How to Educate and Train Science Teachers in IBSE Experimentation

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ABSTRACT

School experiments are a core tool of science education. Inquiry-Based Science Education (IBSE) is considered to be an innovative educational method which has a strong motivational effect on students and teachers. This method is based on experimentation. Experiments have different roles and characteristics in each of the four levels of IBSE. The presented research tries to answer questions aimed at: the characteristics of experiments at each of the IBSE levels, principles for applying IBSE experiments, and teacher training methods suitable for IBSE experimentation. A mixed research method combining a theoretical comparative analysis and design-based research, was used. The primary outcome of our research is the taxonomy of IBSE experiments. The study describes four types of IBSE experiments, including specific examples from hydromechanics. Principles for implementing IBSE experiments are also presented. The taxonomy of IBSE experiments and the principles for their implementation into teaching/learning science must be added to pre-service and in-service physics teacher training. This task is performed by the European project PROFILES.

Keywords: Experiments, Inquiry-based science education, taxonomy, science education, teacher training.

1. INTRODUCTION

Inquiry-based science education (IBSE) is an innovative educational method which has a strong motivational impact on students and teachers. This method is based on experimentation which has a decisive role in science education. The motivational role of experiments is based on the importance of experiments in science research [12] and the cognitive importance of experiments in science education [2]. That is why the teachers' professional competence in using experiments in IBSE (hereinafter IBSE experiments) is a very important part of their pre-service and in-service training. Motivation, understanding, training, and experience in the use of IBSE experiments are integral parts of the pedagogical content knowledge [11] of science teachers and should be improved by the implementation of connectivist [10] educational and training methods.

2. RATIONALE

IBSE is based on understanding the process of science learning [6]. The main principles of IBSE are student involvement in discovering natural laws, linking information into a meaningful context, developing critical thinking, and promoting positive attitudes towards science ([5], [8]).

In terms of teacher involvement, there are four levels of IBSE [1]:

(1) Confirmation level

(2) Structured level

(3) Guided level

(4) Open level

Experiments play a crucial role at all four IBSE levels because they are the foundation of inquiry in science education.

Five acquiring stages exist in developing teachers' skills [9].

(1) Motivation Stage: the stage of teacher's motivation

(2) Orientation Stage: the stage of teacher's orientation in the acquired skill

(3) Stabilization Stage: the stage of new skill stabilization

(4) Completing Stage: the stage of completing the skill and its inclusion in a wider contextual frame

(5) Integral Stage: the stage during which a new skill is integrated into the skill structure

The first three stages can be developed during the teachers' pre-service training; the fourth and the fifth stages are possible to complete during the teachers' in-service training.

Our study focuses on the education and training of teachers to use IBSE experiments at all four IBSE levels based on a connectivist approach.

3. RESEARCH QUESTIONS AND METHODOLOGY

The aim of this study is to create the foundations for teacher education in IBSE experimentation in the form of a taxonomy of IBSE experiments and to determine of the role of IBSE experiments. Our research has applications in finding suitable training methods for teachers in IBSE experimentation.

The research questions are:

(a) *Are experiments different at various levels of IBSE? In which characteristics do they differ?* On this basis it is necessary to create a taxonomy of IBSE experiments.

(b) *What are the principles of the implementing experiments at various levels of IBSE?* These principles should then be defined and applied to IBSE.

(c) *What teacher training methods with connectivist elements are suitable for IBSE experimentation?* The teacher training methods will later be used in practice.

A mixed research method combining a theoretical comparative analysis and design-based research, was used. The theoretical IBSE analysis led to the creation of the basic characteristics of IBSE experiments at various levels. The combined method of a video study and a questionnaire for teachers examining the incidence of these four types of IBSE experiments in teaching followed. Using design-based research, we discovered specific patterns of IBSE experiments and verified their compatibility with different IBSE levels. Using action research, which was part of the design-based research, we modified the characteristics of each type of IBSE experiment.

4. RESULTS

4.1 Taxonomy of IBSE experiments

By comparing the role of experiments at all four levels of IBSE we found four basic types of IBSE experiments. Each type is supplemented by particular examples of physics experiments ([15], [14]).

4.1.1 Confirmation experiments: The outcome of this type of experiment is the confirmation of knowledge of principles, concepts, and theories. Students gain experience and specific inquiry skills, such as collecting and recording data. Students carry out confirmation experiments following their teacher's detailed instructions and under his/her direct supervision. The expected results of the experiments are known in advance; the students confirm or verify laws.

Example: Floating and sinking 1.

Students gradually insert balls, which are made from substances of known density, into water (Figure 1).

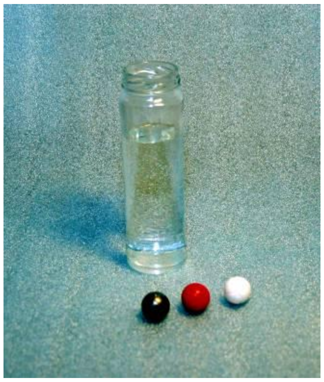

Figure 1. Glass of water; polystyrene, plastic, and iron balls

The worksheet (Table 1) contains a table which identifies the substances and their densities. They are listed with the reference density of water with which the students initially compared the density of the balls. By immersing the balls in water, the students confirm the expected behavior.

Table 1. Worksheet – confirmation experiment

	Substance	***Density of the substance***	***Behavior in water***
1	iron	7,8 g/cm3	sinking
2	plastic	1,0 g/cm3	hovering
3	expanded polystyrene	0,03 g/cm3	floating

4.1.2 Structured experiments: In these experiments, the teacher has an influence on the procedure and helps students in their inquiry by asking appropriate questions. Students generate an explanation supported by evidence they have collected through experimentation. The process of structured experimentation is determined by the teacher, but the solution is not known in advance; the teacher significantly affects the students' inquiry by asking guiding questions and by determining the method of inquiry. Students express their creativity in discovering laws.

Example: Floating and sinking 2.

Students place small balls, which are made from different substances of known density, into water (Figure 2).

Figure 2. Balls with different density

Students enter the substance's name and density into the table. They record the behavior of the solids in the liquid (Table 2). The final analysis of the balls' density leads to the conclusion that their behavior depends on their density in comparison with the density of liquid.

Table 2. Worksheet – structured experiment

	Substance	***Density of the substance***	***Behavior in water (sinking, hovering, floating)***
1	iron	7,8 g/cm3	
2	aluminum	2,7 g/cm3	
3	glass	2,5 g/cm3	
4	plastic	1,0 g/cm3	
5	ice	0,92 g/cm3	
6	dry spruce wood	0,33 g/cm3	
7	expanded polystyrene	0,03 g/cm3	

4.1.3 Guided experiments: Here, the teacher is the "guide" of the inquiry. He/she encourages the students using research questions and provides the students with guidance about their investigation plans. The students design procedures to test their questions and the resulting explanations. The students propose their own methods and guided experiments to address the research questions; the teacher cooperates with the students to provide them with the research questions and gives advice on planning and implementing of the research.

Example: Floating and sinking 3.
The teacher only gives students a research question. They do not have given procedures and experiments. The basic research question might be: "Find the factors which determine the behavior of solids in a liquid." Students should seek out their own experiments and equipment (Figures 3, 4, 5).

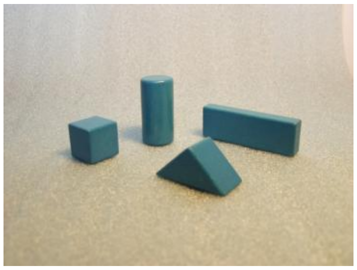

Figure 3. Solids only differing in shape

Figure 4. Solids only differing in volume

Figure 5. Solids only differing in density

Guided experiments are also very effective in the fixation and application phase of instruction. It is effective here to ask guiding questions such as: "Can a solid of high density float in water? Can a solid float in a liquid of lower volume than the volume of the solid itself? Does the behavior of solids in a liquid change with its changing temperature? Explain the function of the Galileo thermometer (see Figure 6)!" Students themselves generate and verify hypotheses leading to the solution of the problem identified by the teacher at the beginning. They perform additional experiments and measurements. In the end, they synthesize their research and discover their own way to resolve the problem.

Figure 6. Galileo thermometer

4.1.4 Open experiments: At this level, **s**tudents should be able to come up with questions, design and carry out investigations using experiments, record and analyze data, and draw conclusions from the evidence they have collected. Because this requires a high level of scientific reasoning and places a high cognitive demand on students, it is generally more suitable for the development of gifted students. Students form their own research questions, methods, and procedures; they carry out open experiments on their own.

Example: Floating and sinking 4.
An inflated rubber balloon is sealed in a plastic bottle closed by a cap with a valve (Figure 7). The air in the bottle and inside the balloon is compressed by a bicycle pump. The volume of the balloon decreases. When the overpressure has been relieved, the balloon returns to its original dimensions.

Figure 7. A model of a lung when diving in a hyperbaric chamber

The experiment simulates the phenomenon that occurs when diving. The volume of air-filled body cavities (the lungs, the middle ear) is reduced to half at a depth of 10 meters and to a *quarter at a depth of 30 meters. The diver's breathing apparatus automatically balances these conditions by increasing the pressure of the breathing gas. Rapid emergence (faster than 18 meters per minute) may cause barotrauma (lung rupture, fatal bleeding, and air embolism).*

4.2 Principles of IBSE experimentation

We discovered the following principles for implementing IBSE experiments:

- the selection of experiments from daily life;
- an emphasis on student experiments;
- the creation of alternative student experiments;
- the functional use of ICT during experimentation.

These principles must be verified and completed.

4.3 Teacher training methods for IBSE experimentation

Continuous professional development (CPD) of teachers is very important because the way is taught depends on the teachers. It is essential for teachers to acquire the necessary professional competency to apply IBSE experiments through the acquiring of a set of specific skills. Teachers need to be able to determine what level of IBSE can be used, and what knowledge and skills their students should acquire, at what level and in what order.

Five acquiring stages exist in developing teachers' skills applying IBSE experiments:
(a) Motivation Stage: Acquiring professional interest and attitudes towards IBSE experiments
(b) Orientation Stage: Acquiring the knowledge necessary for IBSE experimentation
(c) Stabilization Stage: Solving simple applied tasks in applying IBSE experiments
(d) Completing Stage: Solving complicated applied tasks in applying IBSE experiments
(e) Integration Stage: Solving teaching situation problems in school practice (new skills are integrated into the existing skill structure)
The completing and integration stages are conditioned by several years of experience on the part of the teacher which is why the complete acquisition of these skills is not possible by the end of pre-service teacher training.

In pre-service professional training at university, a teacher candidate is usually able to handle only the first three stages of skill development. An appropriate training method is an introduction to IBSE experimentation where the teacher candidate plays the role of a student. A video analysis of lessons has been successful as well. Later the teacher candidate, led by experienced teachers and university educators, uses IBSE experiments in their teaching practice at schools. 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, a teacher can reach the other two levels of IBSE. A necessary condition is sufficient teaching experience.

The discovery that today's students (the "Net Generation") have a different learning styles, preferences, and world views has lead to the origination of the new pedagogical theory of connectivism as a "theory of digital age learning" [10]. Connectivism reflects the influence of ICT on education. Young teachers are already members of the Net Generation, so the principles of connectivism are natural for them. Older teachers are influenced by contact with students and young colleagues and they adopt connectivistic elements in their behavior. So we came to the conclusion that it is necessary to introduce connectivism into teacher training. This is consistent with the standards and resources within UNESCO's project "ICT Competency Standards for Teachers" [16] that provide guidelines for all teachers, specifically for planning teacher education programs and training.

We decided to educate and train teachers in IBSE experimentation in a web-based environment and use teacher collaboration to improve their skills in how to teach effectively [13]. We verified this training in our international project PROFILES [7]. Teachers create teams of 4-5 members and together prepare teaching/learning modules and solve problems during their implementation. They share ideas, experiences, and prepared materials together in a web-based environment.

5. CONCLUSIONS AND IMPLICATIONS

IBSE is an innovative educational method which supports the development of critical thinking and promotes positive attitudes towards science. According to research findings, IBSE experiments are very important motivational tools for increasing student interest.

But the implementation of IBSE experiments in instruction alone does not lead to appropriate and sufficient learning outcomes and the development of student knowledge and skills. Teachers have to know how to apply experiments in their instruction. It is primarily necessary to improve primarily the implementation methods of IBSE experiments.

A subsequent research problem in IBSE is teacher proficiency in: combining experiments and problem tasks [3], simple experimenting [4], project teaching, etc. It is necessary to implement the principles of using experiments and their IBSE taxonomy in physics teacher training.

Teachers have to acquire the skills necessary to implement IBSE experiments into instruction. It is not possible to complete the development of teacher professional skills in IBSE experimentation during pre-service science teacher training. That is why there is a need to educate and train teachers in understanding and training in the use of IBSE experiments during their entire CPD. We verified the development of this professional teacher competence using connectivist educational and training methods.

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