REVIJA ZA ELEMENTARNO IZOBRAŽEVANJE
JOURNAL OF ELEMENTARY EDUCATION
Vol. 17, No. 2, pp. 223–239, June 2024

METACOGNITIVE SKILLS OF PUPILS IN PRIMARY MATHEMATICS EDUCATION

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Potrjeno/Accepted
27. 2. 2024

Objavljeno/Published
27. 6. 2024

Izvleček/Abstract

In educational theory and research, metacognition is increasingly seen as an important predictor of successful learning – it is the key to learning and academic achievement. The study investigates "off-line" metacognition (i.e. the level of prediction and the level of self-evaluation) in relation to the solving of mathematical problems by primary school pupils. The research was carried out on a group of 311 pupils of 16 classes of primary schools. We used the test consisting of five tasks, which also included questions aimed at finding out the level of pupils' prediction and their level of self-evaluation. We processed the obtained data with the intentions of a quantitative methodological approach. It follows from the research findings that students who were successful in solving the tasks achieved a higher level of prediction and self-assessment than students who were not successful.

Keywords:
Metacognition, prediction, self-evaluation, solving of problems.

Metakognitivne spretnosti učencev v primarnem matematičnem izobraževanje

V izobraževalni teoriji in raziskavah se metakognicija vedno bolj obravnava kot pomemben napovednik uspešnega učenja – je ključ do učenja in akademskih dosežkov. Študija raziskuje »off-line« metakognicijo (tj. raven napovedovanja in raven samoevalvacije) v povezavi z reševanjem matematičnih problemov osnovnošolcev. Raziskava je bila izvedena na skupini 311 učencev 16 razredov osnovnih šol. Uporabili smo test, sestavljen iz petih nalog, ki so vključevale tudi vprašanja, s katerimi smo želeli ugotoviti stopnjo napovedovanja in stopnjo samoevalvacije učencev. Uporabili smo metodologijo kvantitativnega pedagoškega raziskovanja. Iz ugotovitev raziskave izhaja, da so učenci, ki so bili uspešni pri reševanju nalog, dosegli višjo stopnjo napovedovanja in samoocenjevanja kot učenci, ki so bili pri reševanju nalog neuspešni.

Ključne besede:
komunikacijski pouk, šolska interpretacija, književno besedilo, interpretativno branje, pogledi učiteljev.

UDK/UDC:
37.015.3:51

DOI https://doi.org/10.18690/rei.3274

University of Maribor Press

Introduction

The study focuses on the issue of metacognition in primary school pupils. In our previous research, we indicated the possible use of metacognition when solving tasks from the Mathematical Kangaroo competition (Nováková, 2018). This international contest, coordinated by the Center Association Kangourou sans frontières (AKSF), based in Paris, is intended for pupils aged 8-18. More than 3 million solvers in more than 60 countries across the world register each year. The competition is unique since, on the same day, all participants in their respective age categories solve the same tasks. In the Czech Republic, approximately 300,000 participants take part every year; in the Ècolier category (4th and 5th graders of primary school) almost 70,000 pupils participate. The author of this study is a guarantor of the pre-ècolier category in the Czech Republic (Nováková, 2016). It was the findings from that analysis that inspired us to prepare and implement this research.

Solving tasks from the Mathematical Kangaroo contest is indeed a useful means of assessing prediction accuracy and pupil self-evaluation. This is facilitated by the scoring system used in the competition. At the beginning of the problem-solving session, each pupil is awarded 24 points. For each incorrect solution, the pupil loses 1 point, while each correct solution earns a corresponding number of points based on the difficulty of the task (3, 4, or 5 points).

Prediction is used in this competition at the point when pupils read the problem and consider whether to start solving it or to evaluate the problem as too difficult, or time-consuming and to continue solving another problem. The competition has a time limit, which is why participants must decide which problems to solve. Self-assessment also has its place in this competition. After pupils solve respective problems, they decide whether the solutions are correct. If yes, they write them into the answer sheet. Even when a participant successfully solves a given problem, there is the option available not to record their answer, skipping it and not earning the corresponding points. We believe that this metacognitive strategy is not limited to one specific contest but can to some extent manifest itself when solving problems on any school test, not only a mathematical one. Anticipating, monitoring, and self-assessment as part of the metacognitive process can have a significant impact on the pupil's success in a test (Duckworth et al., 2009).

In our study, we have linked problem solving to a more general issue of metacognition, i.e., "the ability to reflect on one's own thinking processes and ways to improve one's thinking" (Sternberg, 2002, p. 215), because we believe that this connection has a scholarly foundation (Schoenfeld, 1992).

Theoretical framework and background

The concept of metacognition was first introduced in developmental psychology by Flavell (1979), who coined the theoretical construct and defined aspects of metacognition related to an individual's own cognitive processes. Since then, the concept of metacognition has continued to evolve and has begun to appear more and more frequently in educational theory and research, primarily because it has come to be seen as a significant predictor of successful learning.

Previous research in the field of metacognition was influenced by the contemporary paradigm of the development of cognitive functions, as proposed by Jean Piaget. It was not assumed that children who had not yet reached the stage of formal operations could develop metacognitive skills. Based on this paradigm, metacognition was considered a skill that developed later in life, which was related to pupils' inability to detect hidden meanings or subtexts, or to make inferences. Flavell (1979) pointed out the egocentrism of younger children, which prevented them from treating their own thinking process as an object of thought. However, the earlier assumption that metacognitive skills did not develop in children before the age of 10-12 is now frequently debated and challenged (Hrbáčková, 2011). Critics of Piaget argue that changes in children's cognitive processes occur not only because of maturation but also through learning, gaining experience, or systematic training (a summary of critical views is provided, e.g., by Hrbáčková, 2011).

More recent research findings support the claim that metacognition develops at a much younger age than previously thought and provide models for assessing early metacognition, executive function, and motivation (Marulis and Nelson, 2021).

For the development of advancements during school education, there is considerable empirical evidence showing that self-assessment knowledge begins to develop during the first two years of school attendance (Annevirta et al., 2007). On the other hand, the development of metacognitive knowledge about more complex learning processes (such as the deployment and effectiveness of strategies) occurs later and is not completed even by the end of primary education (Fritz et al., 2010). Azevedo (2009) emphasizes that we cannot view the development of metacognition in a linear or hierarchical manner; the process of forming metacognition is long-term and gradual. Given the unique individuality of each person, it takes varying amounts of time and takes on an original form (Vališová and Kasíková, 2010). According to Vygotsky (2004), children under the age of ten can regulate their own learning processes. They can focus their attention to control and direct their own activities. Parents, teachers, and other people in the child's environment can make significant contributions to this process by taking gradual action to facilitate the child's learning (Duckworth et al., 2009; Sternberg, 2002). Research also confirms (Perry and Drummond, 2002; Perry et al., 2002; Perry et al., 2003) that elements of self-regulated behaviour, such as planning, monitoring, problem-solving, and evaluation, emerge in children under the age of ten when working on complex tasks related to reading and writing. Research on metacognition and self-regulation in primary school students is rarely reported, and their occurrence is not well elaborated, although some authors – Bryce et al. (2015); Hrbáčková (2011); Larkin (2010) or Perry and Drummond (2002) – suggest that even younger school-age pupils may reach a certain level of metacognition, being able to plan, monitor and evaluate their own learning. This to some extent relates to the accelerated thinking that occurs as children adapt to new demands upon starting their school education (Říčan, 2017).

Metacognition is considered a key factor in cognitive processing of information and in constructivist learning theory (Cano et al., 2014; Lokajíčková, 2014). Research on learning efficiency shows that metacognitive experiences influence children's subsequent success in school and outside (Duckworth et al.; 2009; Larkin, 2010; Lawson and Farah, 2017; Rodek, 2019). In Rozencwajg's (2003, p. 289) view, "teaching metacognitive strategies could be one way to improve pupils' school/academic success".

One line of research addresses the use of metacognitive strategies in problem solving, which includes tasks in mathematics (Schneider and Artelt, 2010; Silver, 1987) and other sciences built on exact research (biology, physics, chemistry (Listiana et al., 2016)).

Findings from empirical research demonstrate that through systematic practice, students' metacognitive potential can be developed. The intervention leads to significant positive changes in participating subjects (Schraw, 1998; Schleifer and Dull, 2009; Susantini et al., 2018).

Elements of self-regulatory and metacognitive problem-solving behaviour and their evaluation are also noted elsewhere (Perry et al., 2003; Perry and Drummond, 2002; Hnátová and Mokriš, 2020). These show that individuals assess the relative adequacy and effectiveness of the strategy in relation to themselves and to demands of the task. According to Flavell (Dawson, 2008), self-knowledge relates to knowledge about oneself, the nature of the task, and the strategies. Among the most often used methods for detecting the level of metacognitive knowledge and skills attained are self-assessment instruments capturing the frequency of metacognitive behavioural manifestations based on a dichotomous approach (item appeared × item did not appear) or on a specific response scale (Luciano et al., 2004).

In the context of our research, metacognition will be understood as a set of abilities and skills of learners to become aware of their own cognitive (learning) activities, and to predict and evaluate the procedures applied when exposed to a learning/teaching situation (Didau, 2018). Reflection on one's own activity is reflection "on action", which Desoete (2001) refers to as "off-line" metacognition. He includes two metacognitive skills among the elements of "off-line" metacognition: prediction (anticipation) and self-evaluation. In our research, the level of prediction and self-evaluation has been investigated in conjunction with solving routine and non-routine mathematical word problems. We were interested in whether students who achieve different levels of success in solving problems differ in their levels of prediction and self-assessment.

Methods

Aim, research question and research hypothesis

The aim of the research was to investigate the level of "off-line" metacognition (i.e., the level of prediction and the level of self-evaluation) among 5th-grade primary school pupils in solving routine and non-routine (non-standard) problems.

The following research questions and their related hypotheses were posed:

1) What is the level of prediction and self-assessment among pupils in the 5th grade of elementary school when solving problems?

H_1: There will be significant differences in the prediction and self-evaluation of individual pupils. A higher level of prediction and self-evaluation will be achieved in routine tasks than in non-routine tasks.

2) How does the level of prediction and self-assessment among 5th-grade elementary school pupils differ depending on the success in solving problems?

H_2: Pupils who are successful in solving tasks will achieve a significantly higher level of prediction and self-evaluation than unsuccessful pupils.

When formulating research questions and hypotheses, we operationalized the following variables:

a) Pupils' performance as their success rate at solving problems: the total number (sum) of points from the solution of a competition test consisting of 5 tasks. A correct answer was evaluated by 2 points, partially correct by 1 point, an incorrect or missing answer by 0 points. Each respondent could gain a maximum of 10 points. Based on the success rate, solvers were divided into successful (10–6 points) and unsuccessful (5–0 points).
b) Prediction rate of pupils related to solution of problems, i.e., comparison of perceived ability and actual performance (max. 10 points),
c) Level of pupils' self-evaluation, i.e. comparison of the subsequent perception of success in solving problems and actual performance (max. 10 points).

Research design: participants, research method

The research was conducted on a sample of 311 pupils in 16 primary school classes. We used a test consisting of five tasks (2 routine ones, 3 non-routine/non-standard ones), which also included questions aimed at determining the level of prediction of the pupils and their level of self-evaluation as a basic research technique.

Routine tasks:

1) *Georg bought 5 two-meter planks. How many meter boards can he cut from them?*
2) *Jana likes walking. This morning, she walked 12 km, which was 3 km more than in the afternoon. How many kilometres did Jana walk that day?*

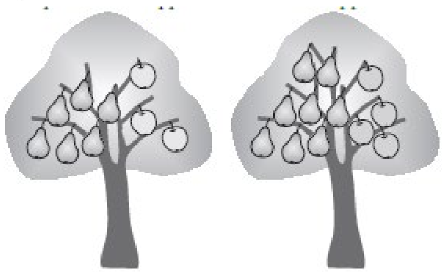
Routine tasks with a real-life context. The solution requires performing arithmetic operations.

Non-routine tasks (taken from the test of the Mathematical Kangaroo competition):

3) Guests arrived at the castle celebration in black and white carriages. The colours of the carriages alternated regularly: black, white, black, white,... Each black carriage was pulled by *a black horse, each white carriage was pulled by two white horses. A total of 15 horses pulled all the carriages. How many of them were white?*

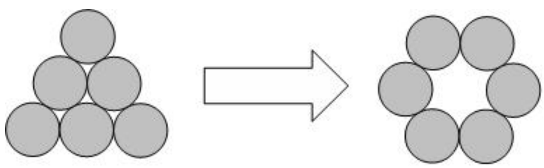
Solving the task does not require any demanding mathematical knowledge and skills. It is based on the idea of "rhythmic alternation" of the number of horses pulling the carriage: 1 + 2 + 1 + 2 +...= 15.

4) In a magic garden, there grow two kinds of magic trees. On the trees of one kind there grow 6 pears and 3 apples; on the trees of the other kind there are 8 pears and 4 apples. The sum of apples in the garden is 25. How many pears are there?



The solution is based on an intuitive understanding of direct proportionality. Every magic tree has twice as many pears as apples, so there must be twice as many pears on all the trees in the whole garden, i.e. 50.

5) Charles placed 6 identical coins in the shape of a triangle (as in the figure on the left). What is the least number of coins he had to move so that the coins formed a circle depicted in the second figure?



Solving the task is based on mental manipulation, requires spatial imagination by the solver and respect for the condition in the assignment ("...least number of coins").

Instructions for pupils:

1. *In the test, you will find some mathematical problems. Read all the tasks from 1 to 5, but do not try to solve them yet.*
2. *Try to anticipate whether you can solve each task. Tick for every task your prediction. Move from task 1 to task 5.*
3. *Now, try to solve the tasks. Under the wording of each task, write your solution.*
4. *Finally, tick the answer in the table indicating how you think you solved each task. Proceed again from task 1 to task 5.*

To each task in the test, one question has been assigned connected with prediction and one question connected with self-evaluation, which made a total of 5 questions examining the degree of prediction and 5 questions examining the level of self-evaluation. When evaluating the degree of prediction and self-evaluation, we did not consider the sum of points ticked by the pupils on the scale (i.e., their subjectively perceived value), but the real measure of their prediction and self-evaluation. This means that we compared the prediction with their actual performance in solving test tasks (in each task separately). For example, if a given pupil anticipated solving the task correctly and indeed, he did, then the pupil was awarded 2 points. If a pupil considered his correct solution as probable only and solved the task correctly, then the pupil was awarded 1 point. When pupils were sure that the task was solved correctly yet were wrong in fact, no point was awarded. The relationship between prediction and pupils' actual success on the task (score prediction rate) is described in Table1.

Table 1. Relation between prediction and actual pupil performance.

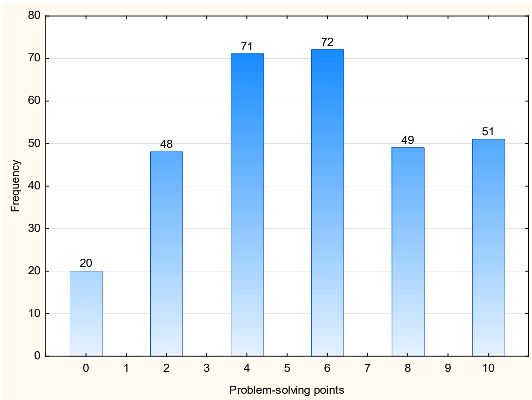
Prediction	Performance	
	Correct solution	Incorrect or no solution
I will definitely solve the task correctly	2	0
I probably will solve the task correctly	1	0
I probably won't solve the task correctly	0	1
I definitely won't solve the task correctly	0	2

Analogically, we proceeded in terms of the relation between pupil's self-evaluation, made immediately after solving the problem, and real performance.

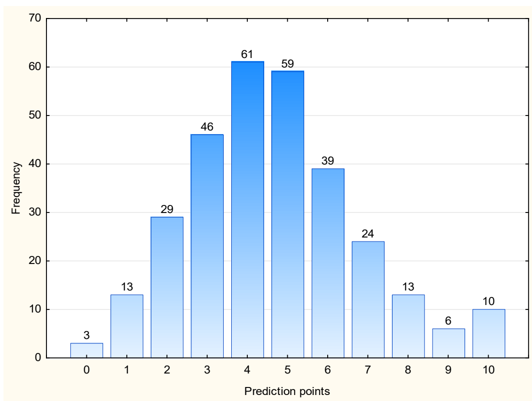
Research results

The data was processed through a quantitative methodological approach. Statistical methods and procedures were used to process the research results. The data was recorded in tables in which we expressed absolute and relative frequencies. Box plots were added for easier interpretation. We used methods of mathematical statistics (Student's t-test, Wilcoxon test) to find answers to our research questions and to test the stated hypotheses (StatSoft, Inc., 2013).

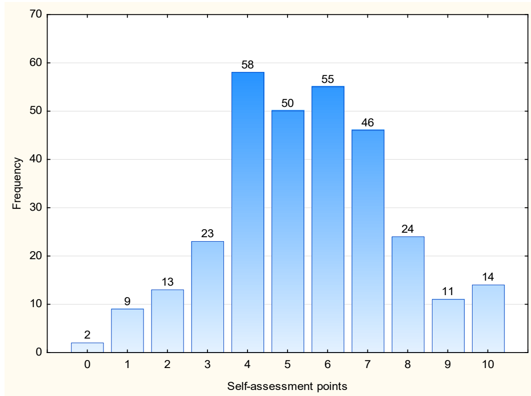
The research found a low level of success in solving the test word problems - an average success rate of 5.5 out of 10 possible points. Only 51 solvers (16.4 %) solved all problems correctly, 20 solvers (6.4 %) did not solve any problem correctly. There were 172 successful solvers (with 10–6 points) and 139 unsuccessful solvers (with 5–0 points). The average success rate for routine problems was 3.0 (out of a maximum of 4 points, i.e. 75.0 %), and for non-routine problems 2.5 (out of a maximum of 6 points, i.e. 41.8 %).



Graph 1. Bar chart of problem-solving points for all five tasks.



Graph 2. Bar chart of prediction points for all five tasks.



Graph 3. Bar chart of self-assessment points for all five tasks.

The relation between the success rate on routine and non-routine tasks is expressed by the contingency table.

Table 2. The relation between success in solving routine and non-routine tasks.

Contingency table				
non-routine points	routine points both tasks wrong	routine points just one task correctly	routine points both tasks correctly	row totals
all tasks wrong	20	43	31	94
only one task correctly	5	39	55	99
only two tasks correctly	1	17	45	63
all tasks correctly	0	4	51	55
all groups	26	103	182	311

To research question 1

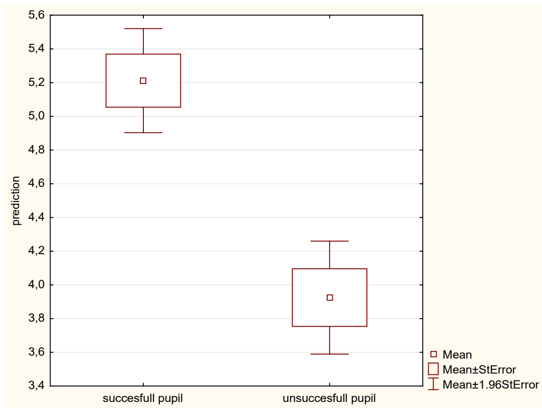
Prediction and self-evaluation scores are relatively low, with self-evaluation scores higher than prediction scores. The overall prediction level averaged 4.6 out of 10 points, and the overall self-evaluation level reached an average value of 5.5 out of 10 points.

To research question 2:

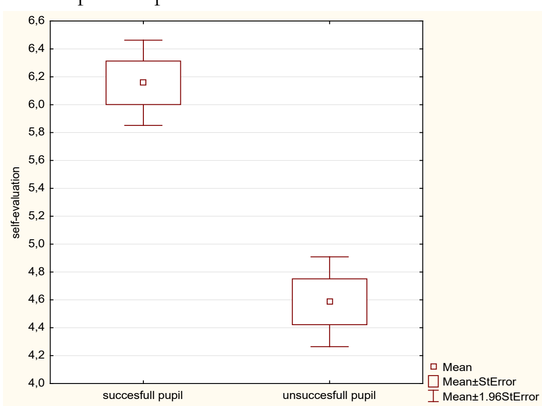
The numbers of points obtained for solution, prediction, and self-evaluation in the groups of successful and unsuccessful students are shown in the table and box plots.

Table 3. The average number of points for solution, prediction, and self-evaluation and the number of successful and unsuccessful pupils.

The variable	mean successful (%)	mean unsuccessful (%)	number successful	number unsuccessful
points solution	7.76	2.73	172	139
points prediction	5.21	3.92	170	133
points self-evaluation	6.16	4.59	172	133



Graph 6. Box plot for prediction of successful and unsuccessful pupils.



Graph 7. Box plot for self-evaluation of successful and unsuccessful pupils.

Hypothesis H_2: "The level of prediction or self-evaluation of successful pupils is at most equal to the level of prediction or self-evaluation of unsuccessful pupils" for research question 2 was tested with a two-sample Student's t-test. Testing was performed at the 0.05 significance level. The test statistic for the level of prediction takes the value of 5.5093, and the corresponding p-value for the right-sided test is close to 0. We have shown that the *prediction rate of successful pupils is higher than prediction of unsuccessful pupils*. The test statistic for the *self-evaluation level* takes the value of 6.8661, while the corresponding p-value for the right-sided test is close to 0. We show that the *level of self-evaluation among successful pupils is higher than the level of self-evaluation among unsuccessful pupils*.

Discussion, limits, and conclusions

The success rate in solving the problems was low. This could be because the solution required comprehension of the worded task in the open-ended test problems. Non-routine (non-standard) problems were solved with a significantly lower success rate of 41.8%, compared to the 75.0% correct solutions to routine problems. When solving word problems at school, pupils use the mathematical apparatus as they have learned, without considering the actual logic of the problem, which is confirmed by some foreign research (Verschaffel et al., 2000). The wording of the conditions and questions in non-routine problems (see our sample) was more complicated, more difficult to comprehend. The results lead us to confirm the view, reflecting the previous experience from Czech (Vondrová et al., 2019) and foreign (Swoboda, 2014) research, but also from the educational practice in elementary schools – that solving non-routine problems is not among the common and frequent activities in mathematics education.

For our study, we have chosen to explore the link between metacognition and solving mathematical problems. Mathematics, much like metacognition, is based on critical thinking, creativity, and ingenuity; it has the potential to enhance pupils' learning and create a "mathematical culture" that is supported by metacognition. Schoenfeld (1992) believes that the "microcosm of mathematical culture" encourages pupils to think about mathematics as an integral part of their everyday lives.

Callan and Cleary (2019) found that in terms of predictive influences, pupils' strategic planning, strategy use, and metacognitive monitoring were significantly and positively correlated with mathematics performance, with strategy use and metacognitive monitoring emerging as unique predictors of performance. In their research, Nelson and Fyfe (2019) investigated the metacognitive regulation (monitoring) of elementary school children in connection with mathematical equivalence problems, their ability to control their behaviour through strategic decisions when solving tasks. The results showed significant individual differences that were positively correlated with children's knowledge of mathematical equivalence.

As in the findings from our earlier research (Nováková, 2018; Nováková and Budíková, 2023) our expectations were confirmed that successful word problem solvers would achieve significantly higher levels of prediction and self-evaluation than unsuccessful ones. For non-routine tasks, the differences were even more significant than for routine tasks. We attribute these findings to the fact that by successfully solving non-routine tasks, pupils demonstrate a higher level of cognitive function, along with logical and critical thinking. Although such pupils do not have enough experience with systematic application of metacognitive skills by the end of primary education because metacognitive processes are used to only a limited extent by primary school pupils (Larkin, 2010), it is possible to assume a higher metacognitive potential, which in our research could be manifested.

We are aware of the limitations of our findings. Features of our research and the sample size of respondents do not allow for unambiguous categorical judgments. We did not analyse the influence of other potential variables that could intervene in the success rate at problem solving, the prediction rate and the level of self-evaluation: the personal characteristics of the respondents – gender, mathematics achievement, mathematics liking, the type and nature of the problem solved, its difficulty, the topic, or the way the problem was presented. Nevertheless, we believe that the topic of our research is current and can be further developed. However, these findings can, in our opinion, definitely be considered an impetus and inspiration, since in the Czech context, there is still a lack of research focusing on assessing the level of metacognition among primary school pupils.

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