nature of questions used by the teacher they observed. This ensured that participants gave concrete expressions that reflect their individual understanding. However, there were other potential sources of bias that were noticeable. First, there were cases of misunderstanding of the topic of discussion by some teachers and the interview questions that were asked in some cases. This was mostly attributed to the language being used not being the interviewees' first language. Some teachers had difficulties with using particular terms in English, which impacted on the responses in general. Second, it could also be possible that especially the most experienced teachers opted for being consistent in their talk at the expense of the truthfulness of the content of the talk. However, there was no indication pointing to this conclusion as all the participants seemed interested in the topic and openly shared their views.

Second, adequate sampling implies availability of sufficient data to account for all aspects of the phenomenon (Morse et al., 2002). Attempts were made to ensure an appropriate sample of study subjects or data sources for each of the respective studies in the present thesis. However, for paper I, it was only possible to recruit 11 science (chemistry) teachers. Though this sample was sufficiently diverse in terms of age, teaching experience, and education, the teachers only came from one city. The results from this sample thus may or may not reflect the understanding of other teachers in other parts of the country. Moreover, when the call for participation was sent out, only those teachers who responded were considered, thereby limiting the number to only 11 teachers from the entire Bergen city. The sample was thus a convenience one as a result of several teachers not responding to the call (nonresponse cases). This relatively small number might have had an effect on the conclusions made in paper I.

Nevertheless, for all data obtained a negative case analysis (Miles & Huberman, 1994) was also a part of the inquiry process, involving a multiple revisiting of data of all subjects (paper I) or data accounts (papers II and III) during the analysis. This ensured for example in paper I that interpretations of the teacher's understanding of the topic of questioning that had emerged, reflected an understanding of all teachers. Further still, the study was subject of continuous debrief and peer scrutiny. The analysis procedures were reviewed and emerging interpretations discussed with supervisors and adjusted accordingly. This engagement with other researchers through frequent debriefing or peer scrutiny reduces research bias (Noble & Smith, 2015; Shenton, 2004). In addition, it provided a platform for me to test my developing ideas and interpretations. In the process, it helped in refining my inquiry methods and in developing a better explanation of the research design and strengthened arguments.

Third, to ensure research credibility, it is also important to incorporate correct operational measures for the concepts being studied (Shenton, 2004). Yin (2014) recommends, where possible, the adoption of well-established research methods. In this study, Gadamer's philosophical hermeneutics (Gadamer, 2004) guided the interpretation of teachers' expressions in paper I. Also, Davidson's interpretive-analysis ideas (Davidson, 1973; Klaassen & Lijnse, 1996) were used when characterizing the context in which teacher questions occur in paper III. Though drawing on well-established analysis procedures ensures the possibility of other persons coming to similar conclusions when analyzing similar data (Yin, 2014), the interpretive approach is challenged by it being subjective thereby creating bias on the part of the researcher. Because most of the work in the present thesis was interpretive, it was subject to personal prejudices, which include the researcher's knowledge background, and experiences, as well as the breadth of the researcher's knowledge of existing research knowledge on teaching, methods and perspectives.

Influence of a researcher's experiences and personal values on the interpretive process is a limitation that was also realized when applying the method that is suggested in paper III. When analyzing teacher questions from TIMSS-video study using the proposed approach, it was noted that the interpretive work relied heavily on the researcher's knowledge and competence about teaching in general and hence his personal views and values. The theoretical frameworks employed at each stage, e.g. Louca et al.'s (2012) IIER framework for characterizing the context in which questions occur, could only guide one on what aspects to consider during the analysis. It was my own knowledge and experiences about the practice of questioning that played a substantial role in getting to understand the discourse leading to the questions. It was a similar experience when it came to the second step of judging a question's suitability in a given context. The proposed protocol would only give the working confines within which one could decide on the relevance of the question. Determining whether the question adequately served its purpose or the teacher should have approached the problem in a different way was dependent on the researcher's knowledge and experience on matters of classroom teaching.

Nevertheless, personal values are valuable in a qualitative inquiry process. What is important is for the investigator to "take care not to confuse knowledge intuitively present in advance, embedded in preconceptions, with knowledge emerging from inquiry of systematically obtained material" (Malterud, 2001, p. 484). Several recommendations include a declaration of personal beliefs before the start of the study (Koch, 1999) and having recorded or transcribed data for others to audit (Malterud, 2001). In addition, the bias that comes with the subjective nature of the interpretive approach could be reduced by having another person looking at the same aspect using the same inquiry frame (approach). This would enable comparing of interpretations and individual conceptions, discussing, and where possible reconciling the outcome conclusions as for the case of papers I and III. For paper III for example, the proposed approach was tested independently by two raters using one of the selected lessons. This allowed for a quantification of rater agreements and the computation of a statistical reliability test. For instance, the two independent raters compared their conclusions on variables such as whether the teacher's question was relevant or inappropriate, and relevant-adequate or relevant-convenient. Both the percentage agreement and the Cohen's kappa coefficient were calculated for the variables. The results indicated a good (substantial) inter-reliability. This was seen to increase the results' trustworthiness.

Another limitation especially encountered in paper III concerns what can be available for access when using secondary data. In paper III, archived science lesson videos were analyzed. There is an undeniable distinction between what is available as data to the primary researcher, and that which is accessible to a second researcher (Hammersley, 2010). For primary researchers not only generate data itself, but also have or gain implicit understanding in the process of acquiring data, along with memories of what they have seen, heard or felt (Andersson & Sørvik, 2013). Working with secondary data implies working within a different context in absence of other supplementary data sources such as field notes, memos, etc. The researcher only relies on a good understanding of the object of study for a proper interpretation of for example videotaped data as for the case of paper III (Andersson & Sørvik, 2013).

3.2.2 Transferability

Transferability is concerned with the extent to which findings of one study can be applied to other situations (Merriam, 1998). The results of this study are of two kinds with respect to the goals of the study. The first kind of results from paper I are based on a limited number of teachers from a particular region. The relatively small sample makes it difficult to demonstrate that the findings are applicable to other situations and populations (Shenton, 2004). In addition, having a non-randomly selected sample implies that the results are not generalizable (Shadish, Cook, & Campbell, 2002). However, as Denscombe (2010) argues, although the case may be unique, it is also an example within a broader group (p. 60) and hence the prospect of transferability. The nature of the research problem that led to these first results is a general concern by education researchers that teachers use mainly facts questions. Paper I results and the discussion therefore attempt to capture a general thinking that could be pictured with other teachers in other settings. Like Lincoln and Guba (1985), and Firestone (1993) explained, given a sufficiently explained context within which the study was conducted, other readers can be able to make a transfer of the findings and conclusions to other settings.

The second form of results is a product of undertaking a process to develop and advance a framework and a method for use in teaching and research respectively. The development of both the framework (paper II) and a research method (paper III), followed the examination of previous research findings, methods and frameworks, and thus global methodological issues related to the topic. As such, the outcome approaches/frameworks are proposed for general application within a part of the teaching which they address, and thus applicable to other teaching/research situations.

3.2.3 Ethical concerns

Ethical considerations were addressed for the present study. A permission to conduct an interview study was granted by NSD –National center for research, Norway. The interview guide used in paper I of the present thesis was also submitted and approved by NSD. The teachers who took part in the study in paper I also gave their consent to take part in the study. To prevent the identification of these teachers, pseudonyms were used. NSD stipulates guidelines for treating research raw data after the analysis process. These guidelines were followed accordingly.

Access and use of secondary data from the TIMSS study group ("The TIMSS Video Study," 1999), is in accordance with the guidelines provided by the [5]TIMSS group. There were no attempts to identify the subjects and the de-identification that had been done by the TIMSS group was maintained, and neither did the outcomes of the analysis resulted in re-identifying the participants. In addition, the use of TIMSS videos did not result in any damage or distress of the participants. Lastly, proper acknowledgement of the authors of any information, frameworks or methodology that are employed or discussed in the present study is also ensured.

[5] http://www.timssvideo.com/videos/Science

4. Main results

4.1 How chemistry teachers conceptualize questions, and what influences their questioning practices

Paper I of the present thesis suggests that science teachers perceive the oral questions that they use in whole-class situations to be of two types: facts-questions and thinking-questions. These teachers' oral questions serve mainly three purposes: communicating, initiating thinking, and assessing knowledge (students' understanding of scientific topics). These purposes are revealed in the several reasons teachers mention for asking certain types of questions in certain teaching situations such as, check for students' pre-existing views, to establish what students know about a certain topic, or students views about certain chemical concepts. In general, the analysis suggests that teachers use questions in whole-class situations for classroom management purposes, for preparing students to learn, and for learning purposes. However, the analysis results also suggest that in situations other than whole-class settings, new types of questions and functions arise. For example, results of analysis suggest that teachers use a form of questions to diagonize students to make their thinking visible. In Table 13, a summary of the teachers' types of questions, question functions and teachers' intended purposes for the questions is shown.

Table 13 Questioning functions, intended purposes, and preferred question type

Questioning function	Intended purpose	Preferred question type
Managing		
-attentiveness	Include students in instruction	Fact
	Focus attention	Fact
	Check whether students follow	Fact
- knowledge to be used	Remind of previously learned items	Fact
	Check whether on same level	Fact

	Elicit students' views on and knowledge of phenomena	Fact, but not taught before (experiential knowledge, pre-conceptions)
Learning	Connect experiences to topic	Thinking
	Make connections between topics	Thinking
	Initiate discussions	Thinking
	Make students think/reflect	Thinking

Paper I results suggest that students' knowledge base is central to the teachers' practice of questioning. This knowledge base includes both every-day and curricular knowledge, and it can be declarative and experiential. It also includes subject-related beliefs, ideas, and views even if they are at odds with scientific knowledge. A teacher can tap into that knowledge base by asking questions. Facts-questions specifically tap into curricular knowledge, but are also used when the teacher is preparing students to learn. In this case, facts-questions are for the purpose of managing the learning process. That is to say, the teachers can pose these questions to re-focus students' attention, or to make already known facts readily available for applying in the next stage of learning. On the other hand, thinking-questions are more pronounced after the teacher ensuring the psychological state of students by using facts-questions. With thinking-questions, students draw on what they know from before to construct a new understanding. These questions elicit students' thinking, making of reflections, making of connections among concepts or between science concepts and own experiences, all of which contribute to developing a new understanding.

From their individual experiences, the teachers know that students can answer facts-questions because what is sought by the questions is information that students have covered in previous lessons. If the teacher is to ask for new knowledge (canonical content being introduced for the first time), s/he has to employ thinking-questions, to try to get students' ideas about these new topics instead of getting the actual answers.

In doing so, s/he will have to create situations that can offer students opportunities to give these views. The teacher will thus anticipate that the students will try to think, make connections and give the ideas. This indicates that the teacher is less likely to ask questions for which s/he lacks ideas about what to be expected in terms of students' responses or actions. It is plausible that those teachers who have difficulties creating the needed situations or activities will thus tend to refrain from using thinking-questions and opt for using facts-questions.

The analysis revealed that some teachers (five out of the eleven teachers) find it difficult to ask thinking-questions despite having an awareness of the nature of students' actions that could be elicited with such questions. Also, the teachers in our sample expressed that they do not plan questions ahead of the teaching: at least not in written form. They said that they usually have a tentative plan in mind, but that questions "just come" in the situation. However, two novice teachers said that they sometimes plan and note down a question. This is inspired by what they heard in teacher education, but also their being new in the field (lack of teaching experience) requires them to prepare more. From the results, the new teachers seem less satisfied with their questioning than their counterparts who are very experienced with more than 15 years of teaching in the field. Whereas novice teachers feel they are yet to achieve a desired level in their questioning practice, the experienced teachers portray themselves as confident in the classroom because they know what works.

Finally, with regard to how teachers developed their current knowledge about questioning, the interviews revealed a differentiated picture. The majority said that trial and error in their own classes played an important role in finding out what worked. Some interviewees mentioned professional development courses and conversations with teachers from other schools and their own school as providing ideas for changes in questioning. Teacher education was mentioned to have contributed with ideas especially by those who took their teacher education within about 10 years from the interview. Those with very long experience either did not remember whether questioning was addressed or they remembered names and labels but hardly any details.

Despite having fresh memories, the novice teachers indicated that they seldom have the time to work with their questioning as recommended from teacher education. Another issue was that they did not feel that the recommendations from teacher education were easy to use. None of our teachers mentioned that questioning had been a topic in school practice during teacher education. Time and practical experiences seem to wash away knowledge from teacher education if there are no continuous appraisals.

4.2 A framework for developing and using oral questions

In paper II, question classification taxonomies were examined for their potential use in chemistry classrooms. Of the examined taxonomies, Fraenkel's conceptualization of the "right questions" (Fraenkel, 1966), seemed to align best with how the teachers think about their questions as explored in paper I. Fraenkel (1966) argued that "there are several different types of questions which teachers may ask depending upon what purposes teachers have in mind" (p. 397). According to him, the "right questions" are "those which assist the teacher in achieving a particular objective or a set of objectives s/he considers important" (p. 397). Fraenkel suggested a classification system (see Table 3), where questions are categorized in terms of the purposes which teachers might have, the actions desired of students, and the types of questions which teachers would ask accordingly. Fraenkel's conceptualization of the "right question" seems focused on the situational adequacy of the questions rather than their structural formation. That is, the ability of a question to serve the purpose for which it is intended (Roth, 1996).

However, it was realized that though Fraenkel (1966) conceptualizes questions in a way related to how teachers view their practice (paper I), his question categories do not shed light on how teachers develop and use the desired kinds of questions after deciding on the intention. For instance, what he lists as purposes — knowledge acquisition, knowledge synthesis, analysis and creative thought (Table 3), those kinds of purposes are not clear to the teacher what they mean, though they may to the educator (researcher). It is difficult to understand what "knowledge acquisition" means in terms of a set purpose as it seems to carry a general understanding as the overall objective of a typical lesson. The same applies to other categories and terms used in his framework. Nevertheless, Fraenkel's characterization of the "right questions" by the nature of teacher's intentions or purposes (situational adequacy), was one feature that was not reflected or at least not articulated in the rest of the other systems that were examined in paper II. It is this conceptualization of teachers' questions in terms of the purposes the questions can serve in a particular situation that forms a basis for the framework that I proposed.

The proposed framework comprises two non-hierarchical levels and a knowledge base. At level 1, the teacher determines and sets the intentions or the purpose for the questioning situation, which are connected to the objectives of the lesson. The teacher also starts to think about the kind of expectations from the students or the nature of actions s/he wants to elicit or the desired students' outcomes. At level 2, the teacher starts to formulate the types of questions which match his/her intentions and the desired students' outcomes. The knowledge base provides examples of the possible types of questions and some hints on how to restructure or formulate desired questions.

The three types of questions —recall, algorithmic, and conceptual questions, that are shown in the framework as possible in chemistry classrooms, are described by Nurrenbern and Robinson (1998). "Recall" questions, also known as "factual" questions, ask students to recall facts, equations, or explanations. "Algorithmic" questions ask students to use information or processes in a familiar way similar to the operation of programmed computers and follow a prescribed algorithm or procedure. "Conceptual questions" are questions used to tap into students' understanding of chemical ideas. These questions challenge students to articulate their understanding and students have the opportunity to elaborate on their ideas and construct conceptual knowledge.

For the proposed framework, the question's usefulness lies with the extent to which it is able to achieve the teacher's set objective. The teacher needs to match his/her intentions with the kind of behavior or students' actions desired. S/he has to think about the kind of questions that could assist him/her in achieving what s/he has set out to achieve in the particular lesson in a given situation. Here, the teacher looks at the possible range of questions from recall, algorithmic, and conceptual questions, and then s/he determines which kinds of questions are suitable for a given purpose. The framework is not restrictive in its form and allows the teacher to think about what s/he intends to do and the kind of questions that could be used to achieve what he/she has set out.

Level 1:

- **Determine & list your purpose or intentions**

Examples:
Check students' retention of facts, Mastery of chemical symbols, reaction routes, equations, color changes, review of concepts etc.
Make students think, reflect, make connections, create conceptual knowledge, articulate their understanding, find misconception, etc. as the teacher may deem necessary

- **State your students' expectations/desired outcomes**

Examples:
Use of chemical symbols, units, and terms, chemical language, Grasp of chemical principles to be used at advanced stage.
Students' understanding of ideas behind chemical phenomena, thinking and transfer of knowledge, ability to use factual knowledge, make connections, which translate into constructing conceptual knowledge etc.

Level 2:

- **Develop the questions (formulate or restructure the questions to suit your intentions)**

Examples of question types

i. Recall
ii. Algorithmic

Note:
Algorithmic questions ask students to use information or processes in a familiar way, as in programed computers

iii. Conceptual questions

Note:
Chemical situations can be presented and students asked to; explain why something happens, predict what happens, link two or more areas etc.

Knowledge Base:
Examples and hints to question formulation

i. Recall questions
What is meant by the rate of a chemical reaction?

ii. Algorithmic questions
What is the half-life of a compound if 75 % of a given sample decomposes in 60 min? Assume first-order kinetics.

Formulation hints for Recall and algorithmic questions
Direct use of content to test mastery of specific concepts

iii. Conceptual questions

- Water freezes normally below 0 degrees. Nevertheless, we can melt snow on the streets by salting. How can that occur?
- Aluminium oxide is formed from the reaction of metallic aluminium with oxygen gas. The equation is written as follows; $4Al + 3O_2 \longrightarrow 2Al_2O_3$. Explain how you find the coefficients and subscript numbers in the equation and what they mean.

Formulation hints for conceptual questions
All recall or algorithmic questions can be modified into conceptual questions:
E.g., questions about writing balanced reaction equations can be modified as in example two above

Figure 2 A framework for developing questions for chemistry classrooms

4.3 A three-step methodological approach to studying and evaluating teacher questions in science classrooms

In paper III, a three-step methodological approach is proposed for studying and evaluating teacher questions in science classrooms (Figure 1). The approach comprises three theoretical frameworks, each employed in one of the three analysis steps. The first step employs the Identification, Interpretation—Evaluation, Response (IIER) framework by Louca et al. (2012) to characterize the context of questions, the second step consist of a designed protocol to evaluate the questions' adequacy, and the third step utilizes a classification scheme by Anderson et al. (2001) to determine the cognitive level of questions.

The development followed the reported insufficiency of the existing frameworks to capture the complexity of the discourse, including a myriad of activities and functions, both cognitive and social (Farrar, 1986; Louca et al., 2012). A systematic methodological approach to studying and evaluating teachers' questions, that allows the analyst to sufficiently account for the role questions play in the contexts within which they occur. The proposed approach recognizes the importance of characterizing the discourse that leads to teacher's question and uses this characteristic when evaluating the value of questions.

The approach produces more useful information about the nature of teachers' questions than the earlier methods. It allows for exploring the connections between questions and the lesson structure. The researcher is also able to examine the questions in terms of the content areas or classroom aspects or themes the questions address. As such, the approach enables an exploration of the reasons for why a teacher asked many questions addressing a particular area, thereby enabling an assessment of the question's value in a particular context. For instance, the results from using the approach to study and evaluate teachers' questions in eight TIMSS science lessons in paper III, revealed a strong relationship between the teacher's questioning and the lesson instructional organization. The use of managerial questions was found more in classes with independent practical activities than in whole-class settings, and a larger number of lower-order questions were registered in classes with mainly whole-class work activities. The results also suggested that teachers who attend to students on a one-to-one basis tend to use many questions regardless of how they instructionally organize their lessons. This was an indication that questions despite having a learning function are more used as a tool of communication. Questioning was seen to help teachers initiate and propagate talk between them and students. As a tool of communication, the results suggest that using simple recall questions is preferred by the teachers because responses to these questions are known by teachers and students can produce them through recalling already studied concepts.

Also, for the evaluation protocol (Table 8), it was chosen to use the scale of "relevant-adequate", "relevant-convenient" and "inappropriate", based on the working definitions that we described in the methods section. The results indicated that most teachers' questions were relevant and only a few were inappropriate. A further classification of the teachers' relevant questions indicated that an average of 51 questions for each of the lessons, were adequate in their specific contexts, and only an average of 26 questions were convenient. This picture shows that the respective teachers indeed used a great deal of satisfying questions to address both students' needs and their set objectives, which adds to prior research evidence accounts (Treagust & Tsui, 2014), that support teacher questioning as still a meaningful practice for teaching.

However, if we for instance considered only using a single question classification system like that of Anderson et al. (2001) to characterize questions according to their cognitive levels, as was done in prior research, we could only conclude that the teachers asked more questions at a lower level as step three of our three-step methodological approach revealed (paper III). The results would thus be no different from the findings before about teachers using mainly low-order questions without explicating the underlying reasons for the practice. Therefore, the proposed methodological approach allows for capturing other aspects influencing how questions are used and the nature of questions themselves. It attempts to go beyond judging questions based only on cognitive levels which tends to leave out information regarding the question's contribution in the context in which that question occurs.

5. General discussion

The present study addressed three objectives. First, the aim was to explore how chemistry teachers conceptualize the oral questions they use in their teaching, in order to establish reasons for why science teachers mainly use lower-order questions as consistently reported in research. The second objective was to examine the extent to which existing question classification taxonomies could be employed by chemistry teachers as guides into the formulation and use of classroom questions. Third, the study aimed at devising and advancing a methodological approach to studying and evaluating teacher questions while taking into account the contexts within which those questions occur. The key findings are discussed respectively in each of the three papers, I, II and III, that are included in this thesis.

The findings from paper I of the present thesis suggest that the teachers' practice of questioning is a natural part of their teaching. The teachers, regardless of their experience, are able to evaluate questioning situations from brief accounts consisting of teacher questions and students' answers. The evaluations occur quickly, almost intuitively, revealing that teachers possess practice-based knowledge from an early stage of their career. The two-type question category system of facts and thinking questions that teachers employ in their whole-class teaching, is simpler than most of the category systems used in research, which are based on either Bloom's (1956) cognitive domain or Gallagher and Aschner's (1963) category of questions. The simplicity of the question category system is required because teachers have to apply it on the spot in a classroom. Whereas in research, teachers' thinking-questions have been mostly characterized by the type of answers a teacher is expecting, e.g., Nystrand and Gamoran's (1997) authentic-questions, the teachers' thinking-questions in the present study are characterized by the action that they are intended to trigger in the students. Also, in research, a facts- question, e. g., Nystrand and Gamoran's (1997) test- question, seems to be for only one purpose, one which is not beneficial for learning, whereas the teachers' facts- questions can be used in different situations with varying purposes.

The results from paper I also reveal that the participating chemistry teachers are knowledgeable about the variations in the cognitive demands of certain questions, and hold a substantial knowledge about some of the question classification taxonomies developed in research, such as Bloom's (1956) taxonomy.

Overall, the findings from paper I imply that it is not a lack of knowledge about the several questions types or the different cognitive levels of questions that leads teachers' to dominantly use lower-order questions. Rather, the study reveals two important factors that tend to influence the way teachers use questions in teaching. First, the multiple and at times concurrent roles of questions have consequences for the choice of questions in class. To keep the dialogue with their students going, teacher questions have to initiate cognitive processes that lead to answers within a few seconds. Hence, the communicative role limits the learning function of a question because more demanding challenges have to be provided in a different format and organizational form. This is why the results indicated that in situations other than whole-class settings, new forms of questions and functions arise which are not limited to only facts and thinking questions. Further still, empirical evidence to this is revealed in paper III, where teacher questions in eight science lessons were studied and evaluated. Teachers, who instructionally organized lessons with independent-practical and whole-class practical activities, used more management questions and had fewer questions at lower level than in classes instructionally organized with only whole-class seatwork activities. This indicates that it is difficult for the teachers to boost learning by asking more thinking-questions as it is often recommended in the literature (Treagust & Tsui, 2014), while maintaining the status quo of how they instructionally organize their lessons.

Second, the analysis results from paper I indicate that the teachers' limited use of thinking-questions is due to the difficulties some teachers have with using these questions. Also, some of the teachers showed a lack of ideas on how thinking-questions contribute to students' learning of chemistry. In other words, these teachers have difficulties putting to use the varied students' responses that come with asking thinking-questions. Teachers experiencing difficulties in creating activities or situations to trigger students' thinking or reflections are less likely to use thinking-questions. When such teachers attempt to ask directly for the unknown from students, they are likely to get short undesirable responses or guesses at best or no response at all. As a consequence, these teachers resort to using simple facts (lower-level) questions since they are easy and less demanding.

Earlier research noted that teachers abandoned the use of higher-order questions because they received more incorrect answers with these questions (Sanders, 1972). There was no explanation given in previous research for the incorrect students' responses to higher-order questions, which teachers in paper I characterized as thinking-questions. An important observation is that earlier research recommendations to teachers to raise the number of higher-order questions asked in classrooms (Good & Brophy, 2008), paid little attention to the differences between subjects and the applicability of cognitively demanding questions in whole-class situations. Initiating deep thinking requires that teaching sequences are designed in a different way than the common whole-class lesson organization. What is possible according to the analysis in paper I is that teachers can use prompts to allow students share their results or views in the limited available time. Further still, as mentioned in the previous paragraph, in whole class-situations, teachers are compelled to stick to the rules of the questioning game. That is, even when asking what could be regarded as authentic information seeking questions –questions whose answers are unknown to the questioner, it does not imply that they (teachers) do not know the scientific answers to these questions. Rather the teachers' interest is not in the actual answers, and students have to have ideas about what to respond. In other words, if teachers attempt to ask for the unknown directly from students, all they get are either guesses or incorrect responses at best. The experienced teachers, who are aware of this challenge, refrain from asking for curricular knowledge to which students have not been exposed to previously.

The results from paper I of the present study are largely consistent with earlier research observations that teacher education still has a number of issues to address concerning teacher preparation (Ball & Cohen, 1999; Cochran-Smith, 2003; Metzler & Blankenship, 2008). On questioning, the teachers indicated that they were dissatisfied with the knowledge acquired from teacher education. The teachers indicated that teacher education ideas though relevant and interesting, do not often find their use in the field, as teachers claim to meet a practice focusing on other issues. These teachers' claims further echo Putnam and Borko's (2000) concern about research interventions being inconsistent with how teachers think and view the reality of teaching, about learning experiences from research being too removed from the day-to-day work of the teacher (p. 6). Novice teachers with fresh ideas from teacher education have fewer opportunities to experience how their learned ideas are implemented in actual teaching situations. Instead, they tend to be influenced by how the experienced teachers accomplish similar teaching challenges, and hence tend to emulate those practices which seem to secure the needed outcomes for them.

As one of the efforts to support teachers in formulating and using questions in teaching, I suggest a framework in paper II as a guide to chemistry teachers in formulating and using oral questions. The framework could also be used by other teachers; it only needs to be aligned with the specific curricular of interest. This framework (Figure 2) is suggested with an awareness that prior frameworks and question classification techniques that were presented to teachers for improving their questioning had received little or no success. Indeed, I started by reviewing the several question classification taxonomies, examining their usefulness and applicability in teaching situations. What comes out clear is that training in a given question asking framework is not sufficient to enable a teacher to implement effective questioning. It does not mean that teachers will pervasively and continuously apply the learned skills (Sanders, 1972). Again, teachers' experiential knowledge, beliefs, and perceptions are crucial to taking up and later alone implementing proposed questioning strategies. This is why establishing what teachers know about questioning and how they conceptualize their practice is needed in order to make suggestions that to a large extent are consistent with how teachers perceive their practice. From paper I findings, teachers are less likely to take up research ideas that are not consistent with how they think and experience the reality of teaching situations. For example, whereas some researchers argue that training in the use of Bloom's taxonomy could improve teacher questioning (Allen & Tanner, 2002; Hannel, 2009; Kastberg, 2003), the teachers in paper I stated that the taxonomy does not serve the purpose as it does for other purposes of testing. Also, from the examination of the several question classification taxonomies in paper II, it was revealed that they could not assist teachers in the day-to-day use of oral questions. Most of these taxonomies (Table 2) are complex, involving abstract terms, some of which are not explicit, subject to multiple interpretations. The analysis in paper II revealed that the taxonomies are not easily applicable to teaching situations. They are less suited for the language moves undertaken by a teacher to probe meanings, opinions, preferences or to facilitate a discussion as Furst (1981) put it. Also, the taxonomies are not consistent with teachers' thinking as from the findings on how teachers conceptualize questions in paper I. This would make it difficult for teachers to adopt these taxonomies into their teaching.

The question however remains as to whether having a framework as a guide into a teacher's questioning would be beneficial to the teacher. My conviction is that question classification taxonomies can help teachers work on their questioning skills and also support them in creating activities or situations that trigger students' actions. This can be possible particularly if the taxonomies are to a large extent consistent with how teachers perceive the practice, and also if they are linked with actual teaching situations. This is the premise upon which I suggest a framework in paper II. I suppose that, given that the proposed framework takes into account how teachers think about the practice of questioning, they will be able to adopt it into their working frames. The proposed framework in paper II, does not focus on categorizing questions, rather it focuses on the nature of teacher intentions and students' actions. It is a guide into the possible questions that could help the teacher to achieve a certain intention, and it provides hints on how to formulate such questions.

Nevertheless, looking at the proposed framework for teachers in paper II, it may be perceived as also complex compared to how the teachers reported in paper I conceptualize their question types into a two-question-category system of facts and thinking questions. However, considering that the teachers in paper I do not plan questions ahead of the teaching at least in a written form, but usually have a tentative plan in mind, the proposed framework is a representation of a formal plan structure that teachers could use as a guide. From paper I, teachers use questions mainly for communicating (classroom management and preparation for learning), initiating thinking and assessing knowledge. These teachers' perceived question roles account for the purposes or intentions that teachers should think about and plan formally at level 1 of the proposed framework (Figure 2), as they also think about and start to develop the questions that are suitable for a certain intention at level 2 of the framework. This allows for a conclusion that the proposed framework is localized to the teachers' thinking and should be easy to apply.

Finally, a major challenge of those studying teacher questioning practice in the past has been the lack of methods well suited for this work. Furst (1981) noted that investigators who employed question classification taxonomies to characterize oral questions found the schemes incomplete. The existing taxonomies (Farrar, 1986), and frameworks such as the IRF/E (Louca et al., 2012), fail to capture all the details of the teachers' questioning, and thus the value of the questions themselves. In paper III, a three-step methodological approach to studying and evaluating teacher questions within the contexts the questions occur is suggested (Figure 1). The approach is suggested on the premise that questions have both cognitive and social functions, and that a sufficient examination of contexts within which questions are used warrants a valid judgement about the value of those questions (Farrar, 1986; Ho, 2005; Roth, 1996). It thus allows for studying and characterizing the discourse leading to the teacher's question in order to understand the role served by that question in a particular situation.

The proposed approach provides for visualizing connections between questions and the lesson structural organization. It allows one to explore the main areas addressed by the teachers' questions. In most prior research studies, especially from the process-product[6] paradigm (Carlsen, 1991), researchers used question taxonomies to classify and count the number of questions asked at the respective cognitive levels. The research tools could not provide for evaluating the value, or the suitability of the used questions. In addition, even those studies that invesitigated relationships between teacher questions and students' learning gains, could not easily come up with meaningful explanations for those relations due to a lack of a detailed analysis of the teachers' questioning (Brophy, 1986). It thus seemed difficult for earlier researchers to identify useful implications for the teaching practice in ragard to question asking, since the employed methods at the time fell short of allowing a delatiled analysis and interpretation of the discourse. The proposed framework provides for a detailed exploration of the teachers' questioning practice. The analyst can obtain more information about the teachers' reasons for asking in particular situations, about the appropriateness of questions, about the allowed wait-time, and about how the teacher deals with students' responses and questions, which is the nature of information required to derive explanations about the possible relationships between teacher questioning and students' learning.

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[6] Process-product research includes a number of unrelated studies that have explored effective teaching by correlating particular processes, or teacher behaviors, with particular products, usually defined as student achievement as measured by standardized tests (Carlsen, 1991; Roth, 1996).

5.1 Study implications and further research

Whereas a large body of research on teacher questioning practices continues to emphasize the important role of teachers' thinking-questions (see introduction part), more attention needs to be paid concerning how these questions are operationalized in real teaching situations in order to realize the full potential of teachers' questions. As revealed from paper I, science teachers not only struggle with creating situations that trigger students' thinking, making of connections or reflections, but some of the teachers do not know how to use students varied responses to thinking-questions. Some teachers from paper I for example indicated that it is difficult to use thinking-questions with certain chemistry topics such as atoms, periodic table etc. They seemed to hold a view that students' varied ideas have a limited room in chemistry classrooms, a view that seems inconsistent with efforts towards argumentative practices in science classrooms (Cavagnetto, 2010; Manz, 2014). This lack of use of thinking-questions in science classrooms is one explanation cited by some scholars for why science students from Germany (Nehring et al., 2017; Stanat et al., 2003), and Norway (Andersson-Bakken & Klette, 2016; Kjærnsli et al., 2007) performed below average on PISA tests on scientific argumentation. Since through questioning students have the opportunity to develop their skills in presenting and articulating science knowledge, it is important to orient science teachers in how to trigger students' thinking andreflections. Particular emphasis needs to be put on supporting teachers in how to create activities and settings that elicit students' ideas about phenomena of interest.

Given that teachers display a substantial knowledge about the different question types and their varied cognitive demands and social functions, what is most needed for the teacher is to be oriented in how for example thinking-questions are operationalized in teaching situations. Earlier research reacted to teachers' limited use of thinking-questions by introducing several questioning techniques (Wilen, 1991), and by focusing on training teachers in using question classification systems (Hannel, 2009; Rice, 1977; Vogler, 2005). It is however most likely that the question of how to implement all of the suggested techniques in real settings received minimal attention in earlier research. The challenge teachers have of not being able to create and maintain activities that trigger students' thinking, is a challenge that I perceive to carry a practical dimension. It is not a problem that can simply be answered by citing a list of guidelines to teachers as those for laboratory experiments. This is because questioning has a communicative function. Teachers' questions and students' responses are mutual constructions and are subject to situational influences (Carlsen, 1991). It is also important to note that being able to create activities to trigger students' thinking is not enough to be able to use thinking-questions. It was realized from paper I that the multiple and at times concurrent roles of questions have consequences for the choice of questions in class. This is an aspect to do with how the lesson is instructionally organized. The results from paper III suggest that teachers operating in whole-class situations are much limited in terms of what forms of questions they can employ. Reducing the number of questions in whole-class situations and use the time for the exchange of results and ideas from previous activities, for discussing and evaluating the ideas, and for planning further steps would be an alternative direction to consider. However, this implies also the planning of the cognitively more demanding activities to be conducted by individual students or groups of students.

In the past, researchers noted that the teachers' questioning is affected by a complexity of other activities occurring in the teaching, which are both social and cognitive (Farrar, 1986; Hiebert & Stigler, 2000; Ho, 2005; Roth, 1996). As such, it becomes difficult to isolate questioning as an independent aspect of the teaching and then try to change it without affecting the other parts of the whole teaching activity. It implies that it is not enough to know what questions to ask in order to question well. A focus on the interdependence of all the activities within a teaching situation, verbal or nonverbal, cognitive or social, would be crucial for any meaningful interventions towards transforming the practice. The teachers not only need skills of creating activities that lead to students' active participation, they also need knowledge on how to make good use of students' contributions. In addition, the other classroom activities that directly impact on the teacher's questioning such as how the lesson is organized, which activities are needed for particular objectives, and how the activities themselves should be organized, also demand varied competencies from teachers.

For instance, results from paper I suggested that teachers do not formally plan their questions because they have to react to situations and how students are reacting in the discourse. Whereas that is a satisfying reason, it is also true that teachers do not plan formally because they tend to use facts questions in whole-class settings, which questions are easy for them to ask. A change in how the lesson is instructionally organized will definitely demand not only planning the lesson structure, but also the nature of activities that could be possible. Likewise, if a teacher is to use thinking-questions, with the aim of exploiting the benefits of these questions, this will demand a re-organization of the teaching. Biggs (1996, 2014) proposed in several of his works, the need to align study aims (outcomes), teaching methods and modes of assessment. Accordingly, a teacher has to make clear the learning outcomes of a unit of study, and also specify how the stipulated outcomes will be achieved and assessed before going into the teaching (Biggs, 2014). To outline learning outcomes clearly makes it easier for the teacher to decide on the instructional approach and the activities that will facilitate the achievement of learning outcomes. This is where planning is most crucial to rethink not only the activities to be involved in the lesson, but also the kind of questions that will facilitate an effective discourse. The framework proposed in paper II should be useful to chemistry teachers who may find it difficult to formulate especially thinking questions that are aligned with their intended study objectives.

Further still, from paper III, most of the teachers' questions in the eight analyzed lessons were classified as lower-order questions, except those categorized as management questions. Even though the analyzed lessons were recorded about 17 years ago, a use of Bloom's revised cognitive category system in step three of the proposed approach (paper III), gives a similar picture as that reported in recent research in science classrooms e.g., Andersson-Bakken and Klette (2016); Eliasson, Karlsson, and Sørensen (2017) and Eshach et al. (2014). Quite often, an observed increase in the use of higher-order questions would imply that a teacher is offering more opportunities to students to meaningfully contribute to their learning. This is because higher-order (thinking) questions are characterized as allowing students to think, reflect, make connections, present, discuss and defend their ideas (Good & Brophy, 2008). The distribution of questions revealed in paper III will thus imply that students have fewer opportunities for performing the above actions. However, there is no guarantee that a large portion of higher-order questions implies increased students' achievement, since even research on this matter remains inconclusive (Brophy, 1986). On the distribution between lower-order and higher-order questions, most researchers recommend having a balance between the two (Andersson-Bakken & Klette, 2016; Good & Brophy, 2008). While I agree on the recommended balancing of questions, it is important that teacher questions are aligned with the teacher's lesson aims. A teacher should have a reason for why s/he is asking a given question (Fraenkel, 1966). This brings to the fore the role played by a question in a given teaching situation, and hence a focus on the situational adequacy of a question. If the alignment of teachers' questions with the intended lesson objectives is considered first, then this changes how the distribution of questions in a typical lesson should be viewed. Instead of looking at the cognitive levels of particular questions, we start to focus on what kinds of questions can be employed to achieve a certain purpose under certain circumstances. Depending on a teacher's purpose, then questions of different types could be asked.

Other implications from the present study concern the role of teacher education and professional development programs in improving teacher questioning practice. The results from paper I suggest that some participant teachers seemed dissatisfied with the knowledge that they acquired from teacher education about questioning. Concerning their use of question classification frameworks developed in research such as Bloom et al.'s (1956) taxonomy, the teachers were in agreement with the conclusions drawn in paper II (Kayima, 2016) that such taxonomies served other purposes than being used in the questioning process. Second, the experienced teachers displayed a state of being satisfied with how they question their students and the results that come with it. The implications from these two findings are; first, teacher questioning as part of teacher education training had been given less attention in the past. Now that a growing body of research continues to emphasize the important role of teacher questions in science teaching (Treagust & Tsui, 2014), it is about time that teacher trainers and designers of teacher education curricula for teachers pay as much attention to this component of the teaching as paid to other constituents of classroom teaching. In addition, the claims by teachers of being dissatisfied with theoretical knowledge about questioning obtained from teacher education need not to be overlooked. The practical component of teacher education programs, where teacher trainees have the opportunity to implement what they have learned from teacher education, should also include questioning in order to support teachers in operationalizing the several types of questions.

Second, earlier studies have indicated that teachers' practice of teaching is greatly influenced by their belief system (teachers' experiential knowledge) over the years (Clark & Peterson, 1986; Levitt, 2002; Pajares, 1992; Tabacbnick & Zeichner, 1984). Consequently, transforming teachers' practice requires working on changing their belief system. Since the experienced teachers in paper I indicated no need for changing their current questioning practice, novice teachers would be a good target for professional development programs aimed at introducing research interventions. The novice teachers showed a substantial level of insecurity with how they execute their teaching which is of course expected since they are new in the field. They showed that they are willing to let in new ideas about effective teaching practices as opposed to their counterparts with many years of teaching. The belief system of the novice teachers is thus much easier to re-organize with new items of knowledge and thinking about effective teaching practice.

Finally in addition to the above implications, I want to point out some suggestions for future work on the topic. First for the present study, I have developed a framework and a three-step methodological approach. The framework (Figure 2) is proposed as a guide to chemistry (science) teachers to formulate and use questions in their teaching, while the three-step methodological approach is intended for science education researchers who would wish to explore teachers' questioning practices and the nature of questions teachers use in teaching. The proposed framework for chemistry/science teachers has not been tested to check its feasibility and applicability in actual teaching situations. With the view that earlier proposed schemes seemed complex and inconsistent with how teachers execute their teaching (Anderson, 1994; Furst, 1981; Kayima, 2016), it is needed that the framework is taken to the teachers in a pilot study, in particular to check on the possibility of operationalizing its propositions in real teaching.

Second, education researchers investigate classroom discourse because with a relevant knowledge base for effective teaching, policy makers and other stake holders can draw on such knowledge to effect changes partaining teaching and learning. When it comes to teacher questioning, the earlier methods of investigation, particularly the process-product research approach produced good research findings about relations between teachers' questions andstudents' responses orachievement without meaningful interpretations for the established relationships (Brophy, 1986). This was because questions were studied outside their contexts (Carlsen, 1991), making it difficult to develop explanations for the observed correlations. The proposed three-step approach is poised to allow for a detailed analyses of questions in their contexts, and thus makes it possible to establish linkages between teacher behavior and students' responses, a basis for developing meaningful interpretations about question- response relationships. It is my hope therefore that researchers will employ the proposed approach to further investigate teachers' questioning practices and how they affect students' learming in science classrooms.

Additionally, though the three-step methodological approach was tested on science lessons from TIMSS and found to be feasible and applicable by the analysts, the categories in the proposed protocol (Table 8) need a further refinement to check for any possible overlaps or for areas that are not covered. There is no better way of achieving this than a further use of the approach to analyze more lessons and with primary data since secondary data were used during the testing of the approach. Drawing on Wittgenstein's (2009) notion of the "language game", different subjects are defined by different language games, in regard to how teaching is conducted, the content language, objects and symbols and thus nature of communication (Mortimer & Scott, 2003). This implies that the nature of questioning in chemistry is dissimilar to that in physics or biology, and thus from subject to subject. The present work in paper I focuses on how chemistry teachers conceptualize the questions they use in teaching. The qualifications and characterizations pertaining to the types of questions teachers claim to use in their teaching that are presented in this study are interpretations of the teachers' reflections about their questioning practices. The information does not inform on the differences in the questioning in other subjects as this was not pursued in this study. Similarly, in developing the three-step methodological approach in paper III, not much attention has been paid to discussing the differences in teachers' questioning in the different subjects. A follow-up empirical study attempting to identify similar or unique teacher practices in different actual teaching situations, which also extends to find how the variation in subject content affects a teacher's questioning, would further strengthen the findings and conclusions made in papers I and III. Here researchers can attempt to use the proposed three-step methodological approach to allow for a sufficient characterization of the context of questions.

Third, findings from both papers I and III indicate that the teachers' use of oral questions in especially whole-class situations is mainly for communication with their students. Teachers opt for using simple recall questions and their questions emerge in teaching situations without any formal planning. I would thus suppose that teacher questions are less used for learning purposes in whole-class situations, and the use of many recall type questions is driven by the desire by teachers to reach out to their students. Of the suggestions, the need for teachers to reduce the number of questions in order to create space for other activities is proposed in paper I. In so doing, it is noted that a teacher will have to instructionally organize the lesson in a different way, thereby creating and including activities to trigger students thinking and views. Admittedly, this requires that teachers are able to plan these both socially and cognitively demanding activities and yet the present study makes no attempt to address how this could be achieved. Therefore, future research could explore practical possibilities on how teachers could trigger students thinking with questions and the forms of activities that would promote it. Notice that training teachers in using question classification taxonomies did not yield pervasive or substantial effects in the past. A focus on teaching as a whole would be more productive since questioning is a component influenced by other activities in the teaching. Research is also needed in regard to what forms of oral question planning are possible in teaching situations, forms that not only focus on the nature of teacher questions, but also the fact that classroom interaction changes with how students respond to teacher's questions.

Forth, there is the need to examine and wherever possible make recommendations in regard to what form of knowledge about questioning is offered in science teacher education training/teacher education in general. The teachers in paper I give sketchy information on this matter. Indeed, earlier research on how teachers use questions in their teaching should have started with establishing what kind of knowledge about questioning teachers obtain from their training programs. Then researchers would be in a proper position to establish why the actual teachers' practice of questioning differs from how they are taught to question during teacher training. However, given that there is not a clear documentation on what knowledge about questioning science teachers obtain from teacher training, it is difficult to evaluate teachers on their use of questions and later alone attempt to influence their questioning which they claim to have developed through practice.

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7. PAPERS I – III

II

PAPER II

Question classification taxonomies as guides to formulating questions for use in chemistry classrooms

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Question classification taxonomies as guides to formulating questions for use in chemistry classrooms

Kayima Festo
Department of Chemistry, University of Bergen, Bergen, Norway
For correspondence: kayimawkn@gmail.com, festo.kayima@uib.no

Abstract:
Teacher questions play an important role in facilitating classroom discourse. Using appropriate question types and proper questioning techniques help to create reflective- active learners. Teacher questions can elicit students' explanations, elaboration of their ideas and thinking, and they can be used to disclose students' misconceptions. Despite knowing about the benefits of good questioning, most classroom teachers fail to question their students in ways which go beyond mere requests for explicit, factual information. Several of the question taxonomies developed in the past for classifying teachers' questions exhibit a potential to serve as guiding frameworks for teachers in formulating and using questions. This paper examines the extent to which existing question classification taxonomies could guide chemistry teachers in developing and using classroom questions. A framework is also suggested to guide chemistry teachers in formulating and using the desired kinds of questions.

Keywords: teacher questions, question classification, question formulation, taxonomy of questions

Introduction

Teacher classroom questions are important tools for facilitating students' understanding of chemical language and concepts. Appropriate use of questions mediates students' knowledge construction and influence the type of cognitive processes engaged in (Alison, 1994; Roth, 1996). Teacher questions can also facilitate students' acquiring of specific languages unique to individual subjects (Mortimer & Scott, 2003), vocabulary and representational practices of a subject. Regardless of their potential contribution to learning, developing and using good questions is challenging to most classroom teachers (Graesser & Person, 1994). Most often, a large part (60 %) of teacher questions only request explicit, factual information from students (Gall, 1970; Hannel, 2009; Lee & Kinzie, 2012).

There are several question classification taxonomies developed in the past with a perceived potential to guide teachers in formulating and using classroom questions. These have been identified and summarized by researchers Crump (1970); Gall (1970); Riegle (1976) and Wilen (1986). In the past, there have been also efforts by researchers to train classroom teachers in questioning techniques and in using some of the existing question classification taxonomies. Classroom teachers were reported to change in their practice of questioning after undergoing training in the use of specific question classification taxonomies (Galassi, Gall, Dunning, & Banks, 1974; Gilbert, 1992; Godbold, 1973; Hamblen, 1984; Wilen, 1991). However, it was also noticed that those teachers who had been trained in several questioning techniques often failed to implement those skills in a pervasive and continuous way (N. M. Sanders, 1972). This is thought to be attributed to the existing gap between how teachers and researchers view the role of questions (Eshach, Dor-Ziderman, & Yefroimsky, 2014), the unsuitability of a number of question taxonomies to classroom settings (Furst, 1981), teachers' beliefs about teaching and learning which seem inconsistent with using question taxonomies, the complexity of the taxonomies themselves (Anderson, 1994), and the inconsistencies in meanings and terms used in several question classification taxonomies which end up confusing teachers (Reed, 1977).

Despite the concerns reported about the teachers' inability to continuously apply the learned questioning techniques, education researchers contend that question classification taxonomies can help teachers to match the questions they ask with the type of thinking that they are trying to develop (Hannel, 2009; Vogler, 2005; Wimer, Ridenour, Thomas, & Place, 2001). The taxonomies are also perceived to support teachers in formulating questions and clarifying instructional objectives (Allen & Tanner, 2002; Kastberg, 2003). In this article, analysis is made of the existing question classification taxonomies to assess their potential as frameworks that could guide teachers in formulating and using questions in chemistry classrooms.

Question classification taxonomies

Originally question classification systems were understood as systematic observation instruments that could be used in the observation and collection of objective data on such aspects of questions as cognitive level, length and frequency (Wilen, 1991). This kind of explanation draws from that much interest during 1950s and 1960s, when researchers needed to study, identify and analyze classroom thinking operations, instructional goals and teaching activities (Clegg, 1987; Wilen, 1991). However, researchers did not only stop at studying and characterizing teachers' classroom practices, but they also wanted to improve the way teachers executed their practices. As such, several researchers focused on developing question taxonomies to guide and impact on classroom teacher questioning behaviors. Thus, several sets of categories into which teachers' questions can or could be classified were developed by several researchers (Crump, 1970; Gall, 1970; Riegle, 1976; Wilen, 1986).

Bloom, Engelhart, Furst, Hill, and Krathwohl (1956) developed a classification scheme of educational objectives in the cognitive domain where six hierarchical classes of objectives (simple to complex intellectual operations) were identified. These intellectual operations included; knowledge, comprehension, application, analysis, synthesis and evaluation. Around the same period, Guilford (1956) devised a three-dimensional model of intellectual processes, classifying mental abilities. The feature in Guilford's model that provoked the most interest related to classroom questioning was the identification of convergent and divergent thinking processes as they relate to creativity (Clegg, 1987, p. 15). Gallagher and Aschner (1963) using Guilford's work, constructed a category system to examine teacher-student classroom interaction. Their system comprised of five question types often found in teaching situations (cognitive memory, convergent, divergent, evaluative and routine questions). A number of question classification taxonomies that emerged later were built based on either, the work of Bloom et al. (1956) and or Gallagher and Aschner (1963)'s conceptualization of questions.

Generally, up to 41 different authors have made suggestions of different question categories which altogether reflect the conceptualizations of Bloom et al. (1956) and or Gallagher and Aschner (1963). This list includes; Adams (1964); Anderson et al. (2001); Aschner (1961); Barnes (1969); Biber, Johansson, Leech, Conrad, and Finegan (1999); Bloom et al. (1956); Blosser (1973); Carner (1963); Chinn, Anderson, and Waggoner (2001); Christenbury and Kelly (1983); M. H. Clements, Fielder, and Tabachnick (1966); R. D. Clements (1964); Crump (1970); Davis and Tinsley (1967); Douglass (1967); Elstgeest (1985); Enokson (1973); Fraenkel (1966); Gallagher and Aschner (1963); Galton, Simon, and Croll (1980); Graesser, Person, and Huber (1992); Guszak (1967); Herber (1978); Hunkins (1972); Hyman (1979); Kaiser (1979); Long and Sato (1983); Marzano (2001); Minor (1966); Moyer (1965); Nystrand and Gamoran (1997); Parsons (1968); Pate and Bremer (1967); Riegle (1976); Ruddell (1974); N. M. Sanders (1966); Schreiber (1967); B. O. Smith, Meux, and Coombs (1960); R. J. Smith (1969); Taba (1967), and (Wilen, 1985).

Given that the existing question classification taxonomies or question category systems were all developed based on the conceptualizations of two independent authors as we have mentioned in the previous two paragraphs, it is reasonable to say that there are majorly two ways of classifying questions despite having several versions of classification systems by different researchers. The first way of classifying questions is the non-hierarchical form where questions are classified as convergent or divergent originally from Gallagher and Aschner (1963). Other non-hierarchical forms of classifying questions involve using terms such as open and closed (Blosser, 1973), real and synthetic (Minor, 1966), authentic and test questions (Nystrand & Gamoran, 1997). The second way of classifying questions is to classify them based on their cognitive level or complexity (Bloom et al., 1956).

In this paper I analyze five different question taxonomies suggested by different researchers, N. M. Sanders (1966), Fraenkel (1966), Minor (1966), Blosser (1973), and Nystrand and Gamoran (1997), examining the extent to which they could serve as question formulating guides to chemistry teachers. N. M. Sanders (1966)'s taxonomy is an adaptation of Bloom's cognitive categories and its selection represents all other question taxonomies which classify questions based on the complexity of cognitive levels. Fraenkel (1966) devised a taxonomy of questions based on the purpose the question is to address and his taxonomy was selected for analysis because of this feature, which is not common to most other taxonomies. Minor (1966) and Nystrand and Gamoran (1997)'s question categories were selected because the authors use unique terms ('real/synthetic' and 'authentic/test' respectively) to characterize questions, which terms are not common to other question taxonomies. Blosser (1973)'s question category system was selected for those category systems which distinguish questions into closed and open categories. Table 1 shows a summary of question categories of the selected taxonomies by different authors.

Table 1: A summary of question categories by selected authors

<table>
<tr><td>Authors</td><td>Question categories</td></tr>
<tr><td>N. M. Sanders (1966)</td><td>(i) Memory, (ii) Translation, (iii) Interpretation, (iv) Application, (v) Analysis, (vi) Synthesis, (vii) Evaluation</td></tr>
<tr><td>Fraenkel (1966)</td><td>
<table>
<tr><td>Purpose</td><td>Type of question</td><td>Student action desired</td></tr>
<tr><td>Knowledge acquisition</td><td>Factual</td><td>Remembering</td></tr>
<tr><td>Knowledge synthesis</td><td>Descriptive</td><td>Remembering</td></tr>
<tr><td>Knowledge synthesis</td><td>Explanatory</td><td>Reasoning/exercising judgement</td></tr>
<tr><td>Creative thought</td><td>Heuristic</td><td>Divergent thinking</td></tr>
</table>
</td></tr>
<tr><td>Minor (1966)</td><td>(i) Real questions and (ii) Synthetic questions</td></tr>
<tr><td>Blosser (1973)</td><td>(i) Managerial questions, (ii) Rhetorical questions, (iii) Closed and (iv) open questions</td></tr>
<tr><td>Nystrand and Gamoran (1997)</td><td>(i) Authentic questions and (ii) Test questions</td></tr>
</table>

Analyzing question taxonomies for their possible use in chemistry classrooms

Analysis as used here implies breaking the topic, concept, and themes or terms down into parts in order to inspect, understand and or restructure them in a way that makes sense with respect to an individual interpretation of meaning and perception. The process involves reading the author's contribution and identifying its strengths and weakness with respect to the purpose and intentions of the analysis. In analyzing the question taxonomies, emphasis was on figuring out what the individual authors implied (meaning of the used terms, explanations, illustrations or interventions). Based on the respective authors' arguments, comments and conclusions were made to the content (text, terms, frameworks, or interventions), with respect to the usefulness and applicability of the respective taxonomies as question formulation-guiding frameworks to chemistry teachers. Overall, the analysis involved two important steps;

i. Reading the article as whole, determining the purpose, structure and the direction of the paper: The individual articles were read as a whole in order to establish authors' statements of purpose, the respective authors' main points and the target audience, accounts of evidence that the authors used and any identified limitations or gaps.

ii. Critiquing, assessing and evaluating the article's content/themes/terms or taxonomies with respect to the aim of the analysis.

A personal reaction to the works of the article was made. This part involved thinking about the respective authors' nature of conceptualizing questions, the proposals made, the terms or question labels used and the meanings the authors attached to the different terms used in the question taxonomies. This was followed by trying to envision how the proposed schemes could be used in the teaching situation, also given from the analyst's personal experience as a teacher, and from empirical accounts about teacher beliefs and perceptions about questioning.

N. M. Sanders (1966)'s taxonomy of questions

Sanders adopted Bloom et al. (1956)'s taxonomy of educational objectives to devise a taxonomy of questions, seeking to demonstrate the potential of applying Bloom's taxonomy to everyday classroom situations. Sanders used Bloom's model as a guide for identifying and describing the many types of questions that teachers ask, categorizing them at various levels of Bloom's taxonomy. The taxonomy which consists of seven categories defines the types of questions which could be used in each of Bloom's categories of thinking. The categories (table 1) include; (i) memory; involves recall or recognition of factual or conceptual information (fact, definition, generalization, and skill, true or false questions), (ii) translation; involves translating ideas from one communication to another, (iii) interpretation category involves questions relating facts, generalizations, definitions, values, and skills, to discover or use a relationship between two or more ideas (iv) application; presenting problems that approximate the form and context in which they would be encountered in life, (v) analysis; involves detecting, classifying, discriminating, categorizing, deduction, (vi) synthesis; engaging in imaginative, original thinking, where diverse solutions are elicited, (vii) evaluation; the process of making judgement about the value of an idea, a solution, a method, using criteria developed by the individual himself.

Teacher questions following Sanders' taxonomy require students to engage in specific kinds of thinking from low level recall of knowledge to higher level-evaluation type questions. If the classroom teacher is able to structure the questions according to the levels stipulated in the taxonomy, then the taxonomy offers a framework with which the teacher can determine the kinds of intellectual activities might require of his/her students. However, in developing/structuring or formulating the questions needed for classroom discussions, the taxonomy provides little support. Teachers are clear with the kind of intentions they want to achieve as well as the desired actions from students, such as students being able to make connections, use factual knowledge and create new understanding among others (Amos, 2002; Eshach et al., 2014). However they fail to formulate such questions as required for achieving these intentions.

N. M. Sanders (1972) also acknowledged the fact that even when teachers are trained in a respective taxonomy, they find it hard to put the taxonomy into practice. This is simply due to the fact that the many category distinctions of questions are not needed as they fragmentize into pieces that what teachers have conceptualized as whole. For example, the teachers generally know that questions fall into mainly two categories; factual and those questions that demand for students' thinking, reflection and connection of different ideas. In this case the teachers' challenge is not to categorize questions but to develop them. However Sanders' framework and many others seem to provide no explicit criteria for when the question categories should be used, and consequently the framework might not serve well for teachers as a guide for developing the desired questions. As Furst (1981) concluded about Bloom et al. (1956)'s taxonomy being not a suitable tool for classifying oral questions and facilitating classroom discussion, Sanders' taxonomy of questions also seems to focus more at the outcomes of instruction rather than at the language moves a teacher might undertake.

Blosser (1973)'s question categories

Blosser (1973) devised what she called the 'Question Category System for Science (QCSS)', consisting of four types of question categories (table 1); closed, open, managerial and rhetorical questions. Blosser describes managerial questions as those used by teachers to keep the classroom operating, move activities and pupils toward the desired goals for a given period or lesson (e.g. Will you turn to page 15 please?), and rhetorical questions as used by teachers to reinforce a point or for emphasis and teachers do not really anticipate an oral student response (the green colouring matter in plants is called chlorophyll, right?). Closed questions are those for which there are a limited number of acceptable responses or 'right answers', and it is expected that students have already had contact with the information being requested (e.g. what is the chemical formula for water?). Open questions on the other hand are questions according to Blosser which anticipate a wide range of acceptable responses rather than one or two 'right answers' and draw on students' past experiences, cause students to give opinions, reasons for given opinions, to infer or identify implications, formulate hypotheses, or make judgments based on their own values and standards. Blosser's category system was devised as a framework for teachers to analyze their questioning strategies, to be able to reduce the percentage of recall questions and increase the percentage of questions that require students to think. Indeed, she goes ahead to suggest that teachers can determine the types of questions they are using frequently by analysing the number of acceptable responses possible and to assess whether the question encourages or requires students to go beyond past information in formulating a response.

Blosser provides clear explanations for the question categories, the terms used and she also gives examples in each question category. There is an overall appreciation of the clarity and simplicity of what Blosser puts across. However, when it comes to developing classroom questions (written or oral), classifying questions as open or closed may not provide the sufficient support to teachers to able to develop questions. The definitions or explanations attached to open and closed are subject to different teacher interpretations and thus do not provide sufficient guide towards identifying suitable questions. Like Blosser argued, starting questions with 'why, explain, compare or interpret' may not warrant the kind of actions the students engage in and neither indicate the teacher's encouragement of students.

In addition Edward and Furlong, cited in Cazden (2001, pp. 92-93) also noted that identifying what is open and closed might be difficult for researchers owing to the context in which they are used. They argued that many questions appear to be open in one context only to be closed in another, and that distinguishing between open and closed might have to wait until the teacher intention is clearly spelt out. This difficulty also applies to teachers when they attempt to identify questions using the two distinctions of open and closed, and especially if the two categories are only differentiated by the range of answers or responses (that is one correct pre-defined answer for closed questions, and two or more for the open category). Blosser's question classification category therefore becomes of less use when it comes to developing or formulating questions for chemistry classrooms owing the lack of specificity in the used terms. The taxonomy however finds more productive application in the general classification of the questions that occur in classrooms.

Nystrand and Gamoran (1997) and Minor (1966)'s categorizations

Teacher questions were classified by Nystrand and Gamoran (1997) into two groups; that is authentic and test questions. Authentic questions were defined as those questions asked to get information, questions for which the asker (questioner) has not prespecified an answer. These kinds of questions include requests for information as well as open-ended questions, and indicate the priority the teacher places on thinking. On the other hand test questions were classified as questions for which only one possible right answer is allowed, questions of recitation, which allow students no control over the flow of the discussion. Nystrand and Gamoran (1997)'s classification is related to Minor (1966)'s conceptualization of teacher questions. Minor (1966) used the terms; 'real' and 'synthetic'. Real questions according to Minor, are those questions for which the questioners are yet to find answers, questions which make discovery possible and synthetic questions as questions having known answers (one possible known answer), which at best test a student's store of facts.

Considering the descriptions of the terms 'authentic' and or 'real' questions, it might well happen that the teacher comes into a situation where s/he does not know the answer, but such situations are rare or else usually occur when students are asking the questions. The purpose of the teacher asking questions is either to check for students' knowledge or to initiate a thinking operation and probably other functions as outlined in educational research. In all cases the teacher knows about the issue at hand and in addition s/he exhibits certain expectations regarding answers and all the time the teacher is obliged to exhibit a substantive amount of information to be able to execute the process. Thus the necessity of a teacher having full knowledge of what is being taught cannot be overlooked. Secondly, a teacher either knowing or not knowing answers to questions being asked seem not the most important part of a question but rather the value of the question in terms of objective achievement. A true/real question resides in its power to achieve a set objective rather than focusing on whether the teacher knows the answer or not.

There are other questioning situations where asking questions to which the questioner knows no answers is more pronounced. However classroom teaching questioning situations are treated uniquely owing to the unique functions attached to the nature and type of questions used. In everyday practice for example, it is common to ask questions where the questioner does not know the answer or when the questioner seeks information s/he does not have. This may not be the case with classroom teaching situations. In teaching, intentions are somehow different depending on the subject and the type of knowledge. Science teaching is about interpreting the world (phenomena) in a scientific way which often is different from the everyday interpretation. Therefore it is hard to imagine that questions to which the questioner knows no answer will service a similar purpose as it is now for the common questions in the education setting without changing the aims of an education program. Indeed like Cazden (2001) said, the criticisms of teachers asking questions for which they know the answers are over simplified and miss out on these important points. Eliciting students' thinking or making them to reflect on different concepts to construct new understanding, or having a dialogue with students in class is not dependent on asking questions for which the teacher knows no answers but on the ability to formulate questions in a form that will open up for the exploration of these aspects. In this respect Nystrand and Gamoran (1997) and Minor (1966)'s question conceptualizations, might not serve as suitable frameworks that could guide chemistry teachers in developing classroom questions.

Fraenkel (1966)'s taxonomy of questions

Fraenkel (1966) presented important arguments pertaining how to ask the 'right' questions, and even went ahead to suggest a taxonomy of questions that could help teachers in asking the "right" questions. He argued that there are several different types of questions which teachers may ask depending upon what purposes teachers have in mind. In this respect, these are the 'right' questions according to Fraenkel, questions which assist the teacher in achieving a particular objective or a set of objectives considered important in that particular context. He added that, teachers need to ask themselves and also attempt to find a satisfactory answer to the question; 'why they are doing what they do', that way, Fraenkel contends that teachers will be able to determine what questions to ask their students. He suggested a taxonomy of questions where questions are categorized in terms of the purposes which teachers might have, the actions required or desired of students, and the types of questions which teachers would ask accordingly (table 1).

The idea of first considering teachers' purposes, intentions, justifying reasons and students expected or desired actions/behavior as put forward by Fraenkel is key to getting started with formulating and using good questions. Given that classroom teachers understand the important role of questions as key elements in the learning process (Amos, 2002; Eshach et al., 2014); the close connection between the functions of questions and teacher intentions for asking would provide a basis for formulating the appropriate question types. Fraenkel's conceptualization of what right questions are appears to focus on the situational adequacy of the questions rather than their structural formation. The question's situational adequacy lies in the ability of that question to serve the purpose for which it is intended to serve (Roth, 1996). With this perspective, all questions will be good questions if they are able to serve the different purposes for which they are intended. Therefore the onus remains on the teacher to be able to clearly define his/her purpose/objectives or intentions and then try to formulate those questions that can help him or her to achieve the set out purposes/objectives.

Fraenkel's taxonomy is also perceived to be localized to the teaching settings. The taxonomy seems to align with the teachers' initial preparation stages prior to the lesson. It is common practice (formally or informally) that teachers often have a minute or more where they sit and contemplate on what they are going to teach in the next few minutes, the lesson purpose, lesson instructional approach and expected outcomes. That way, the taxonomy can be assimilated into the teacher's lesson plan without demanding much preparation and time from teachers. Teachers only need to stress out and reflect on their intentions, expected outcomes, students' behavior expected or desired students' outcomes and then try to formulate the kind of questions that could help them achieve their set targets. This way, the taxonomy could be of use to teachers as a guide to developing the questions used orally during classroom teaching and those for discussions even before going to the classrooms.

Discussion

In the analysis of the five question taxonomies explanations have been given to justify either the unsuitability or suitability of the individual taxonomies to serve as guiding frameworks for teachers for developing or formulating classroom questions. From the analysis, Fraenkel (1966)'s conceptualization of the 'right' questions seems to provide an appropriate way to conceptualize teacher questions. Fraenkel's taxonomy of questions appears to be more feasible as a framework that can be localized to teachers' thinking and perceptions, and it could serve with modifications as a framework for developing and using questions in classrooms. However, it must be stressed that the five question category systems (table 1) were exclusively examined in the context of being used by classroom teachers in developing or formulating questions and not the other purposes for which they are believed or perceived to serve. That way Fraenkel's framework was seen from the analysis as one which approximates serving this kind of purpose. This is due to the taxonomy's ability to account for teachers' role as developers of questions, allowing for teachers' participation as opposed to teachers being imposed on terms which are inconsistent with their own thinking.

One probable reason most question taxonomies have failed to help teachers improve their practice of questioning is due to those taxonomies failing to start from a level of knowledge, and thinking also shared by classroom teachers. Accounting for teachers' knowledge and thinking about the use of questions not only facilitate the uptake of suggested innovations by teachers, but can also facilitate teachers' transformation to the desired level of change, since teachers are put in a position where they able to value the innovation being introduced by relating to their own understanding, beliefs and attitudes.

A framework to guide chemistry teachers in formulating good questions

In order for Fraenkel (1966)'s taxonomy (as seen in table 1) to be used in chemistry classrooms, there is need to redefine the categories to suit the target curriculum or subject. For example, there is need to redefine the purpose, kind of questions desired in chemistry classrooms and the students' desired actions or outcomes. Fraenkel's categories are not communicating enough to be used by teachers to develop the kind of desired questions. For instance, in column 1 (see table 1) where he lists the purposes (knowledge acquisition, knowledge synthesis, analysis and creative thought), those kinds of purposes may be clear to education researchers and not to classroom teachers. It is difficult to understand what knowledge acquisition means in terms of a set purpose as it seems to carry a general understanding as the overall objective of a typical lesson. This can be replaced by letting the teacher state what purpose or objective he/she intends to achieve with students (for example, elicit thinking, check on masterly of concepts, use of facts to construct knew knowledge). The same applies to other categories in other columns where there is a general lack of specificity and direction for the terms being used.

In figure 1, I propose a framework to guide chemistry teachers in developing or formulating classroom questions. The proposed framework is based on Fraenkel (1966)'s conceptualization of the 'right questions', whereby questions are considered right or good based on the extent to which they assist the teacher to achieve a particular objective or set of objectives. The framework comprises of two non-hierarchical levels and a knowledge base. At level 1 the teacher determines and sets the intentions or the purpose for the questioning situation, which might be connected to the objectives of the lesson. The teacher also starts to think about the kind of expectations from the students or the nature of actions he/she wants to elicit or the desired students' outcomes. After thinking and working through both the purpose and students' desired actions, at level 2, the teacher then starts to formulate the types of questions which tally with both his/her intentions and the desired students' outcomes. The knowldge base provides examples of the possible types of questions and some hints on how to restructure or formulate the desired questions.

The three types of questions recall, algorithmic, and conceptual which are possible in chemistry classrooms, which are given in the proposed framework are described by Nurrenbern and Robinson (1998). Recall type questions also known as factual questions ask students to recall facts, equations, or explanations. Algorithmic type questions ask students to use information or processes in a familiar way similar to the operation of programmed computers, and follow a prescribed algorithm or procedure. Conceptual questions are questions used to tap students' understanding of chemical ideas. These questions challenge students to articulate their understanding and students have the opportunity to elaborate on their ideas and construct conceptual knowledge.

In the proposed framework, questions are evaluated as effective based on their situational adequacy and the extent to which they are able to achieve teacher set objectives/ intentions or desired outcomes. The teacher needs to match his/her intentions with the kind of behavior or students' actions desired or expected. He/she has to think about the kind of questions that can help him/her in achieving what he/she has set out to achieve in the particular lesson. Here the teacher looks at the possible range of questions from recall, algorithmic, and conceptual questions, and then s/he determines which kinds of questions are suitable for a given purpose. The framework is not restrictive in its form and allows the teacher to think about what he/she intends to do and the kind of questions that could be used to achieve what he/she has set out.

Practical aspects in regard to effective questioning and the use of the framework

There are important aspects that I bring to the attention of teachers in regard to being able to formulate and use appropriate and good classroom questions. First, the proposed framework only serves as a guide to formulating the desired questions depending on the teaching purpose as determined by the teacher. Reading or studying the framework may not warrant being able to formulate good questions. Like R. E. Sanders (1993) argued, good questioning develops with practice and teachers need to continuously put into practice the knowledge and strategies proposed in the framework in order to develop the skill of formulating good questions.

Second, it has been suggested by researchers in the past that to able to ask useful questions, teachers need to have a good knowledge of subject matter (Carlsen, 1987; Chin, 2007; Harris, Phillips, & Penuel, 2012). They need to have a masterly of science ideas and some anticipatory sense about how to move students forward in their thinking (Harris et al., 2012), as well as the pedagogical skills in crafting and sequencing the appropriate questions that progressively build on previous ones Chin (2007). In addition to these requirements, teachers need some form of orientation in the possible kinds of questions and how to structure or formulate these questions. The proposed framework will be productive only if teachers have the opportunity to work through it and continuously try to formulate or restructure questions that match their desired students' outcomes or set purposes.

Third, teacher questions and particularly oral questions do not occur in isolation of other classroom activities during the teaching situation. Questions serve a myriad of functions, both cognitive and social functions and being able to improve one's questioning requires understanding these functions (Farrar, 1986). The type of questions and the nature of questioning are also closely linked with the method of instruction the teacher uses and thus for a teacher who wants to use questions effectively will need to rethink his/her instruction approach. The proposed framework provides question formulation hints and question examples for the nature of questions that can occur in inquiry classrooms. However, to be able to work with such questions where the interest is in giving a chance to students to participate in knowldge construction, the teacher will need to adopt an instruction/teaching approach that provides for these opportunities.

Level 1:

- **Determine & list your purpose or intentions**

Examples:
Check students' retention of facts, Mastery of chemical symbols, reaction routes, equations, color changes, review of concepts etc.
Make students think, reflect, make connections, create conceptual knowledge, articulate their understanding, find misconception, etc. as the teacher may deem necessary

- **State your students' expectations/desired outcomes**

Examples:
Use of chemical symbols, units, and terms, chemical language, Grasp of chemical principles to be used at advanced stage. Students' understanding of ideas behind chemical phenomena, thinking and transfer of knowledge, ability to use factual knowledge, make connections, which

Level 2:

- **Develop the questions (formulate or restructure the questions to suit your intentions)**

<u>Examples of question types</u>

i. Recall
ii. Algorithmic

<u>Note:</u>
Algorithmic questions ask students to use information or processes in a familiar way, as in programed computers

iii. Conceptual questions

<u>Note:</u>
Chemical situations can be presented and students asked to; explain why something happens.

Knowledge Base:
Examples and hints to question formulation

i. <u>Recall questions</u>
What is meant by the rate of a chemical reaction?

ii. <u>Algorithmic questions</u>
What is the half-life of a compound if 75 % of a given sample decomposes in 60 min? Assume first-order kinetics.

<u>Formulation hints for Recall and algorithmic questions</u>
Direct use of content to test mastery of specific concepts

iii. Conceptual questions

- Water freezes normally below 0 degrees. Nevertheless, we can melt snow on the streets by salting. How can that occur?
- Aluminium oxide is formed from the reaction of metallic aluminium with oxygen gas. The equation is written as follows; $4Al + 3O_2 \longrightarrow 2Al_2O_3$. Explain how you find the coefficients and subscript numbers in the equation and what they mean.

<u>Formulation hints for conceptual questions</u>
All recall or algorithmic questions can be modified into conceptual questions:
E.g., questions about writing balanced reaction equations can be modified as in example two above

Figure 1: A framework for developing questions for chemistry classrooms

Forth, there have been concerns about the complexity of question classification taxonomies which make them difficult for teachers to use in their teaching (Anderson, 1994). The issues of complexity surfaces mainly if the concepts or strategies proposed in the taxonomies are alien to teachers and are inconsistent with their thinking about classroom questioning practice. It might happen that teachers will start to think, plan and make use of question classification taxonomies if trained regardless of the complexity, as also supported from Marzano and Kendall (2007)'s submission that "the more familiar one is with a process, the more quickly one executes it and the easier it becomes". However, like N. M. Sanders (1972) argued the teachers are likely to abandon the use of such taxonomies along the way owing to their incompatibility with the teaching contexts. The proposed framework is perceived to provide support to ensure that the teacher takes a step to think about and work on formulating those questions that he/she thinks will support students' understanding. The teacher is pivotal and a key determinant as regards the proposed scheme. It differs from other frameworks in way that it does not impose external terms to the teacher but rather the teacher has the mantle to formulate his questions to his end, depending on the situational need and adequacy.

Summary

In this paper, five question category systems (question classification taxonomies) by different authors have been examined with respect to the extent to which they could guide chemistry teachers in formulating good classroom questions. A framework has been suggested to guide chemistry teachers in formulating and using classroom questions. There is no need for a conceptual refinement of the categories used or theory grounding for that matter. The reason is that the basis for the framework lies majorly on the teacher setting out intentions and then goes ahead to work out those questions that can facilitate the achievement of the set intentions/purposes. Finally, though the implementation of the outlined steps in using the proposed framework seems trivial and simple, teachers need to be oriented in the scheme and how it can be incoporated into their daily planning. As the next step, it is hoped that this framework will be empirically tested for its reliability, validity and usefulness.

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IV

APPENDICES

APPENDIX I: Information data sheet for participant teachers

RESEARCH TOPIC: The Role of Teacher Questions or Questioning In Chemistry Teaching and a New Way to Conceptualize Types of Questions

PARTICIPANT'S BACKGROUND INFORMATION QUESTIONNAIRE

1. Gender
   - Male
   - Female
2. Age
   …………………….
3. Which kind of teacher qualification do you hold?
   - Lektor

☐ Hovedfag+ 1/2yr PPU ☐ Masters +1 yr. PPU ☐ Integrated 5year teacher program

   - Adjunkt

     ☐ 3 yrs. subject study + PPU

     ☐ Bachelor + PPU

     ☐ Integrated 4 yrs. teacher Program

   - Others specify ………………………………………………………………
   - No
4. Which subjects did you specialize in?
   …………………………………………………………………………………………
   …………………………………………………………………………………………
5. In which year did you attain your teaching qualification?
   - Year………………………………….. …………………………………
6. At which grade level(s) have you taught or are you teaching?
   …………………………………………………………………………………………
7. Which subjects are you or have you been teaching?
   ....
   ....
8. How many years have you been teaching?
   ………………………………………………………………………………………….

APPENDIX II: Semi-structured interview guide used in paper I

Questions

1. Please comment on the clip with special focus on the questions the teachers use.
    a. How would you describe the questions/questioning?
    b. What do you think about the teachers' intentions or expectations?
    c. What about student reactions?
    d. Which similarities or differences do you see between the two situations?
2. How do you use questions yourself in your teaching?
    a. Ask for examples when they do not come from the teacher
    b. Ask for reasons (when, why, what intention/expectation)
    c. Ask for when decision for asking a question is made (on the spot, in advance)
    d. Differences depending on part of teaching sequence or lesson (repeating subject matter, introducing new subject matter, classroom discussions, summarizing …)?
    e. In case the teacher does not specify different types of questions; he could be asked if he/she heard about defining different question types or about other ways of differentiating between questions)
3. How do you react to students' answers? What do the answers tell you?
4. Are there certain questions you won't ask in your teaching? (ask for their characteristics if any and for reasons for the teacher's decision for either asking or not asking those kinds of questions)
5. How did your current understanding/thinking about questions/questioning develop? Which sources of information and experiences contributed? (Education, professional development, colleagues, books, articles)

Appendix III:

Approval by NSD - Norsk senter for forskningsdata to conduct interviews with chemistry teachers in Bergen, Norway

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
N-5007 Bergen
Norway
Tel: +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Festo Kayima
Kjemisk institutt Universitetet i Bergen
Realfagbygget, Allégt. 41
5020 BERGEN

Vår dato: 18.10.2013 Vår ref: 35876 / 2 / KH Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 11.10.2013. Meldingen gjelder prosjektet:

35876	*The Role of Teacher Questions or Questioning In Chemistry Teaching and a New Way to Conceptualize Types of Questions*
Behandlingsansvarlig	*Universitetet i Bergen, ved institusjonens øverste leder*
Daglig ansvarlig	*Festo Kayima*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 20.01.2017, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Vigdis Namtvedt Kvalheim

Kjersti Haugstvedt

Kontaktperson: Kjersti Haugstvedt tlf: 55 58 29 53
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 35876

Personvernombudet finner informasjonsskrivet til utvalget tilfredsstillende utformet forutsatt at navnet til stipendiaten også fremkommer.

Personvernombudet forutsetter at det foreligger en databehandleravtale mellom Universitetet i Bergen og ekstern databehandler, jf. personopplysningsloven § 15.

Forventet prosjektslutt er 20.01.2017. Datamaterialet anonymiseres ved at verken direkte eller indirekte personidentifiserbare opplysninger fremgår. Lydopptak og logger slettes.