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IMPLEMENTATION OF INQUIRY-BASED SCIENCE EDUCATION IN SCIENCE TEACHER TRAINING

Assoc. Prof. Dr. Josef Trna
Masaryk University
CZECH REPUBLIC
trna@ped.muni.cz

Assist. Prof. Dr. Eva Trnova
Masaryk University
CZECH REPUBLIC
trnova@ped.muni.cz

Assist. Prof. Dr. Jiri Sibor
Masaryk University
CZECH REPUBLIC
sibor@ped.muni.cz

Abstract

The number of students interested in studying science and technology has decreased all over the world. Research results have shown that one of the main negative factors is an improper outdated method of science teaching in schools. There are also significant changes in students' learning style, which requires innovation of a learning method. It is necessary to prepare young people for lifelong learning. Inquiry-based science education (IBSE) has succeeded as a suitable educational method that greatly motivates students. To make this educational method effective, it is necessary to follow its principles and implement it in education properly. Therefore it should be included in science teacher training. The model of development of science teacher professional skills for IBSE application is presented. Particular curricular materials show the principles of IBSE. The European project PROFILES presents implementation of IBSE into science teacher training.

Key Words: Inquiry-based science education, science education, teacher training.

INTRODUCTION

Yet as scientific knowledge develops and grows, as new scientific tools and technologies emerge and work their way further into civic life, there is grave concern and debates about the quality of science education (Duschl, Schweingruber, & Shouse, 2007). Science educators around the world face the problematic decline in the study of science and technology (OECD, 2006). Researches in the Czech Republic show that increasing age of students brings decreasing interest in the studying of science (Ministry of Education, Youth and Sports CR, 2008). One of the factors leading to this phenomenon is considered an unsuitable outdated method of teaching/learning science in schools (Rocard et al., 2007). Only 15 % of European students are satisfied with the quality of science teaching in schools and nearly 60 % state that science teaching/learning is not interesting enough (Ministry of Education, Youth and Sports CR, 2010). Traditional teaching concepts very often prefer separate knowledge acquisition such as data, formulas, equations, theories, etc., that are difficult to understand for students who just memorize them and forget them very easily. Misunderstood knowledge cannot be used to solve tasks and problems. Students therefore consider science to be very difficult and even though they believe science contents are important for society, they consider them unnecessary in their everyday life. This statement has been confirmed by the results of the research we conducted in the project PROFILES (see below).

Interest has also been found to influence future educational training and career choices (Krapp, 2000), an important aspect in terms of the urgent need to counter the declining interest that young people have in pursuing scientific education and careers (Osborne & Dillon, 2008; Rocard et al., 2007). Developing an understanding of and ability to use evidence is important not only for the study of science, but also for lifelong learning and for solving problems in everyday life. Science is a practice that incorporates more than just concepts and facts, but also involves scientific ways of thinking and reasoning (McNeill, 2010). Evidence, in the form of data that are obtained by experiment and measurement, is used to answer questions, solve problems or make decisions (Aikenhead, 2005). Tytler, Duggan and Gott (2001) argue that the use of evidence is central to the interactions between the public and science. When making a decision, everyone should be able to evaluate information, ask questions, use evidence and argue. Scientifically literate citizens use scientific approaches for analyzing and solving problems requiring investigation, basing their judgments upon evidence rather than presuppositions and bias. For example, Zohar and Nemet (2002) found out that students were able to transfer their argumentative skills from the instruction of genetics and apply them successfully in the dilemmas of everyday life. As an example of application of the scientific process in decision making in everyday life, the solution of vaccination can be mentioned (Aikenhead, 2005).

The current situation in science education suggests that the gap between how science subjects are taught and how they are perceived in society (e.g. on television and in other media) is rapidly increasing (Cakmakci et al., 2011; Osborne, 2007). This is also an argument for the need to implement into science subjects contemporary teaching/learning methods that can reduce the gap between the understanding of nature based on the knowledge taught in school and extracurricular knowledge obtained from different information sources (Ault & Dodick, 2010; Bianchini, 2008). Therefore it is necessary to look for innovative teaching/learning methods that will lead to more effective science education and increase in students´ motivation for science.

Last years have seen a growing call for inquiry to play an important role in science education (American Association for the Advancement of Science, 1994; National Research Council, 1996; Blumenfeld et al., 1991; Linn, diSessa, Pea, & Songer, 1994). For these reasons, inquiry-based science education is becoming increasingly popular and has proved to be a suitable educational method for the development of necessary knowledge and skills, motivating students significantly. Inquiry-based science education holds out the promise of engaging students more productively, of giving them opportunity to enjoy science and find it rewarding.

IBSE IN SCIENCE EDUCATION

Today's rapidly changing world brings in new requirements for education and thus for science education. The importance of knowledge and traditional skills is decreasing because their life span is getting shorter. The society wants schools to equip young people with “new weapons to fight the market” such as creativity, curiosity, change management and life-long learning. In addition, it is necessary to motivate students to get interested in science. This requires changes in science education. It is necessary to revise science contents and apply appropriate modern teaching/learning methods. Such teaching/learning methods include inquiry-based science education (hereinafter IBSE). It is an instructional learner-centred approach that on the bases of inquiry integrates theory and practice, and develops knowledge and skills for a solution to a defined problem. Students have to solve the problem, conduct self-directed learning and work in teams to make their own connection, creation and organization for future application in similar problems. This deviates from didactic, lecture-tutorial, teacher-centred approach where the focus is on only transmission of knowledge from teacher to students. Students in IBSE lessons are encouraged to be able to solve problems independently and competently. This call for inquiry-based learning is based on the recognition that science is essentially a question-driven, open-ended process and that students must have personal experience with scientific inquiry to understand this fundamental aspect of science (Linn, Songer, & Eylon, 1996). Furthermore, inquiry activities provide a valuable context for learners to acquire, clarify, and apply an understanding of science concepts. Research results (Darling-Hammond, 2008; Rocard et al., 2007) prove that IBSE brings the required competences to society, it is effective and increases students´ interest in studying science, and also stimulates the motivation of teachers. This method is effective for all types of students: from the weakest to the smartest (including the gifted ones), boys and girls, students of all ages.

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IBSE levels in science education

However, it is logical that IBSE is age-specific when being applied to science education. Application IBSE needs a large ensemble of activities that constitute "doing science". These activities include conducting investigations, sharing ideas with peers, specialized ways of talking and writing, mechanical, mathematical, and computer-based modelling, and development of representations of phenomena. This type of science education involves active learning, and it takes advantage of children's curiosity by increasing their understanding of the world through problem solving. To develop skills in science, students must have the opportunity to participate in this full range of activities. It would be wrong to assume that young students in primary science are able to conduct scientific research independently and from the beginning as students in secondary science courses, or even as real scientists do. The teacher has to develop individual skills gradually and systematically and lead the students to some extent according to their abilities even in IBSE. Banchi and Bell (2008) defined four IBSE levels (see Table 1) according to the degree of teacher's guidance (help in the process, asking guiding questions and the formulation of the expected output).

Table 1: Four IBSE Levels

IBSE levels	Questions (defined by teacher)	Procedure (defined by teacher)	Solution (defined by teacher)
(1) Confirmation	Yes	Yes	Yes
(2) Structured	Yes	Yes	No
(3) Guided	Yes	No	No
(4) Open	No	No	No

(1) Confirmation inquiry

It is based on confirmation or verification of laws and theories. Confirmatory inquiry is appropriate at the beginning of IBSE implementation, when the teacher aims to develop observational, experimental and analytical skills of the students. When conducting experiments, students follow teacher's detailed instructions under his/her guidance.

(2) Structured inquiry

The teacher significantly influences the inquiry at this level and helps students by asking questions and providing guidance. Students look for solutions (answers) through their inquiry and provide an explanation based on the evidence they have collected. A detailed procedure of experiments is defined by the teacher, but the results are not known in advance. Students show their creativity in discovering laws. However, they are conducted by teacher's instructions in the research. This level of inquiry is very important for developing students' abilities to perform high-level inquiry.

(3) Guided inquiry

The third level of IBSE changes the role of the teacher dramatically. The teacher becomes a students´ guide. He/she cooperates with students in defining research questions (problems) and gives advice on procedures and implementation. Students themselves suggest procedures to verify the inquiry questions and their subsequent solutions. Students are encouraged by the teacher much less than in the previous two levels, which radically increases their level of independence. Students should have previous experience of lower levels to be able to work independently.

(4) Open inquiry

This highest level of IBSE builds on previous three inquiry levels and it resembles a real scientific research. Students should be able to set up their inquiry questions, methods and procedures of research, record and analyze data and draw conclusions from evidence. This requires a high level of scientific thinking and places high cognitive demands on students, so it is applicable for the oldest and/or gifted students.

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These four IBSE levels correspond to different age levels of students. However, it is possible to apply different levels of IBSE to the same age group during group instruction depending on students´ abilities. Similarly, we can choose the appropriate level of IBSE according to the demands of the science course.

IBSE and students´age

Developmental constraints used to be presented as a reason why teaching based on inquiry shouldn't be applied to younger students in primary science. The idea of children being concrete and simplistic thinkers is outdated and shows that children's thinking is surprisingly sophisticated. Current researches show that even young children can be involved in learning using basic scientific procedures (Duschl et al., 2007). Zembal-Saul (2009) believes it is appropriate for younger students to get involved in simple inquiry, not only in the form of fun hands-on activities. Children's development of inquiry-based learning wants students to learn to verify evidence, make arguments, look for connections between findings, discuss and search for alternative explanations. It is also important to encourage younger students´ interest in science education because researches show that increasing age of students brings decreasing interest in science (Simpson & Oliver, 1985; Baram-Tsabari & Yarden, 2009). This statement has been confirmed by the results of a research in the Czech Republic (MEYSCR, 2010). It has been proved that the rejection of science subjects increases with school attendance age. Upper secondary school students reject science more than lower secondary ones. For example, chemistry was turned down by less than a fifth of lower secondary school students, while in upper secondary schools the number was nearly 50 % (MEYSCR, 2010).

Science contents appropriate for IBSE

An appropriate choice of science contents is of great importance for successful IBSE application. Strategy for the selection of a motivating contents for IBSE is in focus on a relevant, meaningful, controversial, and open scientific issue (Blumenfeld et al., 1991; Barron et al., 1998). Absence of relevance is a common complaint of students about their science lessons and a reason for lack of desire to continue studying science beyond school. What is seen as relevant by teachers and other adults may not be perceived as such by young people.

Researches show that students are motivated if the science contents are associated with the problems of everyday life (Baram-Ttsabari & Yarden, 2009). Therefore, one of the most important IBSE principles is to use students´ experience of everyday life as a learning aid for scientific procedures (Warren et al., 2001). Such experience may be similar to or quite different from academic disciplinary practices. It is important for teachers to understand these similarities and differences in order to implement them in instruction in a suitable way (Taylor, 2009). Teachers candidates in pre-service teacher training begin to acquire this very important pedagogical skill and they develop it in their professional life in in-service teacher training. A part of our project PROFILES was research analysing the research question whether students in the Czech Republic are interested in science contents associated with their everyday life. We used a students´ questionnaire as a research method. In 2011 we collected 334 responses of a representative sample of students aged 14-15 years, 158 boys and 176 girls from nine secondary schools. Students expressed their views on whether their lessons contain what they need in everyday life and what is important for the development of society. They considered this issue at two levels. First they expressed their experience of actual or real science lessons and then had the opportunity to express their ideas of imaginary ideal lessons. Partial results of the questionnaire survey are shown below (See Table 2).

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Table 2: Questionnaire Survey Results

ACTUAL or REAL lesssons which students attend in the area of science (number of students = 334)								
Question		Scale and percentage of answers						
1	The level of importance to **my everyday life** of the topics I study in science lessons may be described as:	Extremely important	Very important	Important	Fairly important	Somewhat unimportant	Very unimportant	Extremely unimportant
		1	**6**	**18**	33	29	10	3
2	The level of importance **to society** in general of the topics I study in science lessons may be described as:	Extremely important	Very important	Important	Fairly important	Somewhat unimportant	Very unimportant	Extremely unimportant
		5	**15**	**25**	30	20	4	1
IDEAL lesssons which students attend in the area of science (number of students = 334)								
Question		Scale and percentage of answers						
1	For me, science lessons should be useful in **my everyday life**:	Extremely important	Very important	Important	Fairly important	Somewhat unimportant	Very unimportant	Extremely unimportant
		6	**17**	**33**	22	14	6	2
2	For me, science lessons should be relevant **to society** in general:	Extremely important	Very important	Important	Fairly important	Somewhat unimportant	Very unimportant	Extremely unimportant
		12	**15**	**35**	26	9	2	1

Regarding the real lessons only a quarter of students (25 %) considers science contents to some extent (extremely important + very important + important) important for their daily lives and 45 % of students believe it is important to society. On the contrary, 42 % of students consider science contents to some extent unimportant (somewhat unimportant + very unimportant + extremely unimportant) to their daily lives and about 25 % of students as unimportant to society. Approximately a third of students expressed a neutral opinion to both questions.

Students could express their wishes regarding science contents in the idea of an ideal science lesson. More than half (56 %) of students would like the science contents related to everyday life and 62 % of students said that the science contents should be beneficial to society.

Our research confirms the international experience that problems of everyday life motivate and inspire students to study science. There is evident contradiction between what is really taught in Czech schools and what students would like to be taught. These findings have been confirmed by other studies carried out in the Czech Republic (MEYSCR, 2008; MEYSCR, 2010). Science educators have to consider the fact when innovating teaching/learning methods and also in science teacher training.

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IMPLEMENTATION OF IBSE IN SCIENCE TEACHER TRAINING

We must not forget the important role of teachers in promoting children's curiosity and persistence by directing their attention, structuring their experiences, supporting their learning attempts, and regulating the complexity and difficulty of levels of information for them. To be successful in science, students need carefully structured experiences, instructional support from teachers, and opportunities for sustained engagement with the same set of ideas over weeks, months, and even years (Duschl et al., 2007).

Teacher professional development is very important because how science is taught depends on the teachers. The experience shows no innovation will be sustained unless systematic and ongoing professional development of science teachers is provided to support the changes required in the instruction (Osborne & Dillon, 2008). Pajares (1992) believes teachers' conceptions are a product of their experiences in education as students.
Teacher's PCK (Shulman, 1987) has long-term and complex development, therefore it is necessary to start with the preparation of science teachers for IBSE application in pre-service training and continue in in-service training. Teachers and teacher candidates have confirmed this statement in our opinion surveys.

Regarding the fact, many countries, including the Czech Republic, put emphasis primarily on traditional transmissive teaching methods, so neither teachers nor teacher candidates have their own personal experience with IBSE. This significantly limits the rapid changes of PCK in the context of IBSE acceptance. Teachers sometimes struggle with how to design and implement inquiry instruction with their students. The first step, understanding what inquiry is, can be difficult, let alone designing activities that support the inquiry. Improper application of IBSE in science instruction may not produce the expected positive results and the disappointed teacher comes back to the traditional style of teaching (Darling-Hammond, 2008).

To make IBSE effective, it is essential for teachers to acquire professional competency to apply IBSE consisting of a set of specific skills. Science teachers need to be able to determine what level of IBSE can be used, what knowledge and skills should their students acquire, at what level and in what order. What is also important is the choice of contents and their transformation into a form suitable for IBSE. It is therefore essential to integrate this competence to apply IBSE in the teacher educational programme and continual professional development (CPD).

The model of IBSE implementation in science teacher training

Five acquiring stages exist in the development of science teacher's skills to apply IBSE:
(a) Motivation stage: Completing of professional interest and attitudes towards IBSE.
(b) Orientation stage: Acquiring knowledge necessary for IBSE.
(c) Stabilization stage: Solving of simple applied tasks of IBSE application.
(d) Completing stage: Solving of complicated applied tasks of IBSE application.
(e) Integration stage: Solving of teaching problem situation in school practice (new skill is integrated into skill structure).
Completing and integration stages are conditioned by several-year experience of the teacher and that's why acquiring these skills is not possible to finish as soon as pre-service teacher training.

Science teacher training in IBSE is a long-term process. We can identify by use of design-based research links between the above-mentioned stages of the development of skills to apply IBSE and levels of IBSE applied in instruction by a professionally prepared teacher. This simple model describes the relationship (see Table 3).

Table 3: Model of Development of Skills for IBSE Application

Period of teacher training	Main objective of teacher training	Acquiring stage of skills for IBSE application	Levels of IBSE with full teacher competency to apply	Teacher training methods (examples)
Pre-service	Initial professionalization	(a) Motivation stage (b) Orientation stage (c) Stabilization stage	(1) Confirmation (2) Structured	The actual training using IBSE (teacher in the role of a student); IBSE video analysis; the first practical application of IBSE in school practice
Experience with teaching				
In-service	Continual professional development	(d) Completing stage (e) Integration stage	(3) Guided (4) Open	Action research; design-based research

During the pre-service phase the initial professionalization of a science teacher candidate starts as a part of his/her university studies. At this stage of professional training the teacher candidate is usually able to handle only the first three stages of implementation IBSE skills. An appropriate training method is an introduction to IBSE when the teacher candidate plays the role of a student. A video analysis of IBSE lessons has been successful as well. Later the teacher candidate led by experienced teachers and university educators uses IBSE elements in school practice. At the end of the pre-service training the teacher candidate is usually sufficiently qualified for the first two levels of IBSE: confirmation and structured. During the in-service phase teacher can reach the other two levels of IBSE. A necessary condition is sufficient teaching experience. So the last two stages of acquiring skills for IBSE application can be completed. This model of teacher development for IBSE application can become the basic structure for a teacher training programme.

Science teacher competency for application of IBSE

Teacher training to apply IBSE runs in the pre-service and in-service phase in a different form. Kansanen (2005) distinguishes, similarly to other authors, between different levels: from a novice teacher to an expert teacher. Teachers reach the novice level in university preparation. Teaching experience and further studies may shift the teacher to the expert level. At this level, the teacher can fully apply all IBSE levels.

To implement effective science teacher training for IBSE it is necessary to compile a set of educational objectives in the form of teachers' professional knowledge and skills. This will bring full competency to apply IBSE as a system complex of pedagogical professional teachers´ knowledge, understandings and skills.

We obtained the initial outputs of our design-based research in the field of IBSE application focusing on a role of simple experimentation in IBSE. These conclusions have resulted in defining a set of professional science teachers´ knowledge, understandings and skills for IBSE application:

- Knowledge and understanding of IBSE paradigms and objectives
- Knowledge and understanding of each IBSE level
- Skill to select appropriate contents (from everyday life etc.)
- Skill to transform the contents into individual IBSE levels
- Skill to motivate students (simple experimenting, projects)
- Skill to observe and to do experiment
- Skill to ask questions in accordance with IBSE
- Skill to conduct action research and design-based research
- Skill to apply ICT in IBSE
- Skill to encourage students in communication skills in IBSE

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- Skill to organize student educational activities in IBSE
- Skill to use a wide range of educational techniques (methods, forms, and aids) suitable for IBSE

This and another potential set of professional teacher knowledge, understandings and skills will set up a system - the competency of teachers to apply IBSE effectively. The role of educators of science teachers is to integrate the knowledge, understandings and skills in the pre-service and in-service science teacher training.

DISCUSSIONS AND CONCLUSION

According to the research and international experience IBSE is one of the most promising innovative teaching/learning methods. This method not only motivates students but also science teachers. It is necessary to spread this educational method with science teachers and develop teaching/learning curricular materials such as textbooks, exercise books, collections of tasks, files of experiments, etc. in accordance with IBSE.

The project PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) is a European project that aims to support science teachers in the IBSE application in science teaching so that this method could become a common part of school practice (Profiles, 2011). The PROFILES project offers suitable materials and supports teachers to use IBSE so that the method can become an integral part of science and technology teaching. The project PROFILES includes a set of specific educational modules adapted for IBSE. The authors of this contribution are co-researchers of the project PROFILES and its outputs will be presented in pre-service and in-service science teacher training.

As example of IBSE module in the Project PROFILES can be used an excerpt from the module ***"Brushing up on chemistry"***, developed by G. Tsaparlis and G. Papaphotis (Profiles, 2011):
The teacher assign to students the task of going to a supermarket and buy a small selection of toothpastes, including toothpastes that have different purpose, for instance, whitening, with baking soda, for gingivitis. Following that they identify from the product packages the ingredients of each brand and under the teacher's guidance about a general reference to the composition of toothpastes they divide the ingredients into particular groups, depending on their action/functioning. Students carry out hands on activity preparing home-made toothpaste, using available at home materials. Subsequently they test the effect of homemade toothpaste by comparing with a commercial brand of toothpaste. The cleaning power of the both kinds of toothpastes is compared by testing their ability to remove food colouring from egg shells (see Fig. 1).

Figure 1: Comparison of abrasiveness of homemade and commercial toothpastes

Through the study of the toothpaste, a common, well-known product of daily use, we aim to connect chemistry with everyday life, and increase students' interest in chemistry. In addition, through the toothpaste, we have the opportunity to refer to a large number of chemical substances and students can gain practice in experimenting. Apart from the hands on activity, which is shown in the previous text, there are many others in the full module. Students prepare solutions, measure pH; check reactions of ingredients with acids and hydroxides. Except science skills and knowledge students improve other competences. This activity offers the opportunity to discuss in class the importance of regular dental care for health of teeth and the general health.

Subsequent open research problems in implementation of IBSE in science teacher training are: combining experiments and problem tasks, development of appropriate experiments, reshaping of project teaching, adjustment IBSE for gifted and disabled etc.

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