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Miroslava Jurečková
Matej Bel University, Faculty of Education, Banská Bystrica, Slovakia
Jarmila Kmeťová
Matej Bel University, Faculty of Natural Sciences, Banská Bystrica, Slovakia
Marek Skoršepa
Matej Bel University, Faculty of Natural Sciences, Banská Bystrica, Slovakia

Science Process Skills and Level of Knowledge of Primary Education Pupils

Abstract

The research deals with the influence of inquiry-based science education (IBSE) implementation into science instruction in the 3rd grade of elementary school on the levels of pupils' knowledge and science process skills. The research sample consisted of 395 pupils and 170 primary education teachers. The main research method was a pedagogical experiment. Other research methods were non-standardized didactic tests, observation and a questionnaire. The obtained results showed that the pupils' science process skills increased in the experimental group due to the influence of IBSE. The research results may contribute to the effective implementation of this educational concept in the instruction of natural sciences at elementary schools, with the assumption of increasing pupils' scientific literacy in international measurements.

Keywords: *primary education, IBSE, scientific literacy, science education*

Introduction

Rocard's report (Rocard et al., 2007) concludes that the general level of pupils' positive attitude toward natural sciences and science education has rapidly declined in recent years. Science education is part of the comprehensive education of primary education pupils, through which pupils get to know nature as a complete system of mutual changes and relationships. Inquiry-based science education (IBSE) is considered an inspiring method of learning science because it focuses on pupils' own interests and encourages active learning by allowing pupils to carry out their own investigations while developing ideas about how scientists work and in what way scientific knowledge is constructed (Rocard et al., 2007; Obadović et al., 2013; Khishfe & Abd-El-Khalick, 2002).

Many countries worldwide have discussed education reform as one of the most important topics in recent decades (European Union, 2008; National Research Council, 2012; Voogt & Roblin, 2012). Also, several studies have been carried out (Žoldošová & Prokop, 2006; Rönnebeck et al., 2016; Cavas et al., 2017), dealing with the influence of IBSE on the development of scientific literacy.

The main aim of our research was to achieve better results of pupils' scientific work, the essence of scientific literacy, by implementing IBSE into science education at primary school.

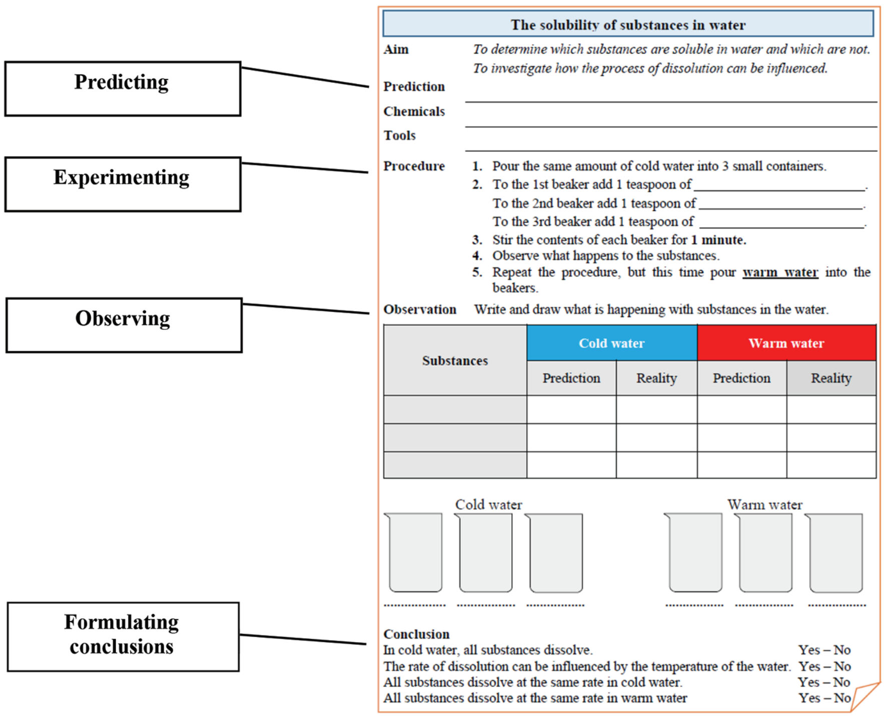
Research Problem

The results of the TIMSS measurements (Mullis et al., 2020) make it clear that the level of Slovak pupils' scientific literacy currently does not reach the average of either OECD or EU countries. In some countries, e.g., Singapore (Curriculum Planning and Development Division, 2022), science education begins only in the third grade of primary education, yet it achieves the best results worldwide. The Pollen research results (Jasmin & van den Berg, 2010) show that it is the effect of natural science instruction by the IBSE method.

In our research, 13 methods were designed using IBSE principles. Each method included i) laboratory protocol for primary education teachers; ii) preparation for class; iii) pupil worksheet. The methods aimed to increase the level of pupils' science process skills directly related to the increase in scientific literacy. Colvill and Pattie (2002) divide science process skills into basic science process skills (observing, inferring, predicting, classifying, measuring) and integrated science process skills (data interpreting, controlling variables, hypothesizing, experimenting, creating graphs and tables, describing relationships between variables, formulating conclusions). Since our research sample consisted of primary school 3rd-grade pupils, the worksheets were designed to develop mainly basic science process skills. The methods were also aimed at pupils' correct and better understanding of scientific facts and concepts (thus eliminating preconceptions or misconceptions) important for understanding natural sciences in higher grades.

To verify the effectiveness of the methods, a pedagogical quasi-experiment was carried out in the school years 2020/2021 and 2021/2022 at nine elementary schools in the Slovak Republic to compare the achieved knowledge scores and the science process skill levels of pupils in the experimental and the control groups.

Figure 1. Pupil worksheet on the topic of solubility of substances in water used in the first lesson



The solubility of substances in water

Aim *To determine which substances are soluble in water and which are not. To investigate how the process of dissolution can be influenced.*

Prediction

Chemicals ______________________

Tools ______________________

Procedure
1. Pour the same amount of cold water into 3 small containers.
2. To the 1st beaker add 1 teaspoon of ______________.
   To the 2nd beaker add 1 teaspoon of ______________.
   To the 3rd beaker add 1 teaspoon of ______________.
3. Stir the contents of each beaker for **1 minute.**
4. Observe what happens to the substances.
5. Repeat the procedure, but this time pour warm water into the beakers.

Observation Write and draw what is happening with substances in the water.

Substances	Cold water		Warm water	
	Prediction	Reality	Prediction	Reality

Conclusion
In cold water, all substances dissolve. Yes – No
The rate of dissolution can be influenced by the temperature of the water. Yes – No
All substances dissolve at the same rate in cold water. Yes – No
All substances dissolve at the same rate in warm water Yes – No

Research Focus

The pedagogical experiment took place during two school years, 2020/2021 and 2021/2022. Non-standard knowledge tests determined the level of knowledge at the beginning of the school year (pretest) and the end of the school year (posttest). The level of science process skills was recorded in observation sheets by teachers during the first and the last pupil experiments.

During 13 weeks, pupils in the experimental group were taught our methods, which were designed using IBSE principles. Each method included: i) teacher laboratory protocol explaining the chemical essence of the experiment and for recording results of the experiments; ii) pupil worksheet designed to develop science process skills; iii) teacher preparation for a class designed according to Kimáková's EUR model (2008).

The research was divided into three phases, each examining one working hypothesis.

- **Phase 1** – at the school year beginning, pupils were divided into the experimental and the control groups, with their knowledge tested (pretest) and the results verified to determine if there was a statistically significant difference between the groups. The aim of the test was to i) find out the level of pupils' science knowledge; ii) verify whether both groups were at the same level in order to prevent one group's higher score at the beginning of the experiment, which would significantly influence results of the whole experiment.
- H1: The experimental group will achieve a higher score than the control group
- **Phase 2** – during 13 weeks, pupils of the experimental group were taught by our methods designed by IBSE principles, while pupils of the control group were taught by the traditional transmissive method. After 13 weeks, pupils from both groups were tested, and the results were statistically verified.
- *H2: The experimental group will score higher in the posttest than the control group*.
- **Phase 3** – the research also focused on the level of pupils' science process skills. It was determined through the observation sheet as a questionnaire where teachers teaching in the classes recorded the levels of pupils' science process skills.

H3: After implementing IBSE into science instruction, the experimental group will achieve higher science process skills than the control group.

Research Methodology

Research Sample

The research sample consisted of N = 395 pupils of the 3rd grade in five regions of the Slovak Republic. The whole research sample consisted of pupils involved in the research in the school year 2020/2021 and 2021/2022.

In September 2020/2021, the research involved 330 pupils from twenty classes, of which 201 were in the experimental group and 129 were in the control group. In the next school year, 2021/2022, the experimental group was added 46 more pupils from two classes and the control group 19 pupils from one class. In September 2020, however, one control group class, 14 pupils, left the research.

In total, for both school years, the experimental group consisted of 247 pupils from twelve classes and the control group of 134 pupils from seven classes.

Pupils were divided into groups after communication with teachers involved in the research, so it was a quasi-experiment. All teachers of the experimental group were previously made familiar with IBSE. Until then, each of them was taught by the workbook by Dobišová Adame and Kováčiková (2016).

Instrument and Procedure

The pretest, administered to pupils at the beginning of the school year determined the level of pupils' knowledge of topics taught in the subject of Elementary Civic and Science Education in the previous school year.

The pretest consisted of 19 scored test items matching the first three levels of Bloom's taxonomy (Bloom et al., 1956), thus tasks for remembering, understanding and applying. The maximum number of scores was 37.

At the end of the school year 2020/2021, pupils were administered a posttest with 28 scored questions for which they could obtain 51 scores. The posttest also matched the first three levels of Bloom's taxonomy.

In addition to the main method - the pedagogical quasi-experiment- teachers used the method of observation and assessment of pupils' science process skills in both the experimental and the control groups.

At the beginning and the end of the period studied, teachers in both groups (2020/2021, 2021/2022) were administered questionnaires as observation sheets.

Science process skills were assessed on a Likert scale, where teachers chose one point from 1 to 5, with 1 = excellent, 2 = commendable, 3 = good, 4 = sufficient, and 5 = insufficient, which allowed for more objective and thorough information about the group of pupils studied.

Teachers in the experimental group applied our methods in the first and the last lessons in the first half of the school years 2020/2021 and 2021/2022, and teachers in the control group used the same methods only in the first lesson in the above school years.

The experiment's conclusions and results were based on comparing the values from both groups' observation sheets between the beginning and the end of the period studied.

Statistical methods used included descriptive statistics and comparative analysis. The obtained data were processed using the statistical software package IBM SPSS ver. 29 (SPSS Inc., 2023).

Research Results

Pretest

In th school year 2020/2021, pupils (N = 317) were administered the pretest. To verify the research hypothesis in the first phase of the research, the non-parametric Mann-Whitney U-test for two independent samples was used, since the measured data did not meet requirements of normal distribution.

There was no statistically significant difference between the experimental group (*N = 192, Mdn = 29*) and the control group (*N = 125, Mdn = 29*) in pretest scores, *U = 11630, Z = 0.466*. The alternative hypothesis was rejected in favour of the zero hypothesis H_0 at the 5% level of significance $p > 0.05$ ($p = 0.642$). It means that both the experimental and control groups entered the pedagogical experiment at the same level of knowledge of natural sciences.

In the school year 2021/2022, the same test was administered to 58 pupils.

Again, there was no statistically significant difference between the experimental group (*N = 40, Mdn = 31*) and the control group (*N = 18, Mdn = 30.5*) in the pretest scores, *U = 341, Z = 0.321*. The alternative hypothesis was rejected in favour of the zero hypothesis H_0 at the 5% level of significance $p > 0.05$ ($p = 0.748$). It means that the experimental and control groups entered the pedagogical experiment at the same level of knowledge of natural sciences.

Posttest

In the school year 2020/2021, the posttest was administered to N = 299 elementary school pupils in the 3rd grade.

To verify hypothesis H2, the parametric Student test for two independent samples (Field, 2009) was used, since the measured data met requirements of normal distribution.

Also, the value of the so-called *effect size* between the groups was calculated, determining the strength of the relationship or the difference between two groups. It indicates the size of the effect of the phenomenon studied, regardless of the sample size (Howell, 2010). The effect size was calculated according to Rosenthal (1991) as follows:

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Where *t* was the Student test statistic, calculated by dividing the mean deviation by the standard error of differences in the sample, and *df* were degrees of freedom calculated by adding the sizes of both samples and then subtracting the number of samples. The evaluation of the obtained effect size value was based on Cohen's (1988) classification, defining the intervals for the effect size of the Student t-test as follows:

- r = 0.1 (small effect)
- r = 0.3 (medium effect)
- r = 0.5 (large effect)

There was a statistically significant difference between the experimental group (*N = 185, M = 37.09, SE = 0.477*) and the control group (*N = 114, M = 38.89, SE = 0.559*) in the posttest scores at the 5% level of significance *p = 0.016*, falling in the interval of small effect *r = 0.14*.

The number of pupils administered the posttest in the school year 2021/2022 was *N = 54*, out of which 40 pupils were in the experimental group and 14 in the control group.

To verify hypothesis H2, the non-parametric Mann-Whitney U-test for two independent samples was used because the measured data did not meet the requirements of normal distribution.

The obtained data showed a statistically significant difference between the experimental group (*N = 40, Mdn = 39*) and the control group (*N = 14, Mdn = 29.29*) in the posttest scores falling in the interval of medium and large effect, *U = 77.50, Z = 4.007 r = 0.5*. Based on the results, the zero hypothesis was rejected in favour of the alternative hypothesis H_a at the 5% level of significance $p < 0.000$.

Observation

The structured observation was conducted in the first lessons in September 2020 and 2021. Teachers' tasks were to evaluate science process skills presented in Table 1 on a Likert scale as objectively as possible. Teachers were previously informed of what to evaluate, in what form, and by what criteria.

Next, using the data from eleven teachers of the experimental group and five teachers of the control group, the working hypothesis of the research third phase was verified by the Chi-square (χ^2) good fit test for two independent samples.

Table 1. Statistical evaluation of results of observation of pupils' science process skills

Science process skills	χ^2	*df*	sig.	Cramer's V
Making assumptions	10.415	2	0.005	0.807
Observing the action in progress	12.897	2	0.002	0.898
Interpreting the data	16.000	3	0.001	1
Formulating conclusions	16.000	3	0.001	1

According to Field (2009), Cramer's V value corresponds to the effect size value in the interval from 0 to 1. Since our results fell in this interval, Cramer's V values were interpreted as the effect size.

Kim (2017) presented the following effect size values for Cramer's V for individual degrees of freedom (*df*):

Table 2. Effect size for Cramer's V values (Kim, 2017)

Df	Small	Medium	Large
1	0.10	0.30	0.50
2	0.07	0.21	0.35
3	0.06	0.17	0.29
4	0.05	0.15	0.25
5	0.04	0.13	0.22

Statistical verification found a significant relationship between the implementation of IBSE elements into natural science instruction and pupils' levels to:

- Make assumptions, χ^2 (2) = 10.415, p = 0.005, V = 0.807, with large effect
- Observe the action in progress, χ^2 (2) = 12.897, p = 0.002, V = 0.898, with large effect
- Interpret data, χ^2 (3) = 16, p = 0.001, V = 1, with small effect
- Formulate conclusions, χ^2 (3) = 16, p = 0.001, V = 1, with small effect

Limitations and Future Implications

We are aware of the following limitations that could affect the research results. The first one is that the research was carried out during the COVID-19 pandemic when pupils did not attend school due to the lockdown lasting several weeks to months, but they learnt online. Pupils' experiments in inanimate nature carried out during the first 13 weeks of that school year were not influenced by the lockdown. However, during the next half-year, instruction ran online when taught about animate nature, which could influence pupils' results in this subject. A second factor is potentially lower objectivity in assessing pupils' scientific work by their primary education teachers. Confirmation of positive results of IBSE elements implementation into primary education instruction requires further research studies.

Discussion

The research aimed to verify whether implementing IBSE into natural science instruction positively influenced natural science instruction at the primary level of education in terms of improving pupils' science knowledge and skills. In the past, other authors also dealt with similar investigations, finding out that natural science instruction through IBSE positively contributed to improving pupils' science process skills and scientific thinking in understanding natural phenomena (Ergül et al., 2011).

Our research showed that IBSE implementation into natural science instruction in the 3rd grade of primary education positively influenced pupils' knowledge and science process skills. Our research confirmed many studies investigating the effectiveness of IBSE implementation into instruction to improve pupils' science knowledge, skills or attitudes to natural science education (Ozdemir & Isık, 2015).

Şimşek and Kabapınar (2010) published empirical evidence of IBSE improving pupils' conceptual understanding of natural sciences. Their quantitative findings showed that implementing IBSE activities into pupils' instruction increased the number of scientifically correct answers.

Based on the mentioned studies, our results confirm previous research that effective implementation of IBSE into instruction increases pupils' science knowledge and skills.

Conclusions

Every country has addressed the issue of natural science education at a different level. The Slovak Republic tries to change the concept of natural science education at elementary schools through the ongoing curricular reform introducing IBSE into natural science instruction. Despite introducing IBSE into the educational process, primary education teachers' preparation and understanding of IBSE principles application to natural science education is currently a problem. Therefore, many countries around the world, e.g., the Czech Republic (Trna et al., 2012), the USA (Lehman et al., 2006), Thailand (Safkolam et al., 2024), Australia (Marangio et al., 2024) focus on the preparation of primary education teachers in introducing IBSE into instruction.

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AUTHORS

MIROSLAVA JUREČKOVÁ

Mgr., PhD., Matej Bel University, Faculty of Education,
Ružová 13, 974 11 Banská Bystrica, Slovakia.
E-mail: miroslava.jureckova@student.umb.sk

JARMILA KMEŤOVÁ

Associate Professor. RNDr., PhD., MBA., Matej Bel University, Faculty of Natural Sciences,
Tajovského 40, 974 01 Banská Bystrica, Slovakia.
E-mail: jarmila.kmetova@umb.sk
ORCID: https://orcid.org/0000-0002-5380-3945

MAREK SKORŠEPA

Associate Professor. RNDr., PhD., Matej Bel University, Faculty of Natural Sciences,
Tajovského 40, 974 01 Banská Bystrica, Slovakia.
E-mail: marek.skorsepa@umb.sk
ORCID: https://orcid.org/0000-0003-0996-9152