LATVIAN CHEMISTRY TEACHERS' SKILLS TO ORGANIZE STUDENT SCIENTIFIC INQUIRY

Jelena Volkinsteine, Dace Namsone, Liga Cakane
University of Latvia, Riga, Latvia
E-mail: jelena.volkinsteine@lu.lv, dace.namsone@lu.lv, liga.cakane@lu.lv

Abstract

In 2005 a new chemistry subject standard for basic education was developed in Latvia. It includes a new component, 'scientific inquiry'. In order to develop students' inquiry skills, their teachers need to master them first. The purpose of this study was to examine Latvian chemistry teachers' skills to effectively organize student scientific inquiry within their lessons.

From 2009 to 2011, experts from the project 'Natural Sciences and Mathematics' observed and analyzed the performance of 18 chemistry teachers at basic schools in 31 lessons. 56 lesson observation and analysis work sheets were analized on the student scientific inquiry.

Chemistry teachers with experience in modernized chemistry contents have better skills to plan the study process towards the results, to apply study methods correctly and organize collaboration among students, to provide efficient feedback, analyze their performance in the lesson and reflect on it. In order to develop teachers' skills to organize student scientific inquiry, it is important to focus on teachers' skills to organize their work during the lesson and to reflect on it. This can be done through organizing teachers' learning groups for investigating their professional performance, conferences and experience exchange seminars with lesson observation and analyses.

Key words: *chemistry teachers' skills, lesson observation, scientific inquiry*.

Introduction

Since the introduction of a new education reform in 2005 that aimed at the development of a competent personality and its functional comprehension (Trowbridge & Bybee, 2006), new chemistry subject standards for basic and general secondary education have been evolved in Latvia (Regulations No 1027, 2006 and No 715, 2008 of the Cabinet of Ministers of the Republic of Latvia). The new standards of the chemistry subject contain a component called 'scientific inquiry', which is going to change the approach to learning chemistry and enhance student participation in the lesson (Osborne & Dillon, 2008).

Scientific inquiry means the cognition; the process during which information or comprehension is being sought (Klopfer, 1990). Inquiry in the science classroom includes these essential features:

- The learner is engaged in a scientifically oriented questions;
- The learner gives priority to evidence in responding to the question;
- The learner uses evidence to develop an explanation;
- The learner connects the explanation to scientific knowledge;
- The learner communicates and justifies the explanation (National Research Council, 2000).

All these features center on the learner's mental activity (Bybee & Fuchs, 2006). Learning through scientific inquiry encourages student involvement in scientific thinking and discussion, and allows them to experience research the way scientists do it. Consequently the students develop their own ideas, draw up hypotheses and observe how these hypotheses are tested (Atkinson, 1990).

The idea of the inquiry is also revealed in the following quote: 'Competency in inquiry-based instruction is not developed solely by providing inquiry lessons to students or by giving them opportunities to do inquiry based labs. The process is more than that. Inquiry is a personal and professional investigation that starts with developing a constructivist-based philosophy and reflecting, both individually and with others.' (Llewellyn, 2005).

In order to develop the aforementioned students' inquiry skills, the teachers need to possess knowledge of how to effectively organize inquiry-based science education (IBSE).

Research shows that teachers and teaching have a huge impact on students' progress - effect size (ES) is 0,47 and 0,43 accordingly (Hattie, 2012). Therefore teachers' skills to organize scientific inquiry and their professional development should be put first, and only then can improvement of student's progress be addressed (Fullan, 1996).

In all countries where teachers use IBSE, experts point to the teachers' difficulty in organizing scientific inquiry (Anderson & Michener, 1994; Bybee & Fuchs, 2006). Among the factors contributing to the problem, experts mentioned lack of time, insufficient knowledge of the subject, insufficient understanding of scientific inquiry, lack of resources and materials, conflict between the teachers' learning style and the inherent style of inquiry (Kraus, 2008).

Inquiry based approach to teaching chemistry is a new thing for the teachers of Latvia. Chemistry teachers of Latvia have gained significant experience organizing and leading the traditional students' laboratory work (Namsone, 2010). However the need for better student scientific inquiry skills is obvious. It has been concluded that efficient teaching of inquiry skills in the school is impossible without teachers' understanding of the concept, diversity and continuity of the scientific inquiry, as well as the following skills:

- Ability to identify the achievable results of scientific inquiry and their conformity to the expected results;
- Effective use of the teaching method/technique for the development of students' scientific inquiry;
- Effective organization of student collaboration during the scientific inquiry;
- Effective communication of feedback on students' scientific inquiry.

This idea has been supported by a number of scientists in their research.

For example, researchers conclude that in order to organize an effective lesson, teachers need general skills (Bishop & Denley, 2007), skills to plan the teaching based on the current knowledge of the students and their way of thinking, teachers should be able to word the teaching goals and success criteria in a way that students can achieve progress according to the expected criteria (Hattie, 2012). Researchers also highlight the importance of the following skills: to select appropriate contents (from everyday life, etc.); to transform the contents into individual IBSE levels; to observe and conduct experiments; to ask questions in accordance with IBSE; to conduct action research and design-based research. However, understanding of students' scientific inquiry here plays the most important role (Mukhopadhyay, 2013).

It is important for teachers to understand the difference between different levels of scientific inquiry (Banchi & Bell, 2008) and use these criteria accordingly in the classroom. Based on the role of the teacher in the classroom and his/her guidance (assistance, asking leading questions, wording of the expected results) there are at least four scientific inquiry levels: confirmation, structured inquiry, guided inquiry, open inquiry. Guided inquiry means the change of the teachers' role, that is, irrespective of the teacher's participation in the wording of the inquiry problem he/she acts as a student's guide. In this way the teacher has a lesser impact on the students than in the previous levels of inquiry and the students' performance is independent – the students develop the plan and conduct the experiment to test their hypothesis independently (Kuhlthau at al., 2007).

Open inquiry is the highest level of IBSE – the students' word the inquiry problem independently, choose the tools, plan and conduct the experiment, record the data, analyze them and make evidence-based conclusions. This encourages students to use their advanced thinking skills (Banchi & Bell, 2008) and an internal readiness. The process fails if any of the previous scientific inquiry stages are skipped.

The scientific inquiry teaching is closely related to other lesson efficiency enhancing strategies. Teachers' questions, conversation and dialogue skills are crucial. In order to develop students' scientific inquiry skills, which require a certain way of thinking, the teachers need to use advanced thinking level questions and encourage the students to ask questions. The research shows that 60% of the questions asked during lessons are about facts and 20% are procedural, that is, 20% of the questions are of a reproductive character (Brualdi, 1998).

Scientific inquiry includes students' group work. However a student grouping up does not always mean real group work (Galton & Patrick, 1990). Therefore, teachers need appropriate encouragement and group work leading skills.

One of the most vital preconditions for successful teaching is effective feedback ES 0,79 (Hattie, 2012). Many researchers point out the following teachers' shortcomings in organizing formative evaluation: most often formative evaluation takes place frontally for the entire class, and many students fail to understand teachers' feedback and to correctly interpret the message.

Teachers wrongly focus on the volume of the feedback instead of the quality of the contents and the message that the students were supposed to receive (Carless, 2006; Goldstein, 2006; Nuthall, 2007).

So, in order for the teaching in the classroom to be effective and help students master scientific inquiry skills during the lesson, it has to be clearly communicated what is going to be taught (achievable results or learning goal); students should be involved in the process where the teacher is skillfully making a conversation during scientific inquiry and organizing collaboration among students. The student needs to receive feedback that helps him/her understand the progress and shortcomings.

This is crucial to understand because scientists conclude that in the case of failure teachers are most likely to return back to the traditional teaching (Darling-Hammond et al., 2008).

Problem of Research

Scientific inquiry approach defined in curriculum documents is new for chemistry teachers in Latvia and no research about how it works in the school practice has been done. Students' benefits on scientific inquiry are closely connected with their teachers' abilities to effectively organize inquiry-based science education. That is why it is important what and how teachers do in their lessons in order to develop students' inquiry skills.

Research Focus

The main research purpose was to examine Latvian chemistry teachers' skills to effectively organize students' scientific inquiry in the lessons.

The current research was framed by three research questions:

- Do chemistry teachers implement scientific inquiry in teaching-learning process?
- Do chemistry teachers have appropriate skills to effectively organize students' scientific inquiry in the lessons?
- What are the relationships, if any, among skills to effectively organize students' scientific inquiry by chemistry teachers with and without experience to analyze and reflect on their professional performance?

Methodology of Research

General Background of Research

The research design for this study was a case study (Yin, 2009) of Latvian chemistry teachers' experience in organizing students' scientific inquiry in the lessons. The case study

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was conducted within the project 'Natural sciences and mathematics' lead by the National Centre for Curriculum Development and Examinations from 2009 to 2011. Scientific inquiry for Latvian chemistry teachers is a new approach to teaching chemistry. How science is taught depends on the teachers, so it is important to clarify how successfully teachers implement the new approach in the classroom, and whether they have appropriate skills to do that effectively or they need support in the IBSE application in chemistry teaching.

Sample of Research

The research included 18 chemistry teachers from local schools which were selected according to the definite criteria and involved in the development project 'Natural sciences and mathematics' lead by the National Centre for Curriculum Development and Examinations, 2008. The goal of the teachers in the project was to pilot modernized chemistry contents for basic school, and based on one of the project priorities focus on organization of students' scientific inquiry in chemistry lessons (Project, 2008).

Based on the teachers' background, their chemistry teaching and scientific inquiry organizing experience, as well as their knowledge of analyzing, reflecting on their professional performance and collaboration with colleagues, the teachers subject to the research were divided into two target groups: A and B (see Table 1).

Table1. Description of research participants.

Criteria	Participants to the research (N=18)	
	Group A teachers (N=11)	Group B teachers (N=7)
Place of employment	Basic school	Secondary school
Teaches chemistry	Grades 8-9	Grades 8-12
Background of the chemistry teacher	2 teachers	6 teachers
Teaches second subject (biology, etc.)	9 teachers	2 teachers
Experience in organizing scientific inquiry before 2008	none	3 years
Experience to analyze and reflect on their professional performance, collaborate with others before 2008	none	3 years

As the table shows, before 2008 teachers of Group A had neither experience in organizing scientific inquiry teaching nor had they improved their analysis and reflection skills. Only since 2008 over a period of three years teachers of Group A enrolled in regular classes teaching them how to lead scientific inquiry, analyze and reflect on their own and their colleagues' performance and how to develop their collaboration skills. In their turn, teachers of Group B had already accumulated particular experience before 2008 (they had piloted modernized chemistry contents for secondary school since 2006) which was enhanced over a period of the following three years.

Instrument and Procedures

The instrument used in this study consists of a lesson structured observation and experts' observation and analyses sheets.

From October 2009 to April 2011 over a period of 5-7 months the experts observed and analyzed two chemistry lessons by each teacher; a total of 36 lessons. The experts' team consisted of 5 chemistry and 13 natural sciences specialists with over 10 years' experience in natural sciences methods and teacher training. These specialists had been accumulating experience as experts diversely working with natural sciences teachers and analyzing and evaluating implementation of scientific inquiry in teaching. As the scientific inquiry approach is being implemented in the country anew, experience in this field is limited.

How did lesson observation take place?

The observation took place in a natural environment. In order to achieve the maximum objectivity, each lesson was observed by two experts – a chemistry and a different subject specialist. Each expert had an observation sheet: the chemistry expert was focusing on the teacher's performance while the other observer was recording student' performance. After the lesson the experts filled out an analysis sheet with the expert's conclusion based on the received observation data.

In this research 56 experts' observation and 56 experts' analysis sheets on 31 lessons with student scientific inquiry were analyzed: 18 lessons with teachers of Group A and 13 lessons with teachers of Group B.

Data Analysis

For structured observation, frequencies of scientific inquiry activities or events, or experts evaluations were counted. The obtained quantitative data were processed by using the software Microsoft Office Excel.

The obtained qualitative data (experts' comments in analysis sheets) were processed by using the software NVivo 7.

Results of the research

Experts observed 36 lessons in order to evaluate teachers' performance in implementing scientific inquiry teaching and skills needed for organizing effective teaching. The observations showed that student scientific inquiry was present in 31 lessons: in 12 lessons teachers performed guided inquiry and in 19 lessons they were introducing separate inquiry elements.

Experts concluded that in 3 lessons out of 5 inquiry non-related, teachers successfully used an inquiry approach to meet the goals of the lesson. However, teachers of Group A chose the traditional approach – narrative and traditional demonstration. Consequently the experts concluded that '*Students were willing to talk and get involved. However, they were not given a chance. There were episodes when the students could have performed and commented independently; however, it was done by the teacher. Students were passive observers of the lesson*'.

Most often experts observed teachers' performance regarding students' analysis and evaluation skills - 50% lessons and conclusion skills - 70%. Teachers largely focused on students' experimentation skills – about 56% and observation skills - 40%. However, planning experiment and wording hypotheses by students were only observed in up to 30% of lessons (see Figure 1).

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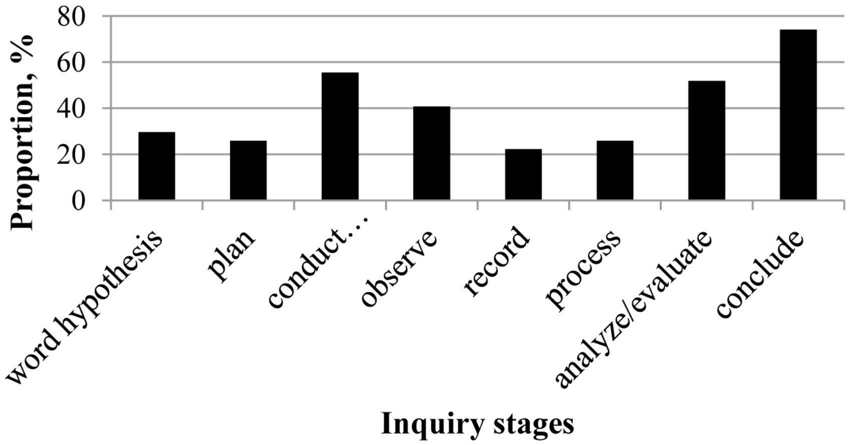

Figure 1: Scientific inquiry stages in the observed lessons (N=31).

The experts' evaluation of teachers' skills to organize student scientific inquiry (skills to plan lessons, to choose and apply an appropriate method in the lesson, to organize student collaboration and support their inquiry learning) are going to be described further.

Based on the observation of 31 lessons the experts evaluated Group A and Group B teachers' skills to organize scientific inquiry teaching and concluded that 66% of the teachers were able to identify the achievable result and state it; about 49% chose the most effective teaching method and successfully applied it in the lesson; about 58% successfully organized student collaboration; 46% did well at providing feedback to the students. However, the research shows that skills of teachers of Group A and Group B to organize scientific inquiry teaching differed.

Teachers' skills to identify the achievable results and their conformity to the expected results (based on experts' evaluation, N= 56)

Planning of the scientific inquiry teaching starts with identifying the results students have to achieve. Then the teacher goes on to build scientific inquiry lesson and at the end follows up on the students' progress.

The research shows that all teachers of Group B possess skills to identify the achievable results and their conformity to the expected results. In its turn, in about 60% and more cases in the observed lessons (N=31) teachers of Group A had difficulty identifying the achievable results and evaluating conformity of the expected and achieved results (see Figure 2).

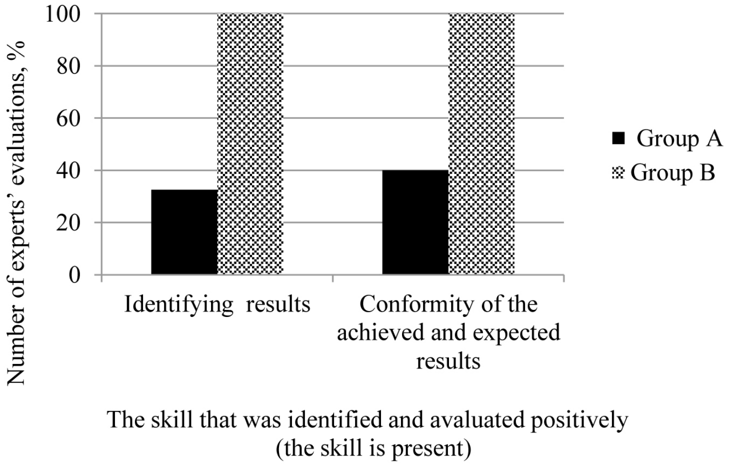

Figure 2: Group A and Group B teachers' skills to identify the achievable results and their conformity to the expected results.

Although teachers of Group A were trying to plan student's achievable results, experts' notes on the lesson analyses sheet said: *'Initially the teacher allows students to plan, but then she starts prompting. There is no time for conclusions and students say 'we had nothing happening in the lesson', 'the teacher did not react'.*

Consequently, teachers of Group A put forward inquiry related achievable results. However, in 68% of observed cases, students failed to achieve them or they were not sure if they had achieved the results, or if they had understood how their performance was evaluated.

Teachers' skills to use the teaching method effectively
(according to experts' evaluation, N= 56)

The research shows that in over 90% of the cases during the observed lessons teachers of Group B possessed the skills of effective application of the teaching method. It was different among teachers of Group A where the effective methods were chosen in only 40% of the cases. Furthermore, teachers of Group A successfully applied the chosen method during the lesson and the students had active participation in the teaching process in only 25% of the cases (see Figure 3).

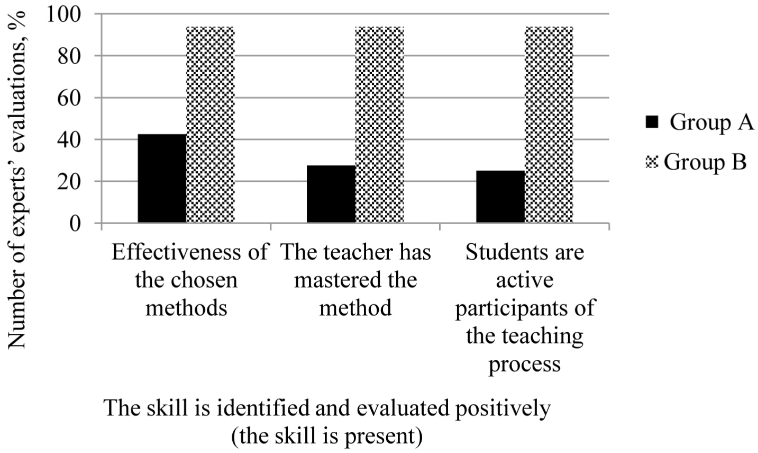

Figure 3: Skills of teachers of Group A and Group B to effectively apply the teaching model.

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An illustrative expert's evaluation and description of this common situation in the classroom on the lesson observation sheet reads as follows: *'The students took formal participation in the lesson. However, only few of them had intellectual involvement. The incentive was taken over by the teacher who did most of the talking, and students had no chance to think or work independently. Consequently, student active participation in the lesson was very limited.'* Even when teachers of Group A did choose an effective inquiry based teaching method, they often failed to apply it (by 16% cases less than chosen, see Figure 3). Expert notes allow us to conclude that teachers of Group A, *'fail to precisely and correctly communicate the assignment to the students',* and *'they lack skills to lead a determined conversation and ask diverse questions'*.

Teachers' skills to effectively organize student collaboration
(according to experts' evaluation, N= 56)

Research showed that in over 80% of cases teachers of Group B had effective student collaboration organizing skills. In about 65% of the observed lessons experts noted that teachers of Group A chose the effective collaboration model while in about 60% of cases teachers of Group A showed shortcomings in organizing student collaboration (see Figure 4).

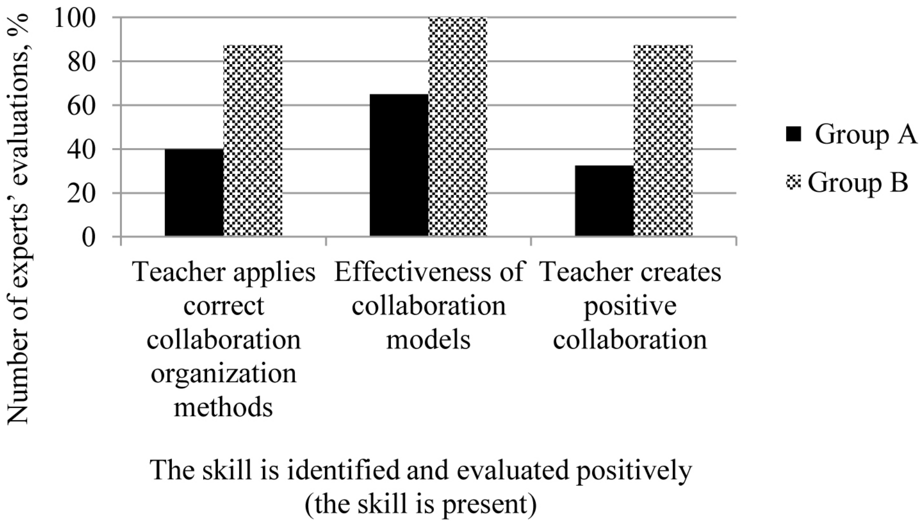

Figure 4: Group A and Group B teachers' skills to effectively organize student collaboration.

Expert notes on the lesson analyses sheets:

'The teacher should master group work organizing principles and explain them to the students'.

'The teacher fails to encourage student discussion on group achievements'.

'Students were confused and had no understanding of what they were supposed to do...... there was no collaboration'.

'The teacher does not seem to know what results to expect from the students and how to lead the group work'.

'During the whole activity the teacher had to separately explain the assignment to each group'.

If we combine the aforegiven expert conclusions on teachers' skills (see Figure 2-4) in the observed scientific inquiry lessons – to plan the lesson towards the achievable result (Result), effectively apply the teaching method (Methods) and students' collaboration in the lesson

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(Collaboration), communicate feedback in the lesson, we can conclude that teachers of Group B demonstrated appropriate skills in 90% of cases. On the contrary among teachers of Group A, from 54% to 73% of cases these skills were inadequate (see Figure 5).

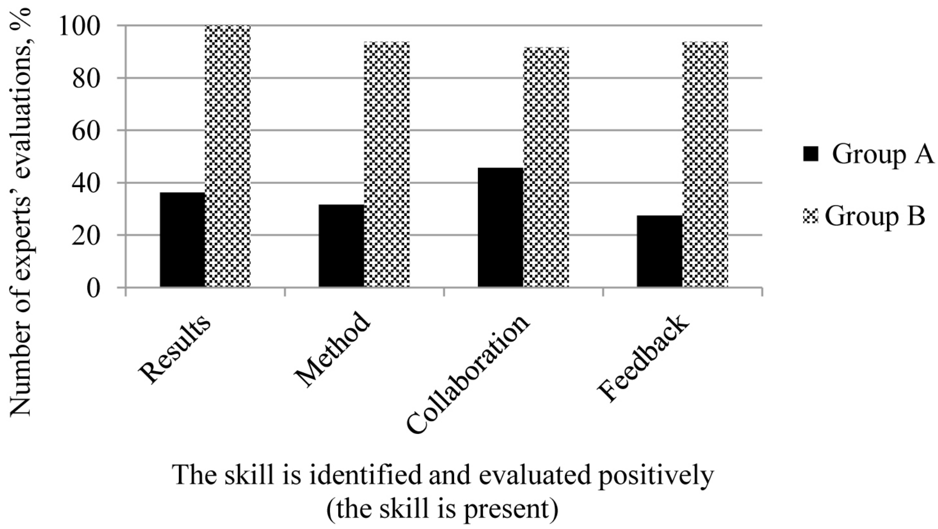

Figure 5: Group A and Group B teachers' skills to effectively organize scientific inquiry.

In about 70% of the cases in the observed lessons teachers of Group A either ignored formative evaluation or performed it incompletely.

Experts often noted that: *'The teacher failed to communicate complete feedback on the answers'*.

So there is a big difference between Group A and B teachers' skills to organize scientific inquiry lesson – while teachers of Group B have rather well-developed skills, for the most part Group A teachers' skills are insufficient.

The skill in focus is teachers' competence to organize scientific inquiry. The data comparing Group A and Group B teachers (see Figure 5) leads us to conclude that the competence of effective scientific inquiry organizing was present in 22% (N=18) and 77% of the observed lessons (N=13) respectively (see Figure 6).

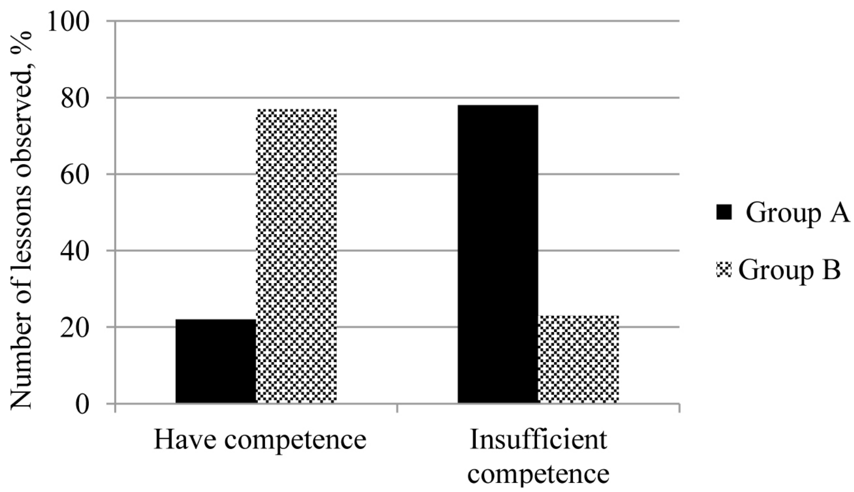

Figure 6: Group A and Group B teachers' competence to organize student scientific inquiry.

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Discussion

During the observed lessons teachers actively used guided inquiry and taught separate inquiry elements, experts did not see open inquiry in the observed lessons. This might be due to the lack of, or insufficient, experience in organizing inquiry based teaching which, combined with a sense of insecurity, explains why teachers do not choose to organize the lesson as inquiry lesson. Moreover, students are in the stage of learning scientific inquiry and they need to understand particular stages of the process. In other words, students were not yet ready for open inquiry.

The experts noted that the teachers focused on students' experimental skills which may be caused by the fact that students start learning chemistry as a separate subject in basic school and these skills are crucial for learning chemistry. If the lesson plan did not include tests, hypothesis or planning the course of action by students, the lesson resembled the traditional laboratory work according to the 'cook book recipe'.

Teachers believe that the skill of formulating conclusions is challenging for students therefore they spend a lot of time on this problem (Namsone at al., 2012). Drawing a conclusion is seldom a formal activity and this testifies to the presence of difficulties that teachers have organizing the lesson and leaving enough time for drawing conclusions. We see that students and teachers often have the same difficulties.

Research points to the differences in the professional capacity of lesson organizing skills between teachers of Group A and Group B which may result from different experience backgrounds in planning the teaching process, analyzing performance, reflecting on it and collaborating with colleagues. Over a period of three years before 2008 teachers of Group B had been working with the project 'Natural sciences and mathematics' and learning how to implement scientific inquiry in secondary schools, demonstrate lessons, analyze and reflect on them as well as work together with their colleagues. Experience may be the factor why teachers of Group B had developed deeper understanding on what they were doing in the lesson, how and why they were achieving goals. This helped teachers of Group B to have better student scientific inquiry lessons than their colleagues from Group A.

Research on Group A skills to organize student scientific inquiry shows that teachers fail to understand that the inquiry process requires active participation on behalf of the students in the teaching process and the change of the teacher's role from an information provider to a consultant. In the past, teachers used to be student chief resource for information and it was easy. However, the practice has changed and the contemporary study process requires teachers to delegate the responsibility to the students. Teachers of Group A mentioned 'plan', 'conclude', 'collaborate' as the achievable goals for their students. However, according to experts, in reality things work out differently and the teacher does all the planning and concluding.

The teaching experience survey of Group A teachers working form 2008 revealed that 71% have frequent or very frequent group work in their lessons, and only 29% seldom practice group work. This means that teachers are familiar with the principles of effective student collaboration. However, experts point to a contradiction between the teachers' evaluation of their skills and the actual performance in the classroom.

The above facts suggest that teachers of Group A fail to admit the lack of knowledge and therefore methodological assistance for effective organization of scientific inquiry in their lessons is much needed. This idea is supported by the teachers who have already improved their scientific inquiry organization skills in a group (Namsone at al., 2012): *'I thought I knew how to do it but I never saw that what I was doing actually didn't work'* or *'I understand that I have to teach students to initiate the problem, but I do not know how to do it'.*

Thus, these results are in accordance with other studies on implementation of inquiry-based science education. As concluded by the researches carried in the Czech Republic, in order to iffectiveely organize student scientifi inquiry, teachers require, for instance, the skill to organize student educational activities in IBSE, the skill to use a wide range of educational techniques (methods, forms, and aids) suitable for IBSE (Trna at al., 2012).

Teachers of Group A faced the same difficulties as other teachers for whom the scientific inquiry approach is new: limited ability to teach constructively, the challenges of assessment, difficulties of group work, the challenges of new teacher roles, the challenges of new student roles (Anderson, 2002).

Researchers note that teachers can work for quite a long time period using a new approach to teaching-learning process before they start to recognize and discuss issues that cause difficulties and before they understand the correlation between their beliefs and values and their classroom practices. Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values and understandings (Blumenfeld at al.,1994).

In order to help teachers identify and improve their skills for effectively organizing scientific inquiry, innovative teacher professional development models providing experts' or colleagues' feedback are very effective.

For example, experts assistance is available if the teacher is willing to improve his/her skill to effectively organize student collaboration in the inquiry lesson. The expert observes the lessons focusing on the desirable areas of the improvement. Then, together the teacher and the expert jointly analyze the lesson, discuss the feedback and seek solutions. If needed, the expert gives advice or helps the teacher develop a lesson plan. The expert becomes the teacher's personal trainer who helps identify and understand the causes of good or poor performance and forecast the future actions. Experience exchange seminars are a great opportunity for teachers to improve their scientific inquiry feedback communication skills. Lesson demonstration is followed by joint analysis with colleagues with the focus on quality of feedback.

Online conferences enable teachers to discuss scientific inquiry teaching problems with other teachers, ask questions and receive answers as well as learn specific issues about inquiry, for example, how to teach experimental planning.

Learning Teams - a small group of teachers united by the idea of improving their effective scientific inquiry organization and students' scientific inquiry skills. The teacher examines his/her professional performance and discusses results with the supportive learning team participants.

Before 2008 teachers of Group B had already attended a number of experience exchange seminars and worked individually with an expert-trainer to learn organization of an effective teaching process for mastering scientific inquiry skills. This helped teachers of Group B to be better prepared for scientific inquiry than teachers of Group A. Organization and leading student scientific research can only be mastered by planning the teaching, practicing it, and analyzing its successes and shortcomings. This shows the significance of the teachers' ability to analyze their performance during the lesson and to reflect on it.

This point of view coincides with the findings of other researchers: *'Good teaching requires that teachers reflect on their practice'* (Sergiovanni,1996) or *'Becoming an inquiry-based teacher will require creating and sustaining reflection practices and discourse with other teachers'* (Liewellyn, 2005).

Conclusions

Chemistry teachers in Latvia are gradually implementing scientific inquiry in teaching at basic school.

An effective teaching of scientific inquiry to students is possible if teachers have the following skills:

- Ability to identify the achievable results of scientific inquiry and their conformity to the expected results;
- Effective use of the teaching method/technique for the development of student scientific inquiry;

- Effective organization of student collaboration during the scientific inquiry;
- Effective communication of feedback on student scientific inquiry.

Teachers of Groups A and B have different levels of effectiveness of scientific inquiry organizing skills. While teachers of Group B have well-developed skills, Group A teachers' skills are quite limited. Group B teachers' experience comes from experience exchange seminars as well as the routine of analyzing and reflecting on their performance during lessons.

The contradiction between the actual situation in the classroom and Group A teachers' opinions confirms the idea that in order to develop effective scientific inquiry organization skills, teachers have to have analysis and reflection skills. In this situation, innovative professional development models can successfully provide methodological support to effective Group A teachers' scientific inquiry organizing skills. These models have to focus on teachers' complete immersion into the lesson and receiving appropriate feedback.

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Advised by Mihails Gorskis, Daugavpils University, Latvia

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Jelena Volkinsteine	PhD, University of Latvia, Faculty of Chemistry, Kr. Valdemara Street 48, Riga, Latvia, LV-1013. E-mail: jelena.volkinsteine@lu.lv Website: http://www.lu.lv/eng/faculties/fch/
Dace Namsone	Senior Researcher, The Centre for Science and Mathematics Education, University of Latvia, Zellu Street 8, Riga, Latvia, LV-1002. E-mail: dace.namsone@lu.lv
Liga Cakane	Researcher, The Centre for Science and Mathematics Education, University of Latvia, Zellu Street 8, Riga, Latvia, LV-1002. E-mail: liga.cakane@lu.lv