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To Think Like a Scientist: an Experience from the Czech Primary School Inquiry-based Learning Programme

Abstract

The paper presents an evaluation of an inquiry-based learning programme for primary school pupils in the Czech Republic. The programme consisted of two parts: in the first part pupils acquired and practised inquiry skills, in the second they applied them to three independent inquiry-based learning lessons. Both pupils and teachers were highly satisfied with the programme. According to the pre/post non-equivalent experimental/control group designed evaluation research, the pupils who participated in the programme significantly improved their understanding of the research cycle representing the basic logic of scientific work. No such change appeared in the control groups. The programme influenced both boys and girls. Even though no significant gender differences for the groups of the 4^{th}-5^{th} grades and 6^{th}-7^{th} grades were found, the girls from the 8^{th}-9^{th} grade received a better score than the boys in both pre- and post-testing.

Keywords: *inquiry-based learning, programme evaluation, Czech Republic, research cycle*

Introduction

Inquiry-based learning (also inquiry-based education or inquiry-based science education) is still a relatively new approach in science education (Magnussen, Ishida, & Itano, 2000; Chiappetta & Adams, 2004; Papacek, 2010a, 2010b; Stuchlikova, 2010). Despite being sometimes interchanged with problem-based learning, it is more often interpreted as a holistic, student-centred approach to science education (Magnussen, Ishida, & Itano, 2000; Hmelo-Silver, 2004; Ashby, 2006). In inquiry-based learning (IBL) pupils follow a procedure similar to that of real scientists, i.e. they formulate their research questions and hypotheses, plan their research, collect, analyze, interpret data, and finally present what they have found (Papacek, 2010a).

IBL might be seen as a complex of various approaches that highlight different aspects of pupils' work. According to Healey (2005), we might differentiate between student- or teacher- run lessons, content or process orientation, or according to the role pupils play in the lesson (audience or participants). Chiapetta and Adams (2004) defined four basic approaches in IBL. According to them, an IBL lesson might focus on content, content with process, process with content, or on process only.

The effectiveness of IBL remains questionable. On the one hand, it is assumed that IBL positively influences a vast variety of educational goals, such as pupils' attitudes towards science, problem-solving skills, understanding scientific concepts, cooperation skills, or motivation to learn (Straits & Wilke, 2002; Papacek, 2010a, 2010b). On the other hand, such claims do not seem to be well supported by research.

According to Hmelo-Silver (2004), even if the positive benefit of IBL on creating new knowledge and developing problem-solving skills might be supported, its effect on developing cooperative skills or motivation to learn is still questionable. Sumerlee and Murray (2010) found a positive effect of IBL on the development of information-processing skills and the motivation of students to participate in university life. Wolf and Laferriere (2009) reported a positive effect of IBL on pupils of the first and second grades of primary school.

Kirchner, Sweller and Clark (2006) questioned the effectiveness of indirect instructional approaches at all. According to them, such lessons provide pupils with a bigger amount of information at one time than the human brain is able to manage. They assumed that indirect approaches might be appropriate only for pupils with a high level of initial conceptual knowledge.

Such an opinion is supported by other papers which did not find any effect of IBL on pupils' skills or knowledge. Magnussen, Ishida and Itano (2000) found no effect of IBL on pupils' critical thinking, and even a negative effect in some of the groups. Gautreau and Binns (2012) found only small changes in pupils' attitudes towards science after participating in IBL and no significant effect on ecology knowledge. Pupils in their study also expressed a negative feeling towards IBL, probably because a new approach challenged their status in the classroom.

Other researchers investigated factors influencing the effectiveness of IBL. Kuech (2004) assumes that group consistency and size, regular reflection and repetition play an important role. According to Pea (2012), an IBL lesson is influenced by the whole school environment, including school management and parents.

In the Czech Republic, IBL is still not well known. According to Papacek (2010a), the main barrier seems to be the limits in pre-service teacher preparation when teachers often have a limited competence in research methodology or a constructivist educational approach.

Even though Czech pupils score well in international testing of science knowledge, they fail in its application in the real world (Paleckova, 2007). This supports the call for developing the inquiry skills of pupils at primary and secondary schools (Pastorova, 2011).

IBL is promoted by both universities and environmental education centres in the Czech Republic (Papacek, 2010a; Dvorackova & Ryplova, 2012; Cincera, 2011). The non-profit organisation Sdruzeni TEREZA (Association TEREZA) is one of the leaders in this field.

The Sdruzeni TEREZA designs, coordinates and disseminates environmental and science education programmes for all types of schools. They coordinate an international science education programme called GLOBE in the Czech Republic (Cincera & Maskova, 2011). In 2011–2013 they managed a new IBL programme for primary schools, Badatele.cz (Explorers.cz).

Programme

The aim of the programme Badatele.cz was to promote the application of IBL into primary schools. To achieve this, the organisation set a team consisting of primary school teachers, university scholars, and members of Sdruzeni TEREZA who played a coordinating and methodological role in the project.

The coordinators prepared guidelines for designing new IBL lessons and coordinated meetings of the team. All the lessons and the guidelines were reviewed by university experts.

For the purpose of evaluation, the participating teachers agreed to implement the lessons in the same fashion. In all of the participating classes, teachers started the programme by teaching and practising research skills. They also explained the general procedure of scientific research that was called 'research cycle' in this project.

In the second part, pupils participated in three different IBL lessons focusing on different science concepts. All the lessons were designed to be manageable in ninety minutes in the classroom. At the beginning of the lessons, the teachers motivated the pupils to investigate a topic. After this, the teachers usually facilitated discussion to help the pupils formulate their research questions and hypotheses. In the next part, the pupils planned and conducted their investigation. In the last part, the pupils summarized their findings and decided if their hypotheses could be accepted. The whole programme was conducted in 3–4 months.

The programme coordinators were interested in the effect of the programme on developing inquiry skills and on a broader understanding of the research cycle. They supposed that after being exposed to both parts of the programme, pupils would be able to describe all the steps of the research cycle, formulate their own hypotheses, or choose the best design for their research.

Methodology

The paper focuses on the following evaluation questions:

- How satisfied were teachers and pupils with the programme?
- Did the programme influence pupils' understanding of the research cycle?
- Are there any differences between girls and boys in the way the programme increased their understanding?

A plethora of instruments have been used for analyzing the effectiveness of IBL, including observation (Ballantyne, Packer, & Everett, 2005), mind mapping (Vanhear & Pace, 2008), rubrics (Marcinkowski, 1997) or single or multiple-choice tests (Cronje, Rohlinger, Crall, & Newman, 2011).

In the study, a quasi-experimental pre- and post-test design was applied. Experimental groups consisted of classes participating in the project with no previous experience of IBL lessons. Control groups consisted of classes not participating in the programme from the same schools. The teachers were asked not to implement any IBL lessons in the control classes. Because of the age variety of classes involved in the project, they were divided into three age groups; each of them was administered by a different, age-suitable version of the test (cf., Table 1).

Table 1. Respondents

Grade	Number of classes	Number of respondents	Mean age	Standard deviation
4th-5th				
Experimental	5	122	9.53	1.29
Control	2	45	9.95	0.7

Grade	Number of classes	Number of respondents	Mean age	Standard deviation
6th-7th				
Experimental	7	138	11.8	0.75
Control	3	55	12.07	0.74
8th-9th				
Experimental	5	100	14.7	11.01
Control	4	72	13.52	0.55

Pre-tests were administered one month before and post-tests 2–3 weeks after the programme. For evaluation of the effect on understanding the research cycle, the respondents got a scenario describing the story of a fictitious researcher. The story consisted of seven (4th-5th grades) or nine (6th-7th and 8th-9th grades) randomly ordered steps of the research cycle (for an example of an instrument for grades 4th-5th, cf. Appendix 1). The respondents were asked to organize the steps in the right order.

For analyzing, the respondents achieved points when their total gain = $|Sb - CoS|$. In this formula, SbR meant 'step by respondent' and CoS stood for 'correct order of a step'. For instance, in the test for the 4th-5th grades (cf., Appendix 1), the step 'Hugo is wondering if the green frogs jump more than the brown frogs' represents the formulation of a research question. Because step 1 (reading a scientific paper) was already given to the students as an example, the correct order should be '2'. If a respondent marked this step as '4', he or she received two points. Step 3 should be the item 'Hugo is writing an assumption (hypothesis) that brown frogs jump more than green frogs.' If a respondent marked this step as '2', he or she received one point.

The respondents from the 4th-5th grades could achieve 0–24 points, the respondents from other groups 0–40 points. Because the sum of points indicates the magnitude of respondents' misunderstanding of the right order of steps in the research cycle, fewer points means a higher level of understanding, and more points mean a lower level of understanding.

For analyzing the statistical significance of differences, non-parametric tests (signed-rank test and Mann-Whitney test) were used (alpha=0.05).

For evaluating the satisfaction of the pupils and their teachers with IBL, a simple questionnaire combining close- and open-ended questions administered after each of the lessons was used. In the teacher survey, 13 respondents evaluated each of the programmes they carried out in the classroom. A simple, 4-item scale was used. Altogether, 48 completed questionnaires were collected.

Similarly, the pupils evaluated every lesson they participated in. The respondents from the group of 4th-5th grades received a short 4-item questionnaire evaluating how they enjoyed the lesson, how well they cooperated in class, how much they had learnt, and how demanding the lesson had been. The respondents from both the other groups received the same, 9-item questionnaire. In both cases, a 7-point scale was used where the numbers were represented by emoticons.

For the coding, lower numbers indicate a low level of evaluated indicator (e.g., enjoyment or difficulty), where 1 stands for the lowest and 7 for the highest level in the pupil groups and 1–4 in the teacher group.

Of the group of respondents (cf., Table 1), 490 evaluation questionnaires for the 4th-5th grade group and 622 for the groups from the 6th-7th grades and 8th-9th grades were collected.

Results

Satisfaction with the programme

Most of the teachers reported a high level of satisfaction with the programme (cf., Table 2). They believed that the lessons were enjoyable for pupils, age-appropriate, and that the lessons achieved their goals. They are also interested in using their lesson again in the future. They do not believe that the lessons were demanding for the pupils.

On the other hand, they reported that preparation for their lesson was quite demanding and they also had difficulties in carrying out the lesson in the set time.

Table 2. Teachers' satisfaction with lessons (%)

A lesson was	Strongly disagree	Disagree	Agree	Strongly agree
Demanding for pupils	6	48	44	2
Enjoyable for pupils	0	6	60	33
Age-appropriate	0	8	21	71
Preparation was time-consuming	4	31	33	27
The lesson was manageable in a lecture time	31	25	29	12,5
Leading the lesson is demanding for a teacher	12,5	27	42	14,6
I would like to use the lesson after finishing the project	0	4	29	65

For the pupils from the 4th-5th grade group, the lessons were enjoyable (mean=5.86, mode=7), they cooperated well with their peers (mean=5.85, mode=7), and they learnt a lot (mean=5.86, mode=7). The difficulty of the lessons was very small (mean=2.21, mode=1).

The same patterns were found for the group of the 6th-9th grades. They enjoyed the lessons (mean=5.2, mode=6), cooperated well (mean=5.48, mode=7), learnt a lot (mean=5.06, mode=6), and reported the lessons were not difficult (mean=2.5, mode=2). The respondents were interested in the topic of their lessons (mean=5.32, mode=7) and they would like to have further lessons like this (mean=5.13, mode=7). The respondents also assumed they could influence the way their lesson was carried out (mean=4.88, mode=6) and they could investigate their own questions (mean=5.26, mode=7).

Understanding of the research cycle

In all of the experimental groups, the level of understanding of the research cycle increased. At the same time, changes in the same variable in the control groups were not significant (cf., Table 3).

Table 3. Understanding of the research cycle

	N	Median PRE	Median POST	Z	P
4th-5th					
Experimental	122	12	8	4	<0.001
Control	45	14	11	1.3	0.18
6th-7th					
Experimental	138	16	9	5.5	<0.001
Control	55	18	13	1	0.31
8th-9th					
Experimental	100	12	8	5.2	<0.001
Control	72	10	10	0.5	0.6

With the exception of the 6th-7th grades, the experimental and control groups differed in their scores before the programme. The control group for the 4th-5th grades scored higher than the experimental group, and lower for the 8th-9th grades. All the groups significantly differed after the programme (cf., Table 4).

Table 4. Comparison of experimental and control groups

	N	Median PRE	Z	P	Median POST	Z	P
4^{th}-5^{th}							
Experimental	122	12	-2	0.04	8	-3.3	<0.001
Control	45	14			11		
6^{th}-7^{th}							
Experimental	138	16	-0.7	0.44	9	-2.5	0.009
Control	55	18			13		
8^{th}-9^{th}							
Experimental	100	12	-2	0.04	8	-3.3	<0.001
Control	72	10			10		

Gender aspects were analyzed for the experimental groups only. The girls and boys from all the groups significantly increased their understanding (cf., Table 5). Gender differences appeared to be significant only for the 8^{th}-9^{th} grades in favour of the girls (cf., Table 6).

Table 5. Results for boys and girls from experimental groups

	N	Median PRE	Median POST	Z	P
4^{th}-5^{th}					
Girls	55	12	8	3.53	<0.001
Boys	66	10	8	2.08	0.03
6^{th}-7^{th}					
Girls	69	14	8	3.8	<0.001
Boys	69	16	10	3.8	<0.001
8^{th}-9^{th}					
Girls	45	11	8	3.28	0.001
Boys	51	14	10	3.5	<0.001

Table 6. Comparison of gender differences in experimental groups

	Girls Median	Boys Median	Z	P
4^{th}-5^{th}				
PRE	12	10	-0.89	0.3
POST	8	8	0.02	0.97
6^{th}-7^{th}				
PRE	14	16	1.15	0.24

	Girls Median	Boys Median	Z	P
POST	8	10	0.76	0.44
8th–9th				
PRE	11	14	-2.3	0.01
POST	8	10	-2.5	0.009

Discussion

The results of the study must be interpreted in the light of its methodological limits. The groups were relatively small and random selection was not applied in all the cases. The differences in the number of the respondents between the experimental and control groups might also have relatively 'disadvantaged' the control groups. The understanding of the research cycle was analyzed with a single item test only.

In spite of this, we might assume that the change in the understanding of the research cycle that was found in the experimental groups could be prescribed to the evaluated programme. It seems that the applied strategy based on initial skills training and repeated IBL lessons helped the pupils to grasp the way scientists work. The pupils learnt the cycle by their own experience, in the process of experiencing, generalizing and repeated application into the following lesson (Kolb, 1984).

Gender differences appeared to be at play in the oldest category of the respondents. The better results of the girls might be surprising in light of the studies assuming negative attitudes of girls to science (Osborne, Simon, & Collins, 2003). However, according to the PISA 2006 survey, the Czech Republic is one of the few countries where more girls plan to study science in the future than boys. Czech girls also achieved better results in some items in the survey than boys (Paleckova, 2007) and declared more positive attitudes towards environmental protection (Bilek, & Schmutzerova, 2010). The different patterns that appeared in the oldest groups might also correspond to Osborne et al. (2003), who found an increase in the negative attitudes towards science of children over eleven years of age.

The research did not support the assumption of Gautreau and Binns (2012) about negative feelings of pupils towards IBL. The pupils liked the programme and negative statements were only marginal. We might conclude that the way IBL is interpreted depends on a complex of contextual factors (Pea, 2012) and cannot be generalized. Pupils might like the lessons because they did not like the traditional style, or because of specific features of the programme.

The study contributes no evidence to the discussion regarding whether or not IBL is an effective approach for teaching scientific concepts. However, it might be considered to be an effective tool for teaching concepts connected with the scientific process, especially the logic of research work.

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Appendix 1. Example of the test for the 4th-5th grades

How does such a 'scientific inquiry' work? You can find an excerpt from the diary of a young researcher, Hugo, who studies frogs. Unfortunately, by mistake it happened that Hugo cut his diary into small pieces during break time. Would you help him to reassemble it again? Your task is to put the steps of his research into the correct order. You should write a number by each of the steps from 2 to 8 (Notice that we have already filled in number 1 for the step when Hugo started his research for you. So you should start with number 2 for the next step, 3 for the next one up to 8 for the last one.)

Example

_1______ Hugo comes to his office and reads an article written by his friend about frogs.

________ Hugo decides if brown frogs really jump more as he originally supposed.

________ Hugo is writing a paper for The Kwak and Splash Journal about his research.

________ Hugo is planning some research where he is going to observe frogs.

_________ Hugo is writing an assumption (hypothesis) that brown frogs jump more than green frogs.
_________ Hugo compares the results of the jumps of the brown and green frogs.
_________ Hugo is wondering if green frogs jump more than brown frogs.
_________ Hugo is lying in the meadow, observing the frogs and noticing how far they jump.