HANDS-ON EXPERIMENTAL ACTIVITIES IN INQUIRY- BASED SCIENCE EDUCATION

Eva Trnova, Josef Trna, *Masaryk University, Brno, Czech Republic*

Abstract

Science experiments are to be organically included in certain teaching/learning methods. One of these methods is Inquiry-Based Science Education (IBSE), which has a strong motivational effect. Hands-on activities play a crucial role in all four levels of inquiry-based learning in science education: confirmation inquiry, structured inquiry, guided inquiry and open inquiry. These implementations of hands-on experiments develop students' knowledge and skills in a constructivist way. The principle of IBSE is presented on a particular example of hands-on activities in the frame of European research project PROFILES.

1. Introduction

The Czech Republic and the entire European Union is struggling with declining interest of young people to study science. Some universities in Europe are reporting a halving in the number of students enrolled in physics since 1995. The way science is taught in schools is considered one of the main causes. In this context it is necessary to think how to change teaching methods and increase students´ motivation for science.

The science education community mostly agrees that one of the suitable possibilities is the IBSE. This teaching/learning way shows great promise according to the results of researches. IBSE has proved its efficacy in increasing students' interest and at the same time stimulating teacher motivation. IBSE is effective with all types of students from the weakest to the most able ones and supports the improvement of the gifted. Moreover, IBSE is beneficial to promoting girls' interest and participation in science activities.

2. Open learning

An important aspect of IBSE is the use of open learning. Open learning is described as a teaching method with no prescribed goals or outcomes students have to achieve. Many educators have dealt with the ideas of open learning. J. Deway is one of the most famous proponents of hands-on learning or experiential education. Dewey's ideas have influenced Project Based Learning (PBL) which allows students to perform the role of researchers. Open learning techniques were promoted by M. Wagenschein as well. He was one of precursors of modern teaching techniques such as constructivism, inquiry-based science, and inquiry learning. He emphasized that students should not be taught only facts, but should be made to understand and explain what they are learning. Open learning plays an important role especially in teaching through experimentation. Students do not only perform experiments like cooking according to recipes but they should understand what they do and how they do it.

3. Inquiry based science education

IBSE is an approach to teaching and learning science that comes from an understanding of how students learn the nature of science inquiry, and a focus on basic content to be learned (Narode 1987). Like any instruction, IBSE can also be divided into student activities and teacher activities. Therefore, it is possible to meet in literature the terms Inquiry Based Science Learning (IBSL) and Inquiry Based Science Teaching (IBT). The activities of teachers and students are close linked and Inquiry Based Science Education (IBSE) is broader term which connects the two activities.

IBSE engages students in the investigative nature of science, helps students put materials into a meaningful context, develops critical thinking and supports positive attitudes toward science (Kyle 1985; Rakow 1986). The emphasis is placed on teaching science as inquiry rather than on teaching science as the memorization of facts and terms. IBSE moves from a system that promotes science primarily as recall of factual information and rote computation to one that emphasizes conceptual understanding and logical process skills. The traditional methodology in which the teacher communicates information to the students should decrease in favour of hands-on activities in which students conduct investigations, discover principles, and practice applying those principles in a variety of situations. IBSE has a strong motivational effect which comes from intrinsic motivation relate to the satisfaction of having learned and understood something or relevance, meaningful of learning content, as considered by the students. Traditional instruction is usually based on the satisfaction of being rewarded - extrinsic motivation (Duschl 2007).

However, it is an erroneous assumption to require students to engage in inquiry oriented activities, like real scientists and doing it from scratch and completely independently. Most students, regardless of age, need extensive practice to develop their inquiry abilities and understandings to a point where they can conduct their own investigation from start to finish (Bell 2005; Herron 1971; Schwab 1962). H. Banchi and R. Bell define according to experience how much guidance (about procedure and expected results or guiding questions) is provided to students by teachers four levels of inquiry: confirmation, structured, guided and open (Banchi 2008).

4. Hands-on activities in IBSE

Very important students´ activities in all four levels of inquiry-based science education are hands-on activities. Their implementation is necessary for inquiry. But they have to be organically included in certain teaching/learning methods, what is the main task for the teacher. It is not easy to transform science content into the form of IBSE. Just as students can not immediately switch from traditional methods of learning to inquiry based learning, teachers must also "learn" how to apply IBSE. It is important to use certain hands-on activities in corresponding inquiry levels. In the following text, we present characteristics of individual inquiry levels and examples of the implementation of hands-on activities.

4.1 Confirmation inquiry

In accordance with the name, confirmation inquiry, the outcome of this level is conformation the knowledge of principles, concepts and theories. The results of experiments are usually known in advance. Confirmation inquiry is useful in the beginning of IBSE when a teacher’s goal is to develop students´ experimental and analytical skills. It is imperative that students have to gain practice and specific inquiry skills, such as collecting and recording data.
Example:
In the frame the curriculum content oxidation-reduction students confirm the sequence of metals in electrochemical series. They choose one of the metals and insert it into the different aqueous solutions of metal ions. They observe chemical reactions and changes with metals. They summarize all their observations in a table and analyze their results. On this base they make conclusions and compare them with theory.

4.2 Structured inquiry

Also at this level the teacher has an influence on procedure and helps students in inquiry by asking appropriate questions. But students generate an explanation supported by the evidence they have collected. This lower-level inquiry is very important for development of student’s abilities to conduct more open-ended inquiry. This kind of inquiry is very common in elementary science curricula as well as confirmation inquiry.
Example:
Students conduct the same experiments as in the first level but electrochemical series should not be told them ahead. The task for students is to determine which metal is less reactive using comparing reactivity of metals during oxidation-reduction experiments. The goals and rationale of this inquiry is to enable constructive building of the electrochemical series.

4.3 Guided inquiry

At the third level, guided inquiry, the teacher is the "guide of inquiry". He encourages students using the research question and provides students with guidance about their investigation plans. Students are less supported than in the preceding levels. They design procedures to test their questions and the resulting explanations. The teacher provides students with guidance about their investigation plans. Students should to have experiences from confirmation and structured inquiry to be able designing their own procedures (Kirschner 2006). Outcomes of inquiry are better when students have had a lot of opportunities to learn and practice different ways to plan experiments.
Example:

To develop deeper understandings of metal oxidation-reduction reactions we ask students to predict on the base experiments which metals it is possible to use to metal plating and why.

4.4 Open inquiry

Fourth and highest level, open inquiry, comes from experiences of preceding inquiries which implies that this level is the closest to "science inquiry". Students should be able to derive questions, design and carry out investigations, record and analyze data and draw conclusions from the evidence they have collected (Hofstein 2005). Because it requires a high level of scientific reasoning and cognitive demand from students it is suitable for development of gifted students.
Example:
During the previous explorations, students made conclusions on the base experiments which were planned by the teacher. In open inquiry students carry out their investigations so they have to suggest procedure of experiments, which metals and aqueous solutions of metal ions will be used. They need to include their focus question, a prediction, a detailed plan for how they will carry out their investigation, and the data table (if necessary) they are going to use.

5. Project PROFILES as a support for teacher in IBSE

European research Project PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) deals with supporting teachers in application IBSE in instruction so that the open inquiry approaches are a major teaching target. PROFILES improves the teachers skills in developing creative, scientific problem-solving and socio-scientific related learning environments; learning environments which enhance students' intrinsic motivation to learn science and their individual competencies such as proper decision-making abilities and abilities in scientific inquiry. Project PROFILES is aiding a better understanding of the changing purpose of teaching science in schools. We present example of hands on activities from Project PROFILES which represent application IBSE in instruction. Here is an excerpt from one module, which is part of the materials used in the Project PROFILES. This module was developed by G. Tsaparlis and G. Papaphotis and it is based on the activity (Trantow 2002).

The excerpt of module: Brushing up on chemistry

(a) Phase: *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.*

(b) Phase: *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.*
Making coloured eggs
1. Pour about 0.5 cup (120 ml) of boiling water into a glass. Stir in 1 teaspoon (5 ml) of vinegar and 20 drops of food colouring (red or blue recommended).
2. Immerse a hard-boiled egg in the food colouring solution until it is stained with colour (at least 5 minutes).
3. Remove the egg from the food colouring solution and place it on a paper towel to dry. Store the stained egg in a refrigerator if you will not be continuing the activity. Otherwise, go on to step 4.
Make and test toothpaste
4. Measure two teaspoons (10 ml) of baking soda and a quarter teaspoon (1.25 ml) of salt into a plastic cup. Stir until it is thoroughly mixed.
5. Add three-quarters of a teaspoon (3.75 ml) of glycerine to the baking soda/salt mixture. Stir it as thoroughly as possible. The mixture will be thick. Add water with a dropper while stirring until the mixture has about the same consistency as commercial toothpaste (see Fig. 1).

Figure 1: Home-made toothpaste

6. Rinse the coloured egg with water and scrub it with a toothbrush. What happens to the colour? Record your observations.
7. With a black permanent marker, draw a line on the eggshell, dividing its surface in half. Label one side C, for commercial toothpaste, and the other side H, for home-made toothpaste.
8. Put a pea-sized amount of commercial toothpaste on the toothbrush, then brush side C of the stained egg for five strokes (one stroke equals one complete back-and forth motion). Rinse the egg and toothbrush thoroughly with water. Then, put a pea-sized amount of homemade toothpaste on the toothbrush and brush side H for five strokes. Rinse the egg and toothbrush with water again. Record your observations (see Fig. 2).

Figure 2: Comparison of abrasiveness

9. Measure the pH of water, the commercial toothpaste, and the homemade toothpaste using paper. Record your observations.
10. Compare the abrasiveness of the homemade and commercial toothpastes by rubbing a pea-sized amount between your fingers, being sure to rinse thoroughly with water your fingers between examinations of samples. Record your observations.

(c) Phase: *The project is completed with an evaluation and recapitulation in class of the performed work. The following questions aim to test student's comprehension of problems related to the activity:*

- *Research the nine categories of ingredients in toothpastes. Give an example of each and explain its function. What is the purpose of each ingredient in your homemade toothpaste? What categories of ingredients are missing from the home-made toothpaste?*
- *Which toothpaste felt more abrasive to you in the touch test in step 10? Why is an abrasive useful in cleaning? Can an abrasive cause any problems in cleaning teeth?*
- *Compare the pH values of tap water, home-made toothpaste, and commercial toothpaste. How could pH affect the cleaning ability of toothpaste?*
- *How do plain water, homemade toothpaste, and commercial toothpaste compare in cleaning ability in steps 6 and 8?*
- *How does fluoride help to prevent cavities? Does it pose any risks to users? Would your home-made toothpaste help to prevent cavities? Does it pose any risks to users?*
- *If you wanted to make"whitening" toothpaste, what ingredient could you add to your mixture? Design an experiment to test your new toothpaste.*

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.

6. Conclusions

IBSE is a way which may be taken to increase knowledge and skills of the students in science. Hands-on activities play a crucial role in IBSE because they are beneficial to promoting students´ interest and participation in science activities. These implementations of hands-on experiments develop students' knowledge and skills in constructivist way. PROFILES Project offers hands-on activities which were prepared by experts and verified in teaching by experienced teachers.

References

Banchi H, Bell R (2008) The Many Levels of Inquiry. Science and Children, 46(2), 26-29

Bell R, Smetana L, Binns I (2005) Simplifying inquiry instruction. The Science Teacher 72(7), 30–34

Duschl R A, Schweingruber H A, Shouse A W (2007) Taking Science to School: Learning and Teaching Science in Grades K–8. Washington, DC, The National Academies Press

Herron M D (1971) The nature of scientific inquiry. SchoolReview 79(2), 171–212

Hofstein A, Navon O, Kipnis M, Mamlok-Naaman R (2005) Developing Students Ability to Ask More and Better Questions Resulting from Inquiry-Type Chem. Laboratories. J. of Res. in Sc. Teach., 42, 791-806

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

Kyle W C (1985) What research says: Science through discovery: Students love it. Science and Children 23(2), 39–41

Narode R (1987) Teaching Thinking Skills: Science. Washington, DC, National Education Association

Rakow S J (1986) Teaching Science as Inquiry. Fastback 246. Bloomington, Phi Delta Kappa Educ. Found.

Schwab J J (1962) The teaching of science as inquiry. In The teaching of science, eds. J.J. Schwab and P.F. Brandwein, 3–103. Cambridge, MA, Harvard University Press

Trantow A (2002) Classroom Activity, Brushing up on chemistry. J. Chem. Educ., 79 (10), 1168A, 47

Acknowledgements

The study initiated within the project PROFILES: Professional Reflection-Oriented Focus on Inquiry-based Learning and Education though Science (FP7-SCIENCE-IN-SOCIETY-2010-1, 266589).