Inquiry-based Science Education and Experiments

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1 Reduction of interest in science education

Today's rapidly changing world brings new requirements for education and thus for science education. The importance of knowledge and traditional skills is decreasing and new ones are asked. 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 connection with the rise and development of scientific knowledge and new technologies which influence work and civic life, there is grave concern and debates about the quality of science education (Duschl et al, 2007). Science educators around the world and especially in developed countries face the problematic decline interest in the study of science and technology (OECD, 2006). Some researches realised in the Czech Republic show that increasing age brings decreasing interest in the study of science (MEYSCR, 2008). One of the factors leading to this phenomenon is considered an unsuitable outdated method of teaching science in schools (Rocard et al., 2007), that does not motivate students. Only 15% of European students are satisfied with the quality of science teaching in schools and nearly 60% state that science teaching is not interesting enough (MEYSCR, 2010). Traditional instruction very often prefers separate knowledge acquisition such as data, formulas, equations, theories, etc., which students only memorize and forget them very easily because they do not understand them.

Misunderstood knowledge cannot be used to solve tasks and problems or to be involved in already created structure. It could be reason why students regard science to be difficult. According our research however students consider that science contents are important for society, but they are not unnecessary in their everyday life.

Promotion of interest in science is important for society and for personal students´ development. Interest has 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). 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 also teaches scientific ways of thinking and reasoning (McNeill, 2010). Students acquire how to use evidence, in the form of data that are obtained by experiment and measurement, for answering questions, solving problems or making decisions (Aikenhead, 2005). Tytler et al. (2001) claim that the use of evidence is important skill for the interactions between the public and science. When making a decision, everyone should be able to evaluate information, ask questions, use evidence and professionally oppose. Scientifically literate citizens use scientific approaches for analysing and solving problems requiring investigation, basing their judgments upon evidence rather than preconception and speculation. Findings of researches (Zohar, & Nemet, 2002) confirm that students are able to transfer their argumentative skills from genetics lessons and apply them successfully in the dilemmas of everyday life. Aikenhead (2005) mentions the solution of vaccination like an example of application of the scientific process in decision making in everyday life.

2 Changes in contemporary science education

The current situation in science education indicates that there is difference between how science is taught and how it is perceived in society (e.g. on television and in other media) (Cakmakci et al., 2011; Osborne, 2007). This is also an argument for implementation into science contemporary teaching/learning methods that can reduce the gap between the understanding of science problems based on the knowledge taught in school and extracurricular knowledge obtained from different information sources (Ault, & Dodick 2010; Bianchini, 2008). Hence 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. Therefore educators lead discussion what is the purpose of problems in science education. There has long been a tension between school science as for future scientists and school science as equipment for general citizen as they will meet it in everyday life. In most countries science is now compulsory and as such, it is argued, the emphasis must be on promoting scientific literacy for all (Osborne, & Dillon, 2008).

Last years a growing call for inquiry to play an important role in science education can be mentioned (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** (hereinafter **IBSE**) is becoming more popular and has proved to be a suitable method for the development of necessary knowledge and skills and motivation students. IBSE could be the way of engaging students more productively, of giving them opportunity to enjoy science and find it rewarding. The case in favour of IBSE becomes clear from considering what we want to achieve through science education. In order to prepare students for the demands of twenty-first century life it is widely accepted that science education should enable students to develop key science concepts ("big ideas") which enable them to understand the events and phenomena of relevance in their current and future lives (Harlen et al, 2010). Students should also develop understanding of how science ideas and knowledge are obtained and the skills and attitudes involved in seeking and using evidence. Science education, together with students' education in other disciplines, should develop awareness of what it means to learn and the desire to continue learning, as is essential in our rapidly changing world (OECD, 2003). In summary, through their science education students should develop:

- Understanding of fundamental scientific ideas
- Understanding of the nature of science, scientific inquiry, reasoning
- Scientific capabilities of gathering and using evidence
- Scientific attitudes, both attitudes within science and towards science
- Skills that support learning throughout life

3 Inquiry-based science education

IBSE is an approach to teaching and learning science that comes from an understanding of how students learn, and a focus on basic content to be learned (Narode, 1987). Like any teaching/learning process, IBSE can also be divided into student activities and teacher activities. Hence it is possible to meet in literature the terms Inquiry Based Science Learning (IBSL) and Inquiry Based Science Teaching (IBST). The activities of teachers and students are close linked and Inquiry Based Science Education (IBSE) is broader term which connects both these activities. Inquiry based science education may seem to be new concept of instruction, but it dates back to the beginning of last century. The philosophy of inquiry based learning finds its antecedents in the work of Piaget, Dewey, Vygotsky, and Freire among others (Dewey, 1997; Vygotsky, 1962; Freire, 1984). IBSE emphasizes constructivist ideas of instruction, where knowledge is built from experience. According to constructivism, all learning begins with the learner (Dewey, 1997). Hence Dewey's description of the four primary interests of the child could be theoretical base for IBSE:

- The child's instinctive desire to find things out
- In conversation, the propensity children have to communicate
- In construction, their delight in making things
- In their gifts of artistic expression

It is in accordance with idea of IBSE as a form of active learning. IBSE is based on an instructional learner-centred approach and integrates theory and practice using inquiry, develops knowledge and skills for a solution to a defined problem. Students are supposed to solve the problem, conduct self-directed learning and co-operate in teams to make their own connection, creation and organization for future application in similar problems. IBSE can be considered a constructivist approach to instruction, emphasizing collaborative and self-directed learning and being supported by flexible teacher scaffolding.

IBSE differs from teacher-centred approach which focuses only on transmission of knowledge from teacher to students. Teachers in IBSE lessons motivate and help students to solve problems independently and competently. Justification of IBSE implementation is connected with 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; Hofstein et al, 2005). Besides, inquiry activities provide a valuable context for learners to acquire, clarify, and apply an understanding of science concepts. According to research findings (Darling-Hammond, 2008; Rocard et al., 2007), IBSE brings the required competences 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. Using IBSE to teach science can serve to develop a number of the new basic skills and help students prepare for the world of work.

4 Contents appropriate for IBSE

An appropriate of the selection science contents is of big importance for successful IBSE application. Strategy for the choice of motivating contents for IBSE is in focus on a relevant, meaningful 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. What is seen as relevant by teachers and other adults may not be perceived as relevant by young people. Researches show that students are motivated if the science contents are connected 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 support 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).

We carried out research analysing the research question whether students in the Czech Republic are interested in science contents associated with their everyday life. We applied 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 lower 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 analysed 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 (Trna, Trnova, & Sibor, 2012) are shown below (see Table 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 25% of students as unimportant to society. Approximately a third of students expressed a neutral opinion to both questions.

Table 1. Science contents for IBSE

REAL SCIENCE LESSONS	Scale and percentage of answers (number of students = 334)						
The level of importance to **my everyday life** of the topics I study in my lessons in science subject may be described as:	Extremely important	Very important	Important	Fairly important	Somewhat unimportant	Very unimportant	Extremely unimportant
	1	**6**	**18**	33	29	10	3
The level of importance **to society** in general of the topics I study in my lessons in science subject 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 SCIENCE LESSONS	Scale and percentage of answers (number of students = 334)						
For me, lessons of science subject 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
For me, lessons of science subject 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

Students could express their wishes regarding science contents in the case of an ideal science lesson. More than half (56 %) of students would like the science contents related to everyday life and 62 % of students expressed 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 mentioned fact when innovating teaching/learning methods and also in science teacher training.

5 IBSE levels

Developmental constraints used to be presented as a reason why IBSE shouldn’t be applied to children 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) claims 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 children 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). It was mentioned before 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).

Nevertheless, it is logical that IBSE is age-specific during implementation in science education. Application IBSE needs a large collection of activities that represent “doing science”. These activities include conducting inquiry, sharing ideas with peers, specialized ways of talking and writing, mechanical, mathematical, and computer-based modelling, and creation 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 in accordance with Dewey's description of the four primary interests. To develop skills in science, students must have the opportunity to realize the range of various activities. It would be wrong to assume that children in primary science are able to carry out scientific research independently and from the beginning as students in secondary science courses, or even as real scientists do. It is necessary to develop individual skills gradually and systematically and lead the students to some extent according to their abilities in inquiry.

In the 1960s Schwab suggested for inquiry to be divided into four levels (Schwab, 1960). Herron later developed the Herron Scale to evaluate the amount of inquiry within a particular lab exercise (Herron, 1971). Since then, there have been proposed revisions of levels of IBSE. Banchi and Bell (2008) defined four IBSE levels (see Table 2) according to the degree of teacher’s guidance (help in the process, asking guiding questions and the formulation of the expected output).

Table 2. 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 analyse 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.

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.

6 Experiments in IBSE

Experimentation is the core of students' inquiry in all four levels of IBSE. Experiments have to be organically included in teaching/learning, what is the main task for science teachers. The role of experiments is different in different levels. That's why we created the taxonomy of experiments for each level IBSE (Trna, & Trnova, 2012).

6.1 Experiments for confirmation inquiry

Confirmation inquiry is useful in the beginning of IBSE to develop students´ experimental skills. The objective of the first level is conformation knowledge (concepts, theories etc.). That is why results of experiments are known in advance. Students have to gain specific inquiry skills, such as realization of experiments, collecting and recording data. We present a specific example of an experiment for this level:

Floating and diving 1.
Students gradually inserted into the water balls, which are made from substances of known density (see Figure 1). The worksheet contains a table named the substance and a table of densities of these substances. It is listed as the reference density of water with which the student initially compared the density of balls. Students checked by immersion in water body behaviour: floating and diving. Balls may have to simplify the experiment, the same volume. On this basis, the relevant theory is confirmed experimentally.

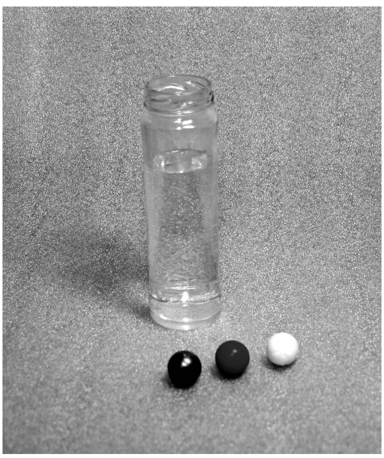

Figure 1. Glass of water; iron, plastic and polystyrene balls

6.2Experiments for structured inquiry

Students generate an explanation supported by the evidence they have collected by a use of experimentation in this level of IBSE. The teacher has an influence on learning process by asking appropriate questions. Students perform experiments prepared by teacher, but does not know their outcome. We present a specific example of an experiment for this level:

Floating and diving 2.

Students placed in water balls, which are made from substances of known density (see Figure 2). Students entered into the table name of the substance and its density. They recorded the behaviour of solids in the liquid (floating, diving). The final analysis of the density of balls leads to the conclusion that their behaviour depends on their density in comparison with the density of liquid. The aim of this experiment is that the students themselves discovered by applicable law.

Figure 2. Different density balls

6.3 Experiments for guided inquiry

The teacher as the "guide of inquiry" encourages students using the research question. Students design procedures to test their questions and create experiments. Outcomes of this inquiry level are better when students have opportunities to learn different ways of experimentations. We present a specific example of an experiment for this level:

Floating and diving 3.

Teacher gives students only a research question. They do not have a solution procedures and experiments. The basic research question might be: "Find the factors in the behaviour of the body fluid," Students should seek their own experiments and equipment (see Figures 3, 4 and 5).

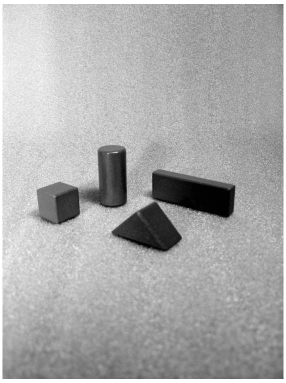

Figure 3. Bodies with only the differing shape

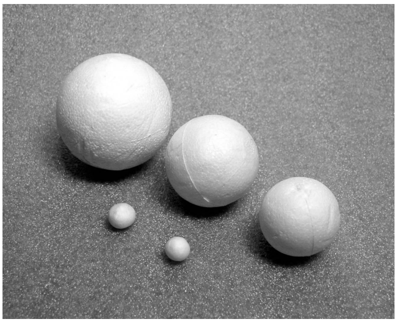

Figure 4. Bodies with only the differing volume

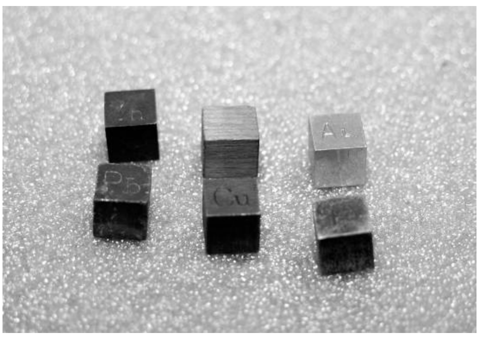

Figure 5. Bodies with only the differing density

6.4 Experiments for open inquiry

This is the highest level of IBSE. Students should be able to derive questions, design and carry out investigations with experimenting, record and analyze data and draw conclusions from the evidence they have collected (Hofstein et al., 2005). Because it requires a high level of scientific reasoning and cognitive demand from students it is especially suitable for development of gifted students. We present a specific example of an experiment for this level:

Floating and diving 4.

Students are almost completely independent. The teacher acts as an implementing partner - consultant. Students are not explicitly specified the research question and experiments. They are suitable experiments, which reflect a set of phenomena. These include melting ice cubes floating in a container with hot water (see Figure 6).

Figure 6. A glass of hot water and melting ice

Experiments in IBSE are different at different levels, but all must follow the principles:

- selection of simple experiments from daily life
- emphasis on simple student's experiments
- creation of alternative student's experiments
- functional use of ICT during experimentation

These principles must be verified and completed.

IBSE is a way which may be taken to increase knowledge and skills of the students in science education. Experiments play a crucial role in IBSE (Trnova, & Trna, 2011). A subsequent research problem in IBSE is teacher proficiency in combining experiments and problem tasks (Hofstein et al, 2005), simple experimentation (Kirschner et al., 2006), project teaching etc.

It is necessary to implement principles of using experiments and their IBSE taxonomy in physics teacher training. Implementation of experiments in IBSE within the European project PROFILES (www.profiles-project.eu).

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