

PROMOTING INQUIRY-BASED TEACHING OF CHEMISTRY¹

Luca Szalay

Eötvös Loránd University, Faculty of Science, Institute of Chemistry, Science Education and Didactics, Pázmány Péter sétány 1/A, H-1117 Budapest, Hungary

Abstract Analysis of student performance in different areas of science in the 2006 PISA showed that Hungarian students demonstrated relative weaknesses in identifying scientific issues, knowledge about science and using scientific evidence. Since then Hungarian students' mean performance on the combined science scale dropped below the average, causing concern amongst experts and decision-makers. Problems of teaching and learning science in Hungary have produced symptoms that have been widely discussed in the literature. Our 2008 investigation showed that science teachers were working under severe constraints in terms of time, lab assistance, external support and funding. Since then several changes have happened in the conditions of teaching. However, science teachers' time remains precious and, together with the fact that the literature is often in English, this means that much education research goes unread. A possible answer to the demand of widening the students' scientific skills might be sets of freely available teaching resources based on inquiry-based learning. One teacher trainee's thesis described her experiences of a small scale pilot of an inquiry activity and summarised the advantages and disadvantages. One hundred and eighteen participants at five in-service chemistry courses were asked to convert 'step-by-step' practical instructions for students into activities, parts of which require groups of students to plan and discuss their work. Alternatively, participants could use a template to write novel activities. Seventy percent of materials produced by the teachers met the main criterion of an inquiry-based activity, but only some met all the criteria. These were edited and published on a website in Hungarian. They are free to try, criticise, modify and develop. The project described here provides a basis for devising and creating an online inquiry-based chemistry resource.

Keywords PISA, motivation, inquiry, practical chemistry, the SOLO taxonomy

1 INTRODUCTION

Analysis of student performance in different areas of science in the 2006 PISA (PISA 2006) showed that Hungarian students scored well in the area of *Physical systems* (measuring factual knowledge of physics and chemistry) and *Explaining phenomena scientifically*, but were relatively weak at *Identifying scientific issues*, devising scientific investigations (*Knowledge about science*) and *Using scientific evidence* (Table 1). This suggests that in the teaching and learning of science in Hungarian schools the emphasis has been on knowledge and understanding, rather than how evidence for scientific ideas is gathered and evaluated and that the ability of Hungarian students in the areas of 'how science works' and 'how scientists work' was relatively under developed.

Table 1. Hungarian students' performance difference between the combined science scale and each scale in 2006 PISA (science score: 504)

Competencies	
Identifying scientific issues	-21.3
Explaining phenomena scientifically	+14.2
Using scientific evidence	-6.9
Knowledge about science	
-11.9	
Knowledge of science	
"Earth and space"	+8.6
"Living systems"	+5.2
"Physical systems"	+29.2

This raises issues about the relationship between society and the scientific community which, in part, has contributed to the spread of pseudoscience. The 2006 PISA analysis states: *"A student who has mastered a scientific theory but who is unable to weigh up evidence, for example, will make limited use of science in adult life"*. Hungary was amongst the countries for whom it was suggested that there was a *"need to consider the ways which they acquire wider scientific skills"*. Since then the mean performance of Hungarian students on the combined science scale dropped below the average of the countries surveyed, causing further concern among experts and decision-makers.

The problems of teaching and learning science in Hungary have produced symptoms similar to the ones described by Peter Childs (Childs, 2009): *"In many countries, interest in studying Science at school and university is falling, and there is concern over falling numbers and falling standards."* An earlier investigation (Kertész, Szalay, 2009) into the reasons for this showed that in Hungary, as in several other countries, science teachers work under significant constraints in terms of available preparation and teaching time, lab assistance, external support and funding. Quality control of teachers' work was largely superficial. Therefore, statements in the science curriculum about competence-based education and active learning had negligible effect on everyday teaching. Since then there have been several changes to regulations concerning quality assurance of teaching, curriculum and finance. Although the changes in the curriculum were made with the intention of reducing the content, many teachers have continued to focus on content and not sufficiently on developing a wider range of scientific skills.

Further, Childs states that *"much education research is never read by practitioners and even less is applied"* (Childs, 2009). Teachers need time and support to understand the outcomes of educational research and their implications. They need skills and support to implement suggested changes to approaches to teaching and learning. In Hungary, since most educational research papers are written in English, language barriers exacerbate the problem. To help this process, approaches to teaching and learning that have produced promising results in other countries should be introduced, tried, tested and evaluated in the Hungarian context.

2 THEORETICAL BACKGROUND

2.1 THEORETICAL SUGGESTIONS TO ENHANCE MOTIVATION

Increasing motivation and interest in learning science is the first step on the long road leading to successfully developed scientific skills. Bolte, Streller and Hofstein (2013) summarised the basic theories underlying these concepts. They quote Hofstein and Waldberg (1995) who "*suggested that in order to enhance motivation in the classroom there is a need: to create an environment in which (a) students are given opportunities to interact physically and intellectually with instructional materials whenever possible through handling, operating and practicing, (b) effort is made by the teacher to provide materials and instruction that gives reality and concreteness to scientific (in our case chemistry) concepts, and (c) teachers vary instructional strategies materials and classroom practice with the aim of increasing effectiveness of teaching and learning by enhancing students' motivation.*" They also describe "*The model of motivational design*" by Keller and Kopp (1987), suggesting: *attention* of students can be raised by challenging their curiosity and posing questions and problems to be solved; *relevance* should be established by making clear how the topic concerns the learner currently and in the future and how it matches their needs; *confidence* can be supported by helping students their likelihood for success; *satisfaction* is important and learners should experience the worth of the learning. Underpinning all of this is the importance of making students aware of learning objectives, prerequisites, performance requirements and evaluation criteria.

The Six C's Modell of Motivation (Turner, Paris, 1995) are also quoted by Bolte, Streller and Hofstein (2013). This says that the learning environment should allow students *choices*. The tasks should be *challenging*, but achievable. Students should have some *control* over the learning process, by participating in decision-making, and become responsible, independent and self-regulated learners. *Collaboration* allows students to share learning experiences and perspectives with each other through social interaction and cooperative work. By *constructing meaning* the students perceive the value of learning. Learning should be connected to positive *consequences* such as rewards, praise and successful experiments.

A model of learner motivational characteristics and pedagogies (Hofstein, Kempa, 1985) described by Bolte, Streller and Hofstein (2013) states that there is no single recipe to foster students' motivation and interest in chemistry education. They categorise students as achievers, curious, conscientious and socially motivated. According to them, the discovery/inquiry-oriented pedagogies and problem-solving are mainly suitable for students with '*curiosity*'-type motivational pattern, but these are disliked by the '*achievers*' and the '*conscientious*' students. Open-ended and student-centred learning activities are preferred only by the '*curious*', but not by any other type students. Collaborative learning activities are suitable for learners with a strong *social motivation* pattern. ('*Achievers*' are likely to be opposed to an involvement in this type of learning activity.) The '*achievers*' and the '*conscientious*' students like formal teaching with emphasis of information and skill transfer.

According to the results of our earlier investigations (Kertész, Szalay, 2009), this latter was (and probably still is) the most often applied teaching method in Hungary. This statement explains the Hungarian students' achievements on PISA 2006 (see above). However, it also means that this instruction method does not suit the '*curious*' and the '*socially motivated*' students.

2.2 Inquiry-based science education

Uno (1990) defines inquiry-based learning as '*a pedagogical method that combines hands-on activities with student-centred discussion and discovery of concepts*'. According to the definition published by the National Research Council of the United States of America in the Inquiry and the National Science Education Standards (Olson, Loucks-Horsley, 2000) inquiry is "*an activity that involves*

- making observations
- posing questions
- examining books and other sources of information to see what is already known
- planning investigations
- reviewing what is already known in light of experimental evidence
- using tools to gather, analyze, and interpret data
- proposing answers, explanations, and predictions
- communicating the result".

Through inquiry-based activities, students can gain a better understanding of the nature of science and the importance of collaboration and communication in science. This could address the under development of skills such as identifying scientific issues, devising scientific investigations and using scientific evidence. In Hungary, students could be challenged to solve problems by working in groups to plan and evaluate practical investigations, using a combination of 'hands-on' and 'minds-on' activities.

Bruck and Towns (2009) wrote guidelines and suggestions about how to prepare students to benefit from inquiry-based activities in the chemistry laboratory. They conclude that

student activities include developing:

- *Foundational knowledge required for engagement in inquiry activities*
- *Appropriate laboratory skills*
- *Independence through generation of experimental procedures, methods of analysis, and communication and defence of results.*

'Inquiry-based science teaching/learning/instruction/education' (IBSE) is thought to raise interest and increase motivation, at least among the '*curious*' and the '*socially motivated*' students (see above and Hofstein, Kempa, 1985). An extended review of 138 studies by Minner *et al.* (2010) "*indicate a clear, positive trend favouring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing*

conclusions from data". These teaching strategies are more likely to increase conceptual understanding than more passive techniques.

However, Kirschner, Sweller, and Clark (2006) state in their provocative article that

minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process

According to them unguided instructions cost more and "there is also evidence that it may have negative results when students acquire misconceptions or incomplete or disorganized knowledge." Hmelo-Silver, Duncan and Chinn (2007) responded by arguing that "*Does it work?*" is the wrong question. The more important questions to ask are under what circumstances do these guided inquiry approaches work, what are the kinds of outcomes for which they are effective, what kinds of valued practices do they promote, and what kinds of support and scaffolding are needed for different populations and learning goals.

The answer to these questions is complex and 'requires one to also consider the goals of education – including not only learning content but also learning "softer skills" such as epistemic practices, self-directed learning, and collaboration

Balancing these reservations and arguments, the National Research Council in the National Science Education Standards recommendation (Olson, Loucks-Horsley, 2000) sensibly suggests that various degree of guidance could be efficient, depending on time, place, participants and the way it is applied. IBSE has also been propagated by the American Chemical Society (Kessler, Galvan, 2007), by the European Commission (Rocard, M., at al., 2007) and the European Union Framework Program 7 (Science Education, FP7 Projects 2007-2010, 2006). The author of this present paper has participated in two of those FP7 projects, titled Mind the Gap and S-TEAM.

3 RESEARCH METHODOLOGY

3.1 A SMALL SCALE PILOT PROJECT

After reviewing the literature of IBSE, a teacher trainee planned and carried out a pilot with three different groups of students as part of her thesis (Rákóczi, 2010). Two student sheets and a teacher guide were written and tried. Working in small groups, students were asked to design two experiments, modelling either the self-heating or the self-cooling cups used in automats providing drinks such as hot chocolate or ice tea¹. Heating or cooling happens because of the exothermic or the endothermic dissolution of two different salts (CaCl₂ or Na₂S₂O₃·5H₂O). Students watched a brief advertisement video that explained how the cups work and were given a drawing showing the different compartments of the cups.

Each group of students was given a certain amount of one of the salts, water, a suitable size beaker, a measuring cylinder, a stirring rod and a thermometer. They were asked to design a model experiment to illustrate and help to explain how the cup heats or cools the

¹ See a website in French about it here: <http://www.miamz.fr/test/test-caldo-caldo-les-boissons-autochauffantes-1398/> (Last visited: 23.12.2014.)

drink that it contains. They were also asked to make calculations, to decide whether the cup could heat up or cool down the drink to the temperature promised by the advertisement. To do this they had to find a data (the specific heat capacity of water) in their book containing scientific constants and tables of data. Further, as a homework that was discussed at the following lesson, they had to consider and evaluate the environmental aspects of using these cups and similar products. No rewards (such as good marks) were offered or given other than praise from the teacher trainee and the feel of success if they accomplished the task well.

3.2 IN-SERVICE TEACHER TRAININGS AND INSTRUCTIONAL MATERIALS

The author of this paper spread the idea of using IBSE in Hungary at conferences and in-service teacher training events (continuous professional development, CPD courses) organised for chemistry teachers. One hundred and eighteen teachers have been participating in five courses between 2011-2014 (Table 3). At each course, a summary of the literature and findings of earlier research (international and the small scale Hungarian pilot) were given. Then two exemplar activities, written by the author of this paper, were tried in practice, with participating teachers playing the students' role. At the end of each training course participants were asked to develop their own IBSE materials or to convert current 'step-by-step' student experiments into 'mini-investigations'. The requirement was to set students a question or problem that they should find interesting and relevant and ask them to work in groups to

- *design and carry out at least one experiment to answer the question or tackle the problem*
- *evaluate the methods used and data obtained.*

Guidelines and a unified structure and format of the instructional materials were provided, as well as the two exemplar files written by the author.

Teachers were asked to try their materials and/or the exemplar files provided with their students and send feedback via e-mail. Edited versions of the original instructional materials were prepared and made freely available for anybody on a website.

3.3 THE SOLO TAXONOMY

Tomperi and Aksela (2014) describe the use of the SOLO (Structure of the Observed Learning Outcome) taxonomy as a tool to estimate the quality of learning attainable for students when performing laboratory tasks according to written instructions.

[It] is based on the Piaget's sequence of cognitive development reflecting the understanding of science at five hierarchic levels where each level builds at the skills that were acquired at previous one.

Tomperi and Aksela state that

focusing on learning outcomes in practical chemistry, laboratory instruction can be written using the SOLO taxonomy at five hierarchical categories with increasing

difficulty. The first three levels, prestructural, unistructural and multistructural levels, correspond to traditional verification »cook-book« laboratory.

Verification means practical activities that illustrate ideas and concepts. They are 'demonstrations' carried out by teachers or by students and do not help students to develop their higher order cognitive skills (HOCS). Only the highest two SOLO taxonomy levels do this: "*Relational and extended abstract SOLO levels ...correspond to the various types of inquiry*".

The content of materials handed in by the in-service participants was subjected to a qualitative analysis. They were categorised and decisions were made whether they could come into the highest two SOLO levels mentioned above and therefore meet the definition of inquiry given by Tomperi and Aksela (2014).

3.3 RESEARCH QUESTIONS

The small scale pilot project was organised to identify the benefits and disadvantages of using the IBSE in Hungarian schools and, further, how the benefits could be enhanced and disadvantages reduced.

The purpose of categorising and editing of materials handed in by the in-service participants was to determine:

The proportion of the participants that embraced the idea of writing or transforming instructional materials according to the requirements of the inquiry to develop HOCS.

The conditions needed for IBSE to be used successfully in the Hungarian schools.

How spreading the practice of IBSE could be supported.

4 RESULTS AND DISCUSSION

4.1 RESULTS OF THE SMALL SCALE PILOT

The experiences of the trials with the three groups of student (Rákóczi, 2010) are summarised as seen in Table 2. These are qualitative statements, since the sample was too small for statistical analysis. The inquiry tasks were motivating, supporting other research observations (e.g. Hofstein, Kempa, 1985). The statement stressed by Bruck and Towns (2009) that previous knowledge and skills necessary for doing the IBSE activity should be ensured and checked in advance, was also supported. Some students had misconceptions that needed correction, in line with a concern about IBSE made by Kirschner, Sweller, and Clark, 2006. And finally, this straightforward inquiry was more time-consuming than expected.

Table 2. Positive and negative experiences of the small scale pilot

Positive experiences	Negative experiences
Students showed genuine interest while working on the students' sheets. Most of them were motivated to achieve good results (without any promise of good marks).	Designing experiments was the most unusual task for students that caused concern among them. (It took a long time before they dared to start doing their already planned experiment.)
Students found it disturbing when they did not know something what they felt they should.	Many of them did not understand the concept of modelling a phenomenon by an experiment.
Skilled and successful accomplishment of the practical part was experienced by the group that had often done student experiments earlier.	Observations written by the students were usually not detailed and thorough enough.
When concentrating on the task and after some guidance given by the teacher many students could solve the calculation problem too.	In several cases, lack of the necessary content knowledge (concerning the heat of dissolution and its related concepts) became obvious by answering the questions on the student sheet.
Matured, environmental-conscious approach on the students' part.	Some students had a misconception by mixing up a physical change by a chemical reaction. Several students could not solve the simple calculation problem in this context at all. Even this simple inquiry task was very time-consuming (much more than previously expected).

To summarise how the results of the pilot matched statements in the literature:

1. Differing types and amounts of inquiry and other student-centred activities and teacher-centred instructional methods are needed for efficient and effective teaching. The different approaches complement one another when it comes to various learning outcomes, acquiring knowledge and developing skills.
2. Inquiry should be introduced gradually, taking into account students' knowledge and experience. Over time students may be given increasing responsibility for their learning.
3. When designing activities the increased time needed when IBSE replaces a part of the traditional 'step-by-step' must be accounted for and weighed against the benefits of developing a wider skills base, especially HOCs.
4. IBSE type tasks should not be started before the previous knowledge necessary to accomplish them is thoroughly checked and/or provided.
5. Interesting contexts for inquiries can motivate the students.
6. After completing an IBSE task a teacher-led summary is helpful (and, sometimes, essential), when all the results are discussed and evaluated together by the whole class. This ensures that the knowledge constructed by the students is not incomplete or disorganised (Kirschner, Sweller, and Clark, 2006). It also provides chances for the teacher to discover and correct the possible misunderstandings and/or misconceptions.

4.2 RESULTS OF THE EXAMINATION OF THE INSTRUCTIONAL MATERIALS MADE BY THE PARTICIPANTS OF THE IN-SERVICE TEACHER COURSES

Ninety nine of the 118 participants of the 5 in-service teacher training CPD courses sent instructional materials to be used for chemistry practical lessons written or transformed by themselves till the deadline (Table 3). This sample of teachers is not representative as they participated voluntarily and were not chosen according, for example, to their qualifications, workplaces, and age of students they teach. However, despite this the results are informative.

All materials were analysed using the SOLO taxonomy (Tomperi and Aksela, 2014) and those that provide an opportunity to develop higher order cognitive skills (HOCS) identified. There were 69. The other 30 had only verification type tasks ('demonstrations'), mostly student experiments written in 'step-by-step' style. This was despite discussions about the importance of theoretical background and the earlier experiences explained at the time of the courses and the provision of exemplar materials. So almost a third of teachers probably misunderstood the task and thought that for transferring a 'cook-book style' experiment to an 'inquiry' is enough if the usual step-by-step experiment is put into context or a question/problem is produced that would probably raise the students' interest before doing the usual 'step-by-step' activity. The qualitative results show that teachers need guidance, including exemplar materials, when they begin to use IBSE methods.

Table 3. Number of participants of the five in-service teacher training CPD courses, the number of instructional materials produced by them and the number of the instructional materials among those activities that could develop higher order cognitive skills (HOCS)

No.	Timing		Number of participants	Number of materials	
	Time period of the CPD course	Deadline to hand in materials		handed in altogether	developing HOCS
I.	12-26 th February 2011	5 th August 2011	22	19	14
II.	11-26 th March 2011	5 th August 2011	23	17	12
III.	30 th June-2 nd July 2011	9 th September 2011	25	23	17
IV.	9-11 th May 2013	26 th August 2013	23	18	8
V.	6-8 th February 2014	17 th June 2014	25	22	18

It was found that many of the 69 activities that provided opportunities for HOCS development were still missing some important components of an effective student activity, despite being provided with a template that had the following headings:

- Title of the activity
- Author (name, workplace, e-mail address)
- Learning objectives
- Necessary previous knowledge
- Instructional suggestions (and advice to organise the activity)
- Preparation
- Assessment

- Further ideas to develop the activity
- References
- Student sheet
- Student sheet with (possible) solutions

The materials produced by teachers were varied greatly. For instance: in many cases the learning objectives were not clear; and/or no context was given; and/or the necessary prior knowledge and skills were not given; and/or assessment methods were not described. However, the remaining activities fulfilled the requirements and nine could be called innovative. Others were based on well-known 'step-by-step' student experiments, but the inquiry element was present that added to the scientific skills developed by the activity.

Materials that provided a good basis for inquiry-based activities were chosen and edited, with the agreement of their authors, to produce for inquiry type practical activities for use in Hungarian schools. Since some topics had more than one related activity, the activities belonging to a given topic were merged together to make a final activity for each topic.

Edited versions of 20 student sheets and teacher guides, together with the two exemplar materials, were published on a website as Word documents in Hungarian² and are free to use. The intention is that they will support Hungarian chemistry teachers who want to introduce meaningful inquiry in their chemistry practical lessons. Some examples are summarised in Table 4.

Table 4. Authors, titles, topics and the brief descriptions of the inquiry tasks of four exemplar activities based on the IBSE materials sent by the participants of the five in-service teacher trainings

Author(s) and title	Description of the inquiry task
J. Balázs, K., Oláh, G., Szakmány, Cs.: 'Changing and unchanged' (Physical and chemical equilibrium)	Some years ago many people received warning e-mails not to eat Mentos candies after drinking coke, because it is said to be very dangerous. According to the letter, a boy's stomach exploded thank to the huge amount of gas formed by the reaction of these two materials. The statement was illustrated by shocking photographs. Could this be true? Design experiments modelling the process and discuss their results.
Baloghné Pálffy, Zs., Borbás R., Magyar, Cs., Nagy, R., Szalay, L.: 'The iron tooth of corrosion' (Corrosion and local batteries)	The leftover of a lasagne dinner remained in a stainless steel oven tray was covered by aluminium foil and put in the refrigerator. Overnight small holes were formed on the aluminium foil, where it was touched by the lasagne. Why do you think this happened and why so quickly?
Györe, H.: 'The blue plum that is red when it is green' (Natural acid-base indicators)	You have got 0.1 mol/dm ³ HCl solution, 0.1 mol/dm ³ NaOH solution, red cabbage indicator, ion-exchanged water, Pasteur pipettes, a 10 cm ³ measuring cylinder and 9 test tubes. Design an experiment when you make a pH scale in the 9 test tubes and determine the pH of the household materials that you find on your tray.

² <http://www.chem.elte.hu/w/modszertani/fellap.html> (Last visited: 23.12.2014.)

Author(s) and title	Description of the inquiry task
Nagy, M.: 'A drop in the sea' (Amount of substances, surface tension, intermolecular bonds)	Try to think of methods how you could determine the volume of a drop of water by using just ion-exchanged water, two beakers (or glasses) and a Pasteur pipette. Determine the volume of one drop of ethanol too. Why do you think the two volumes are different? Calculate the number of molecules both in one drop of water and in one drop of ethanol. How confident are you in your results? How could you increase your confidence?
Hanga, I.: 'The orange and the sciences (Vitamins, redox titrations)	Each effervescent tablets that you find on your tray contains 60 mg vitamin C. It is known that the vitamin C reacts with iodine. Dissolve one tablet in a glass of water, pour 1 cm ³ starch solution in it and stir it. Then add Lugol's solution to it drop by drop (while continuously stirring the solution) until the change of colour of the solution is permanent. Make notes about your observations and try to explain them. How could you determine how much vitamin C is in an average orange? How confident are you in your results? Why? How could you increase your confidence? What do you think is healthier to have: one of the vitamin C tablets that you used for the experiments or an orange?

Eight of the activities were tried and tested by the authors in schools or in thematic summer camps organised for students. One exemplar activity was also tried with two groups of students (N=33) and a control group (N=17), but the sample was insufficient for statistical analysis. Nonetheless, feedbacks from teachers reinforced the experiences of the earlier small scale pilot (see the results above and in Table 2). Teachers were surprised at the difficulties caused by the most straightforward of inquiry tasks, such as determining the volume of a drop of water (see in Table 4) and how much time it takes for the students to work out a feasible plan to do it.

A complex, 120 minutes talent nurturing programme based on the files published on the website mentioned above was also edited by the author of the present paper. The programme was tried with 24 students (age 15-18) when they visited the ELTE University in Budapest in November 2013. It contained 4 activities, each of them consisting of a series of experiments that were partly written in 'step-by-step style', partly 'inquiry style'. Before these activities the students participated at the demonstration of four teacher experiments. The purpose of those was to make sure that the students have the previous knowledge necessary to solve the following inquiry tasks described by the student sheets of the 4 activities. While doing the activities, students worked in 8 groups, each consisting of 3 students of mixed age. The activities took 25-30 minutes as a minimum and 50-60 minutes as a maximum. Two groups did each activity, but some of those were only partly successful. The programme was finished by four spectacular teacher experiments that also gave the opportunity to summarise the experiences of the four student activities previously done by the students.

Not surprisingly, of the four inquiry tasks the students found easiest to do the one that resembled the most to the teacher demonstration they had seen before. After the teacher demonstrations, for a similar reaction both groups could work out how to increase the rate of reaction (heating the solutions of the starting materials) and slow down a reaction (diluting the solutions of the starting materials). They could explain what they did and why. The less instructions and clues were provided, the more difficult the activities proved to be. Both

groups managed to determine the approximate volume of a drop of water and a drop ethanol. However, one group needed hints to work out a feasible plan and did not manage to explain the difference between the volumes (despite watching and analysing a teacher demonstration previously concerning the surface tension). Only one of the two groups that had the task to determine the pH of household materials could design and successfully accomplish the preparation of a pH scale by dilutions. However, even these students failed to write down a detailed enough plan. Neither of the two groups who had the task to design a model experiment of cathodic protection of iron could explain how and why zinc could be used for this purpose, despite of the experiments with electrochemical cells that they had seen and done themselves beforehand. The most important lesson to learn of this trial is that even the inquiry tasks should be composed very carefully. It has to be written down in details, what exactly the students are expected to produce (e.g. a 'step-by-step' description of the experiment designed by their group). The inquiry activities should be followed closely by the teacher, guidance given when it seems to be necessary. Checking points of the plans, calculations and so on might be also needed when there is a danger of complete failure. Misunderstandings and misconceptions should be corrected during or after finishing the inquiry tasks. The format is also important. For example, the most important instructions should be highlighted and there has to be enough space left for detailed answers and calculations, to leave space for tentative plans and mistakes). The description of this programme was corrected according to the experiences and the final version published on the same website, where the other activities are.³

Although teachers found the IBSE methods and the materials published on the website interesting, the general view among them was that these take too much time of the chemistry lessons. Therefore the author of this paper edited four brief inquiry activities in four different topics that could be accomplished in about half an hour each. Therefore they would fit conveniently in a 45 minutes chemistry lesson. These inquiry activities were also tried and tested in the laboratory of the ELTE University by 12 students. Three of the four activities were piloted some months later at the Researchers' Night of 2014 by about forty people of various age in the same laboratory too. These activities are also published on the same website.⁴

A summary of steps leading to the efficient and effective use of inquiry activities in Hungarian chemistry lessons:

1. The descriptions of the tried and tested inquiry activities ready for printing, preferably editable, have to be available for all Hungarian chemistry teachers.
2. Topics should be closely connected to the curriculum. An inquiry activity might originate from a well-known step-by-step practical that is transformed, at least in

³ <http://www.chem.elte.hu/w/modszertani/fellap.html> (Last visited: 23.12.2014.)

⁴ <http://www.chem.elte.hu/w/modszertani/fellap.html> (Last visited: 23.12.2014.)

part, to inquiry tasks, by asking the groups of students to design one or two experiments and discuss the results after finishing it.

3. The context of inquiry activities should be interesting and relevant to the students.
4. Related teacher-led introductions and/or step-by-step experiments should happen before the inquiry tasks. These ensure that the students have the necessary prior theoretical and practical knowledge to accomplish the inquiry task successfully.
5. Students should work in small groups, perhaps consisting of students with mixed motivation types.
6. Guidance and help should be provided by the teacher only when needed while the students are working on the inquiry task.
7. After finishing the activity, a teacher-led plenary is necessary, where experiences are summarised, conclusions are drawn and possible misunderstandings are corrected.
8. The whole activity (together with the teacher-led parts) should fit comfortably in a 45 minutes lesson.

4.3 Further plans

There are insufficient data at present for a critical statistical analysis and evidence-based evaluation of piloting IBSE in Hungary. A more extensive project, led by the author was started in May 2014 and ends in April 2015. It is part of a national project that aims to develop teaching materials to help initial and in-service teacher trainings. Further lesson plans including inquiry instructional materials for practical chemistry have been written to be used in primary and secondary schools. A brief pilot consisting of three chemistry lessons about reaction kinetics is organised in 12 schools involving 16 teachers and more than 800 students. Pre- and post-tests, as well as control groups will be applied to investigate and evaluate the possible effects of using IBSE on the development on the students' scientific skills and their attitude toward science.

References

- Bolte, C., Streller, S., Hofstein, A. (2013) How to motivate students and raise their interest in chemistry education In: I. Eilks & A. Hofstein (eds.) *Teaching Chemistry – A Studybook* (pp. 67-95). Sense Publishers.
- Bruck, L. B., Towns, M. H. (2009) Preparing Students to Benefit from Inquiry-Based Activities in the Chemistry Laboratory: Guidelines and Suggestions, *Journal of Chemical Education*, 7, 820-822.
- Childs, P.E. (2009) Improving chemical education: turning research into effective practice, *Chemistry Education Research and Practice* 10, 189-203.
- Hofstien, A. Kempa, R. F. (1985) Motivating strategies in science education: attempt of an analysis. *European Journal of Science Education*, 3 221-229.
- Hmelo-Silver, C. E., Duncan, R. E., Chinn, C. A. (2007) Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006) *Educational Psychologist*, 42(2), 99–107.
- Hofstein, A., Waldberg, H. J. (1995) Instructional strategies In B. J. Fraser & H. J. Waldberg (eds.) *Improving science education* (pp 70-89). Chicago NSSE.
- Keller, J. M., Kopp, T. W. (1987) An application of the ARCS model of motivational design. In: C. M. Reigeluth (ed.) *Instructional theories in action. lessons illustrating selected theories and models* (pp. 289-320). Hillsdale: Lawrence Erlbaum.
- Kertész, J., Szalay, L. (2009) Summary of the work of the National Public Education Council's ad hoc committee for the investigation of science education, *Hungarian Chemists' Journal*, 64(4), 107-111. (in Hungarian)
- Kessler, J. H., Galvan, P. M. (2007) *Inquiry in Action – Investigating Matter Through Inquiry*, 3rd ed., American Chemical Society Retrieved from: <http://www.inquiryinaction.org/download/> (Last visited: 23.12.2014.)
- Kirschner, P. A. Sweller, J., Clark, R. E. (2006) Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching, *Educational Psychologist*, 41(2), 75–86
- Minner, D.D. *et al.* (2010) Inquiry-based Science Instruction – What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002, *J. Res. Sci. Teach.*, 47(4), 474-496.
- Olson, S., Loucks-Horsley, S. (2000) *Inquiry and the National Science Education Standards*, 29. http://www.nap.edu/openbook.php?record_id=9596 (Last visited: 23.12.2014.)
- PISA 2006: Science Competences for Tomorrow's World, Volume 1: Analysis, 64-68.
- PISA 2012 Snapshot of performance in mathematics, reading and science <http://www.oecd.org/pisa/keyfindings/PISA-2012-results-snapshot-Volume-I-ENG.pdf> (Last visited: 23.12.2014.)
- Rákóczi, M.: *Inquiry-based science education practicals in teaching chemistry* (2010), thesis, Eötvös Loránd University, Faculty of Science, Institute of Chemistry, supervisor: Szalay, L. (In Hungarian)
- Rocard, M., *et al.* (2007), *Science Education Now: A Renewed Pedagogy for the Future of Europe* Retrieved from http://ec.europa.eu/research/swafs/pdf/pub_science_education/report-rocard-on-science-education_en.pdf#view=fit&pagemode=none (Last visited: 23.12.2014.)
- Science Education, FP7 Projects 2007-2010 (2006) Retrieved from: http://ec.europa.eu/research/science-society/document_library/pdf_06/fp7-science-education-contracts-2007-2010_en.pdf (Last visited: 23.12.2014.)
- Tomperi, P., Aksela, M. (2014). In-service Teacher Training Project On Inquiry Based Practical Chemistry. *LUMAT*, 2(2), 2015-226.
- Turner. J., Paris, S. G. (1995) How literacy tasks influence children's motivation for literacy. *The reading teacher*, 48, 662-673.
- Uno, G.E. (1990) "Inquiry in the classroom", *BioScience*, 40(11), 841-843