Inquiry Skills of Primary School Pupils in Slovakia

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Abstract

One of the long-term problems in education in Slovakia is the low level of scientific literacy of pupils, which is below the average of OECD countries participating in the international PISA measurement. Pupils achieve worse results, especially in the tasks that require procedural and epistemic knowledge, as well as the skills associated with the design and evaluation of scientific research and the interpretation of the evidence and data obtained in a scientific way. In recent years, therefore, there has been an effort to apply Inquiry-Based Science Education to develop science ideas and inquiry skills of primary school pupils. For this reason, we focused our research on identifying problematic aspects of selected inquiry skills of 13-15 years old primary school pupils, such as: formulating research questions, identifying a dependent and independent variable, designing an experiment, and predicting the results, observing, recording, and collecting data, processing, analysing and interpreting data, describing relationships between variables, formulating generalizations, and drawing conclusions. The open item test was administered to the sample of 13-15 years old pupils. The results indicate a relatively low level of inquiry skills among pupils. In addition, through open items, we were able to identify original and unexpected alternative solutions and pupils' responses that provide feedback on pupils' thinking in solving tasks based on the implementation of scientific inquiry in biology.

Keywords: biology education; Inquiry-Based Science Education; open items; scientific literacy; test

1. Introduction

One of the fundamental objectives of science education is to develop scientifically literate pupils who can explain the various phenomena in nature, to design and evaluate scientific inquiry, to interpret data and evidence obtained through scientific methods, and to engage in a reasoned discourse about science and technology. Based on these competencies, a scientifically literate pupil can engage in topics related to nature and natural sciences as a reflective citizen (OECD, 2019). According to NRC (1996), a person is increasingly confronted with questions and problems that require a scientific way of thinking during his/her life. If we develop scientifically literate persons from pupils, they will be able to find solutions to many problems and utilize them in their future personal and professional lives.

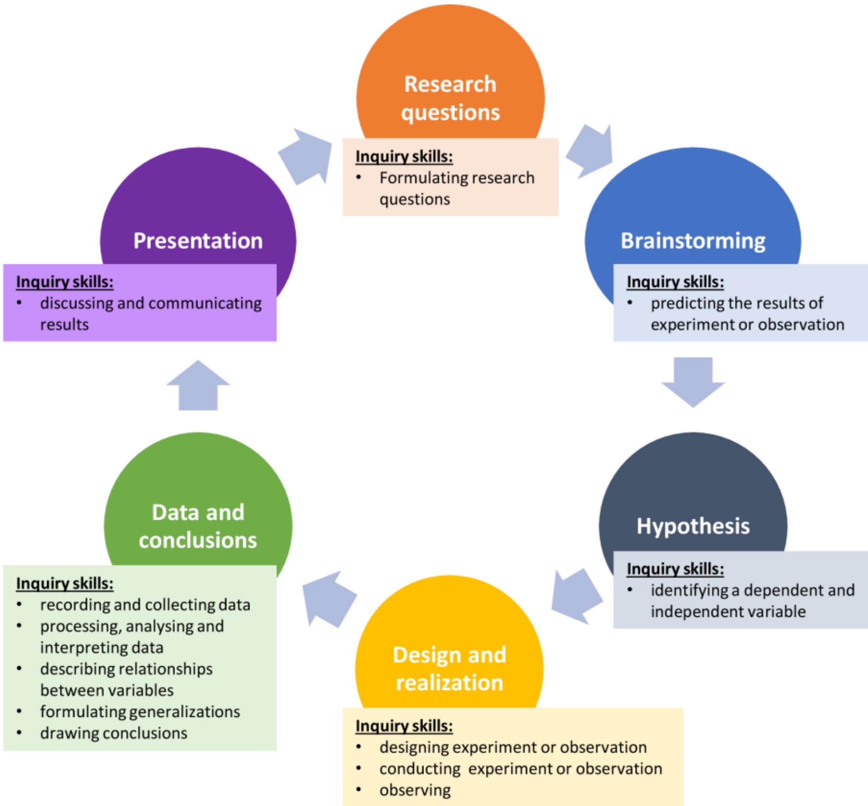
Scientific literacy can be developed among pupils through Inquiry-Based Science Education (e.g., Wen et al., 2020; Ristanto et al., 2017). This concept of education allows pupils to investigate deeper into the world of science, to look at the processes in which scientists obtain data and evidence for their claims, and to learn to present the results of their work based on relevant arguments. In IBSE, the approach to teaching is much more pupil-centred and problem-solving than in transmissive education (O'Connell, 2014).

A constructivist approach is used in inquiry (e.g., Serafín et al., 2015; Eilks, 2012; Taber, 2011) and it emphasises the use of critical and logical thinking (NRC, 1996). Pupils get acquainted with the principles of scientific work and learn ways to implement them. However, the teacher should regard pupils who often do not yet have enough theoretical knowledge, sophistication, and experience of a scientist (e.g., Mulley, 2015; Allen & Tanner, 2005; Kirschner, 1992).

The pupils construct their knowledge structure while the teacher has a role as a facilitator (Woods-McConney et al., 2016). However, the scientific inquiry requires not only knowledge of the science content (Lederman, 2009), but also the acquisition of inquiry skills that include the ability to lead and understand scientific research, including asking questions, designing, and conducting experiments, using appropriate methods and techniques for data collection, analysing relationships between evidence and explanations, designing and evaluating alternative explanations, as well as presenting scientific relevant arguments (NRC, 1996). There are currently different classifications and interpretations of inquiry skills (e.g., Van den Berg, 2013; Wenning, 2012; Wenning, 2007; Fradd et al., 2001; Fuhrman, 1978) depending on what their authors consider crucial in IBSE. In general, selected inquiry skills are usually based on the inquiry cycle.

According to Wenning (2012), the acquisition of inquiry skills should be the aim of science education. At first, pupils should acquire basic skills within lower levels of education, and it is recommended to proceed from conceptual skills to analytical skills, from inductive skills to deductive skills, from general skills to specific skills and from concrete skills to abstract ones. For this reason, we should start developing inquiry skills among primary school pupils. Based on the papers by experts (Fuhrman, 1978; Tamir & Lunetta, 1981; Fradd et al., 2001; Wenning, 2007; Wenning, 2012), foreign and Slovak national curriculum (NRC, 1996; ŠPÚ, 2014, A) and claims for items related to scientific literacy in PISA 2015 measurement (OECD, 2017), we can select inquiry skills for 13-15 years old primary school pupils such as: formulating research questions, identifying a dependent and independent variable, predicting the results of experiment or observation, designing and conducting experiment or observation, observing, recording, and collecting data, processing, analysing and interpreting data, describing relationships between variables, formulating generalizations, drawing conclusions and discussing and communicating results. We can incorporate these skills into the structure of the inquiry cycle (Fig. 1), which framework was created by Llewellyn (2002).

Figure 1: Selected inquiry skills of 13-15 years old primary school pupils incorporated into the inquiry cycle



Source: (framework created by Llewellyn, 2002 - modified)

Research conducted in the background of Slovak high schools and universities (Čipková et al., 2020; Čipková & Karolčík, 2018) showed that students have a relatively low level of inquiry skills. One of the reasons for this situation may be the absence of their development among pupils in primary schools. PISA testing on 15-year-olds pupils in the 9th grade of primary school also determines the need to develop inquiry skills among primary school pupils. The result of PISA testing shows we were below the OECD average in the field of scientific literacy. Pupils achieved worse results in items requiring the application of procedural and epistemic knowledge, and items that tested pupils' abilities associated with the design and evaluation of scientific research and the interpretation of evidence and data in a scientific way (OECD, 2016). For this reason, it is necessary to develop inquiry skills among pupils in primary schools more intensively and to measure their level of inquiry skills regularly. The information about the current level of pupils' skills can provide us with valuable feedback on the effectiveness of inquiry activities incorporated in the science subjects. It can significantly contribute to the increase of pupils' inquiry skills and improve their results in PISA tests and future higher education.

2. Objectives and research questions

The development of inquiry skills among pupils in primary schools can lead not only to the development of scientific literacy but also to the easier acquisition of advanced inquiry skills at higher levels of education. If we want to develop pupils' skills more effectively, it is necessary to find out the current level of their inquiry skills. For this reason, the aim of our research is to find out the level of inquiry skills of 13-15 years old pupils. Within the research we aimed to answer the four following questions:

a) What is the level of selected inquiry skills among 13-15 years old pupils in primary schools in Slovakia?
b) What is the level of selected inquiry skills regarding gender of pupils?
c) What is the level of selected inquiry skills regarding age (grade) of pupils?
d) What is the level of selected inquiry skills regarding mark of pupils?

3. Methods

To find out the level of inquiry skills among pupils in primary schools we used a test of our construction. The test consisted of 20 open-ended items, which were aimed at identifying 10 selected inquiry skills. Each skill was tested through two items. We selected individual inquiry skills based on the analysis of papers (Fuhrman, 1978; Tamir & Lunetta, 1981; Fradd et al., 2001; Wenning, 2007; Wenning, 2012;), national standards (NRC, 1996; ŠPÚ, 2014, A) and analysis of PISA 2015 items (OECD, 2017) as important skills for the development of 13-15 years old primary school pupils. These skills include formulating research questions, identifying a dependent and independent variable, predicting the results of experiment or observation, designing experiment or observation, observing, recording, and collecting data, processing, analysing and interpreting data, describing relationships between variables, formulating generalizations, and drawing conclusions (Fig. 1). However, skills such as conducting experiment and discussing and communicating results cannot be measured through tests, so we did not find out their level among pupils. All items in the test were oriented into the context of biology and were based on the content of the curriculum for primary schools.

The test was pilot-tested on a sample of four pupils and then we optimized the time for its completion (60 minutes). A subsequent interview with these pupils confirmed that they considered the individual items to be clearly and regularly formulated. The test was administered in electronic and printed form to ensure the individual requirements of each school. The test also included demographic questions to determine the pupil's gender, age (grade), mark on the last certificate from biology, the type of school, and the city where the school is located.

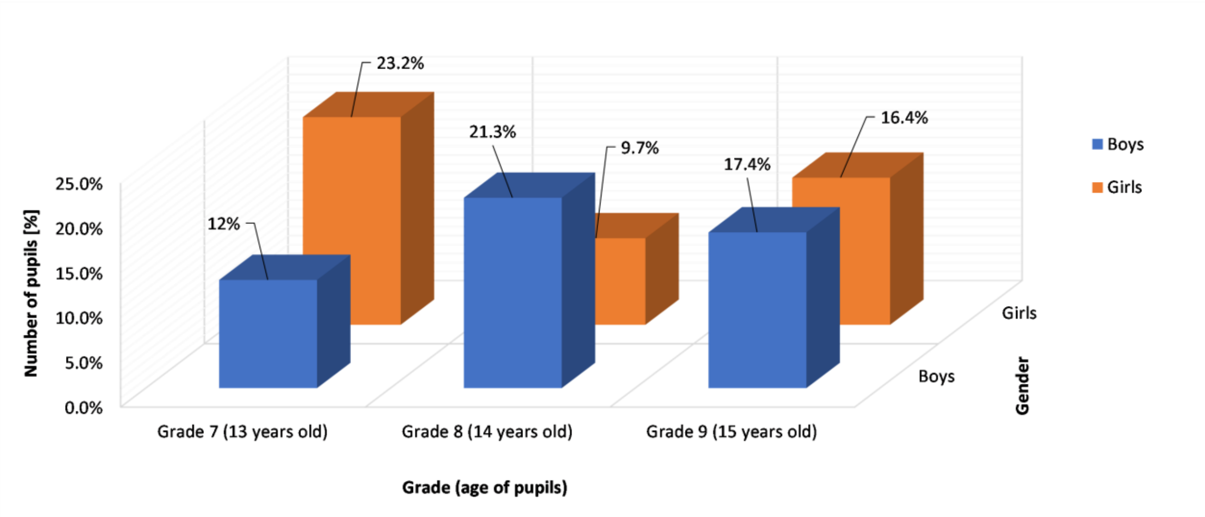
Individual items in the test were not scored dichotomously, so we determined the reliability of the test using Cronbach's Alpha ($\alpha = 0.85$). Thus, we can consider this research instrument as reliable (Streiner, 2003). The content validity of the test was determined by four experts in the field. They evaluated if the items measure defined skills if the items are understandable and if the items are suitable for 13-15 years old pupils in primary schools (Heale & Twycross, 2015).

We analysed the test results by quantitative analysis, which consisted of the descriptive characteristics of the test (e.g., average, median, mode, standard deviation, range, etc.). The Shapiro-Wilk test showed that $p < 0.05$, so we rejected the null hypothesis of normal data distribution (Razali & Wah, 2011). Therefore, we used the Spearman correlation coefficient to determine the statistical dependence between the two ordinal variables. We used the nonparametric alternative to the Student's t-test, the Mann-Whitney (Wilcoxon) test, to determine statistically significant difference between medians of the two groups, and the nonparametric alternative to the ANOVA test, the Kruskal-Wallis test, to determine the statistically significant difference between medians of the three and more groups (Neideen & Brasel, 2007).

4. Research sample

The research involved 207 pupils from eight primary schools located in different regions of Slovakia. The research sample consisted of 50.7 % boys and 49.3 % girls aged 13-15 who attended grades 7-9 (Fig. 2).

Figure 2: Characteristics of the research sample



The introductory items of the test also showed that pupils were mainly graded with mark 1 (54.6%), mark 2 (28.0%) and mark 3 (14.0%) on the last certificate from biology. Only a small number of pupils were graded with mark 4 (2.9%) and mark 5 (0.5%).

5. Results

The analysis of the test's results performed it possible to find out the level of selected inquiry skills among pupils in primary schools and at the same time to find out the most common mistakes of pupils about their thinking and solving problems.

5.1 Level of selected inquiry skills among the pupils

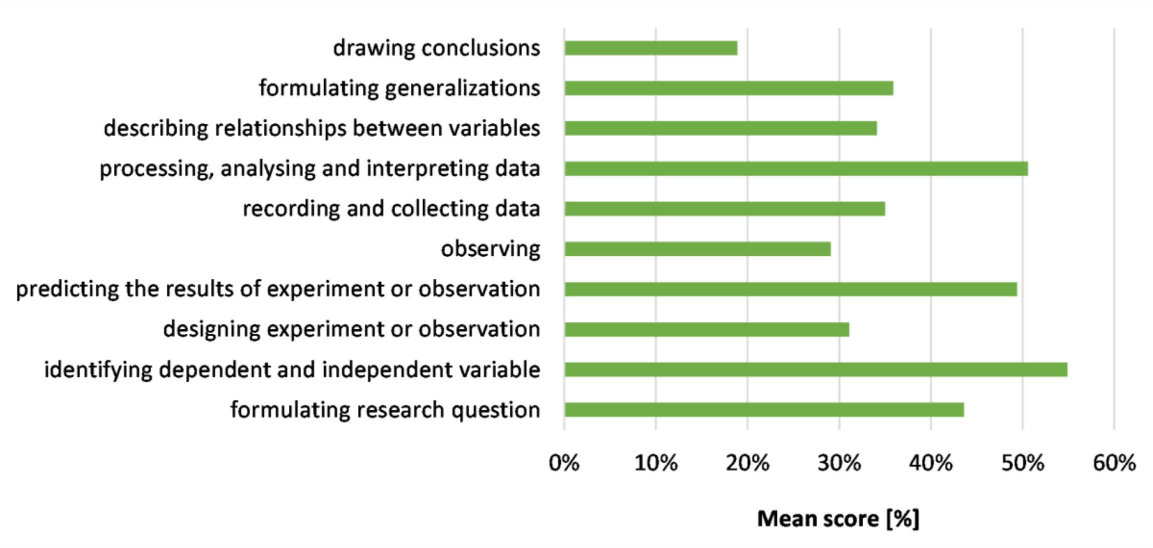
Pupils achieved a mean score of 17.4 points (SD = 8.8) out of a maximum of 48 points, which represents 36.3 %. These results suggest that pupils achieved a below-average level of selected inquiry skills (Tab. 1).

Table 1: Descriptive characteristics of the test

Sample (N)	Average	Median	Mode	Variance	Standard deviation
207	17.4	17.0	21.0	76.95	8.8
Coeff. of variation	**Minimum**	**Maximum**	**Range**	**Stnd. skewness**	**Stnd. kurtosis**
50.4 %	3.0	43.0	40.0	2.43	- 1.42

Pupils achieved the highest mean score in items focused on identifying a dependent and independent variable (54.9 %) and processing, analysing and interpreting data (50.6 %). At the same time, these two skills were the only ones in which students achieved a higher mean score more than 50 % (Fig. 3).

Figure 3: Mean score of selected inquiry skills



By detailed analysis of individual test items measuring the ability to identify variables (Tab. 2), we found that pupils achieved a higher mean score in identifying an independent variable (Item 12) than in identifying a dependent variable (Item 2). We also found a similar difference between items in the skill of processing, analysing and interpreting data, where pupils achieved a higher mean score in the analysis and interpretation data from the table (Item 8) than in the analysis and interpretation data from the graph (Item 17).

Table 2: Pupils' results in the test

Inquiry skills	Test item	Mean score per item [%]	Mean score per skill [%]
formulating research questions	1 7	51.2 36.0	43.6
identifying a dependent and independent variable	2 12	45.4 64.3	54.9
designing experiment or observation	3 15	27.2 34.9	31.1
predicting the results of experiment or observation	4 16	48.1 50.7	49.4
observing	5	31.9	29.1

	13	26.2	
recording and collecting data	6 14	36.1 34.0	35.1
processing, analysing and interpreting data	8 17	60.5 40.6	50.6
describing relationships between variables	9 18	41.5 26.6	34.1
formulating generalizations	10 19	38.9 32.9	35.9
drawing conclusions	11 20	19.6 18.2	18.9

Pupils achieved the lowest mean score in items measuring skills such as drawing conclusions (18.9 %), observing (29.1 %), and designing experiment or observation (31.1 %). To identify problematic aspects of these skills, we analysed the frequency of the most common pupils' mistakes. When pupils draw the conclusion, they often did not provide a summary of the experiment and a clear answer to the research question specified in the stem of items (Tab. 3).

Table 3: Frequency of incorrect answers to items related to the drawing conclusion

Incorrect answers	**Frequency**	
	Item 11	**Item 20**
there is no clear answer to the research question specified in the stem of item	31.9 %	17.9 %
there is no summary of the experiment	28.0 %	27.1 %
there is an incorrect answer to the research questions specified in the stem of item	4.3 %	6.8 %

Pupils did not describe their observations compactly and they often did not notice important elements of observations in the items focused on observing the pictures capturing to run of simple experiments. The pupils did not report significant data in their observation, such as the duration of the experiment, the change in temperature, the change in colour of the solutions and so on. On the contrary, they often described only the principle of the experiment, the procedure of the experiment or the research question. Some pupils even thought that water was boiled in the test tube, although the temperature was approximately 23 °C, and the observed bubbles were formed due to the release of oxygen during the photosynthesis process (Tab. 4).

Table 4: Frequency of incorrect answers to items related to the observation

Incorrect answers	**Frequency**	
	Item 5	**Item 13**
there is no experiment duration	75.8 %	70.5 %
there is no temperature or change in the temperature	8.2 %	61.8 %
there is no change in the colour of the solutions	38.2 %	17.9 %
only the principle, procedure, or research question is described	2.9 %	5.8 %
recording of boiling water already at a temperature of 23 °C	-	4.8 %

In item 3, pupils were to design an experiment that would demonstrate the effect of ambient temperature and humidity on mould growth. Pupils often did not design any control of variables, did not separate variables, or omitted one of the variables altogether (Tab. 5). In item 15, pupils had to choose one of the three factors (temperature, oxygen, water) that affect the germination of pea seeds, and based on their choice, they had to design a suitable experiment. In solving this item, pupils did not control variables, often not realizing that when they choose one factor, which influences germination, other factors must be constant, or did not suggest the design of the experiment, but only a principle or explanation. Some pupils even added their own factor, the light needed for photosynthesis (Tab. 5).

Table 5: Frequency of incorrect answers to items related to the designing experiment or observation

Incorrect answers	**Frequency**	
	Item 3	**Item 15**
there is no control of variables	79.2 %	37.7 %
there is no separation of individual variables	56.5 %	-
one of the variables is missing	25.1 %	-
only the principle or explanation is described	8.2 %	12.6 %
there is no describing of the remaining factors as constant variables	-	37.2 %
the light required for photosynthesis is described as a seed germination factor	-	3.3 %

5.2 Level of selected inquiry skills of the pupils regarding gender, age, and mark of biology

From the test results, we also found out there is a statistically significant difference between the level of inquiry skills among girls and boys. Although girls achieved a slightly higher mean score (x = 18.1, SD = 8.2) than boys (x = 16.7, SD = 9.4), the Mann-Whitney (Wilcoxon) test did not show a statistically significant difference at the level of significance 95 % between gender of pupils and their level of inquiry skills (W = 5717.5, p = 0.4).

We observed a similar result with respect to the age (grade) of pupils. Pupils who have reached the age of 14 and attend the 8th grade of primary school have achieved a higher mean score in the test (x = 18.6, SD = 8.8) than 13 years old pupils of the 7th grade (x = 16.1, SD = 9.1) and 15 years old pupils of the 9th grade (x = 17.6, SD = 8.4). However, the Kruskal-Wallis test did not show a statistically significant difference at the level of significance 95 % between the age of pupils and level of their inquiry skills (KW = 3.5, p = 0.2).

As a part of our research, we also found out whether pupils with better marks on a biology certificate are more successful in the test measuring inquiry skills than the pupils with worse marks. Spearman's correlation coefficient showed a moderately strong negative statistically significant dependence (Cohen, 1988) on the level of significance 95 % (R = - 0.4; $p < 0.05$), which suggests that pupils with worse marks were more successful in the test than pupils with better marks.

6 Discussion and conclusion

In the Slovak education system, an increasing effort is being made to implement IBSE in the teaching of science subjects, as it provides the development of pupils' scientific literacy (e.g., Wen et al., 2020; Ristanto et al., 2017). While developing scientific literacy, we should focus on acquiring knowledge, science concepts and on developing skills that provide pupils to lead and understand scientific research (OECD, 2019). According to Wenning (2012), younger pupils should first acquire basic skills. Research results among 13-15 years old primary school pupils showed that they achieved a below-average level in the selected inquiry skills. In contrast to the results achieved in measuring similar inquiry skills in the 10-16 years old Estonian pupils (Mäeots & Pedaste, 2014), Slovak pupils achieved a much lower score. The absence of inquiry skills among pupils in primary schools can lead to the failure of students in its application to solving problems through scientific methods and processes in higher education levels. This statement is also supported by research conducted at secondary schools (e.g., Ješková et al., 2021; Čipková et al., 2020; Ješková, et al., 2016) and universities (Čipková & Karolčík, 2018), which declared a relatively low level of inquiry skills among pupils and students.

By more detailed analysis of the results, we found that in only two skills pupils achieved a mean score higher than 50 %. These were the skills focused on identifying a dependent and independent variable and processing, analysing and interpreting data. However, a comparison of individual items shows that pupils achieved a low mean score in the analysis and interpretation of data from the graph, which is also identified by Ješková et al. (2016) among older students. Glazer (2011) identified that the correct interpretation of graphs is essential for understanding the present world and developing scientific literacy. We found a similar difference between the items focused on the identification of variables. Pupils achieved a worse mean score in identifying a dependent variable than in identifying an independent variable. Even though this skill is considered problematic among pupils (NRC, 1996), it is necessary to be able to identify both variables to design and conduct the experiment (Padilla, 1991).

Pupils achieved the lowest mean score in items measuring skills such as drawing conclusions, observing, and designing experiment or observation. The low level of these skills surprised us because each of them is firmly incorporated in the national curriculum of science subjects (ŠPÚ, 2014, A; ŠPÚ, 2014, B; ŠPÚ, 2014, C). We found that although pupils were able to interpret data from a graph or table correctly, they could not use these data to formulate relevant conclusions, which is a problem among older students, too (Čipková et al., 2020). Pupils often had problems with controlling and separating various variables in the skill to design an experiment. NRC (1996) identifies this problematic aspect for pupils in a similar age category. In the item in which pupils had to design the experiment proving the effect of water, temperature, or oxygen on pea germination, some of them added the light needed for photosynthesis as the key seed germination factor. According to Lin (2004), this is a common misconception among pupils.

The results did not show a statistically significant difference between the gender and the level of inquiry skills among pupils. It indicates a positive advance moving in overcoming gender stereotypes in the science education process. Similar results among the older pupils were obtained by Čipková et al. (2020) and Ješková et al. (2016). There was also no statistically significant difference between the age and level of inquiry skills among pupils. Due to the low level of acquired skills, we believe that these skills are not systematically developed in individual grades for primary school pupils. Ješková et al. (2016) also obtained similar results among older students. However, research at German schools has shown the different results, older students in higher grades have a higher level of inquiry skills (Kremer et al., 2014).

The pupils' marks on the certificate should reflect their level of knowledge and skills demonstrated in the concrete subject for half-year. The results suggest that pupils who had a worse mark on the certificate were more successful in solving the test than pupils with a better mark on the certificate. We assume that a lot of teachers have still emphasized assessing knowledge than assessing pupils' skills, which could explain our obtained results. Paper by Sotáková et al. (2020) shows that the revision of the teaching lessons through IBSE led to the best development of scientific knowledge and skills among 13-14 years old pupils with worse marks on the last certificate. It is indicated that the implementation of inquiry in science education can motivate worse students to better academic results, and thus break down traditional stereotypes in testing and subsequent evaluation of only mechanically remembered knowledge. Harrison (2014) also draws attention to the need to create a functional evaluation system for evaluating pupils' inquiry activities.

It is necessary to apply inquiry activities into science education systematically and to provide feedback to pupils on their development of inquiry skills regularly. The use of the test with open-ended items has some limits, for example, it cannot be used on a larger sample of pupils because its administration and evaluation are time-consuming (Reiner et al., 2002). However, by analysing the original and unexpected pupils' answers, we found how pupils think about solving test items applying selected inquiry skills, and we created a database of distractors that we can use to create a multiple-choice standardized test, which can remove this limit.

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