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Изследователски проникновения

DEVELOPMENT OF METACOGNITIVE SKILLS IN 11 – 14-YEAR-OLD STUDENTS IN A NON-FORMAL EDUCATIONAL ENVIRONMENT

Dr. Isa Hadjiali, Assoc. Prof.
Sofia University "St. Kliment Ohridski" (Bulgaria)
Dr. Teodora Kolarova, Assoc. Prof.
University of Plovdiv "Paisii Hilendarski" (Bulgaria)

Abstract. The purpose of this study was to determine and assess the impact of non-formal educational activities on the development of metacognitive skills in middle school students (11- to 14-year-old). The research was conducted with 48 students (N= 48) from 5th-grade to 7th-grade classes at urban public middle schools in Gabrovo and Sofia (Bulgaria). The participants were divided into two groups – experimental group (n = 22) and control group (n = 26). Both groups were assigned to study the same biology learning content during the school year 2021/2022 but under different conditions. The students in the experimental group were explicitly taught metacognitive skills focused on using the strategy of "variables control", while performing scientific inquiry in non-formal setting – in a Children's University Foundation. The students in the control group were taught biology topics in a traditional classroom environment without application of metacognitive strategies during the scientific inquiry. Quantitative measures and statistical methods (SPSS) were employed to analyze the data related to participants metacognitive skills (planning, monitoring and evaluation). The results showed that the quality of metacognitive skills exhibited by the experimental group exceeded that of a control group, highlighting the power of non-formal education as a valuable mechanism in the development of students' metacognition.
Keywords: metacognitive skills; von-formal education; strategies; tasks

Introduction

Today has been a general agreement among researchers that metacognitive knowledge and metacognitive skills can be taught, and that such training often results in substantial improvements in student learning (Linn & Bat-Sheva 2006; Veenman 2012). Studies in science education showed that the metacognitive instruction enhances students' outcomes in learning (Anderson & Nashon 2007; Kimberly 2012; Stanton et al. 2021) and increases the performance of the lowest level achievers by helping them manage their thinking (White & Frederiksen 1998; Zohar & Peled 2008). Engaging students in metacognition might help students to recognize their reductive biases, learn the science more deeply, and transfer it more readily (Grotzer & Mittlefehldt 2012). Further, infusing metacognitive activities and strategies into a science learning program improves self-regulation (Blank 2000) and fosters developing of higher order thinking among school students (Zohar & David 2008). In disciplinary science learning in particular, studies indicated that in biology, for example: awareness of the learning process and a stronger ability to monitor, regulate and control the learning contributed to meaningful understanding of various biology concepts and improved scientific inquiry skills (Eilam & Reiter 2014; Zion et al. 2005). However, the vast majority of these investigations were conducted on school students in formal science education; whereas few studies examined the effect of metacognitive training in the context of informal science learning (Chen et al. 2022; Schraw et al. 2011). In the current study we examined whether an explicit training in metacognitive strategies might help middle school students to develop metacognitive skills (planning, monitoring and evaluation) in a non-formal educational setting.

Theoretical Background

Metacognition

The concept "metacognition" was introduced by J. Flavell (Flavell 1979). The author defines metacognition as the ability to analyse one's own strategies for thinking and the management of one's own cognitive activity. Flavel distinguished two general constructs of metacognition – metacognitive knowledge and metacognitive monitoring and self-regulation. Other researchers (Pintrich 2002; Schraw et al. 2006; Veenman 2012) made similar distinctions between knowledge of cognitive activities and regulation of such activities as two components of metacognition. The latter component is also named as metacognitive skills.

Metacognitive knowledge is often characterized by scholars as knowledge of cognition and refers to what we know about our cognition. Metacognitive knowledge usually includes three interrelated sub-categories: 1) knowledge about person; 2) knowledge about task and 3) knowledge about strategies applied to the solution of different tasks. The first, declarative knowledge, includes knowledge "about" oneself as a learner and what factors influence one's performance (Flavell 1979; Schraw et al. 2006). Knowledge of tasks is conditional knowledge and refers to understanding how the nature of task conditions, demands and goals affects cognitive activity. It is therefore closely related to the "when" and "why" components of metacognitive knowledge (Zohar & David 2008). Finally, procedural knowledge, includes knowledge about specific cognitive strategies and other procedures that might be used for various learning tasks. It is closely related to the "how" component of metacognitive knowledge (Flavell 1979; 1985; 1987; Pintrich 2002; Schraw et al. 2006; 2011).

Metacognitive skills are the skills and processes used to monitor, control and regulate activities that take place when learning and solving problems (Veenman 2012). In our research, the focus lies on the second component of metacognition, i.e. the student's metacognitive skills during non-formal learning. Metacognitive skills can be viewed as a process of self-instructions for the regulation of task performance or as the executive component of metacognition. They are critical for managing thinking processes and provide the link between meta-level knowledge of strategies and tasks and cognitive performance (Schraw et al. 2006; 2011; Veenman 2012).

Regulation of one's own cognition typically includes at least *three essential skill* categories: planning, monitoring, and evaluation (Schraw et al. 2006; 2011; Veenman 2012). *Planning* involves setting goals, activating relevant background knowledge, selecting appropriate strategies, and allocating time and resources. *Monitoring* includes the process by which an individual oversees his or her cognitive state or thinking process. *Evaluation* refers to assessing of the products and efficiency of one's learning and thinking (Schraw et al. 2006; Zohar & Barzilai 2015).

Recent studies indicate that metacognitive skills are initially developed within specific tasks and domains, and later on become generalized across multiple domains (Veenman 2012). The general nature of metacognitive skills suggested that they might more readily transfer to new learning tasks and domains. However, development of these skills occurs gradually and some learners may not spontaneously acquire them. Therefore, Veenman proposes three fundamental principles for the successful instruction of metacognitive skills, called WWW&H rules (What to do, When, Why, and How): learners should be instructed, modeled and trained *when* to apply *what* skills, *why* and *how* in the context of the task (Veenman 2012). Any effective instructional program abides with these three principles.

Skill and Task

The system of skills in the present material is constructed on the basis of B. Bloom's revised taxonomy (Anderson & Krathwohl 2011), which contains four general knowledge categories (levels): factual, conceptual, procedural, and metacognitive (Figure 1). While the first three categories were included in the original taxonomy, the metacognitive knowledge level was added. The cognitive processes that learners use to monitor, control and regulate their cognition fit under the six processes categories in the revised taxonomy. Since the objectives of the taxonomy are universal in nature, it can be applied to the instruction of all subject matters, and specifically in the teaching of "Human and Nature" (5^{th} – 6^{th} grade) and "Biology and Health education" (7^{th}-grade). By utilising Bloom's revised taxonomy any learning activity can be represented as a combination of a type of knowledge and a corresponding level of the cognitive process (Anderson & Krathwohl 2011).

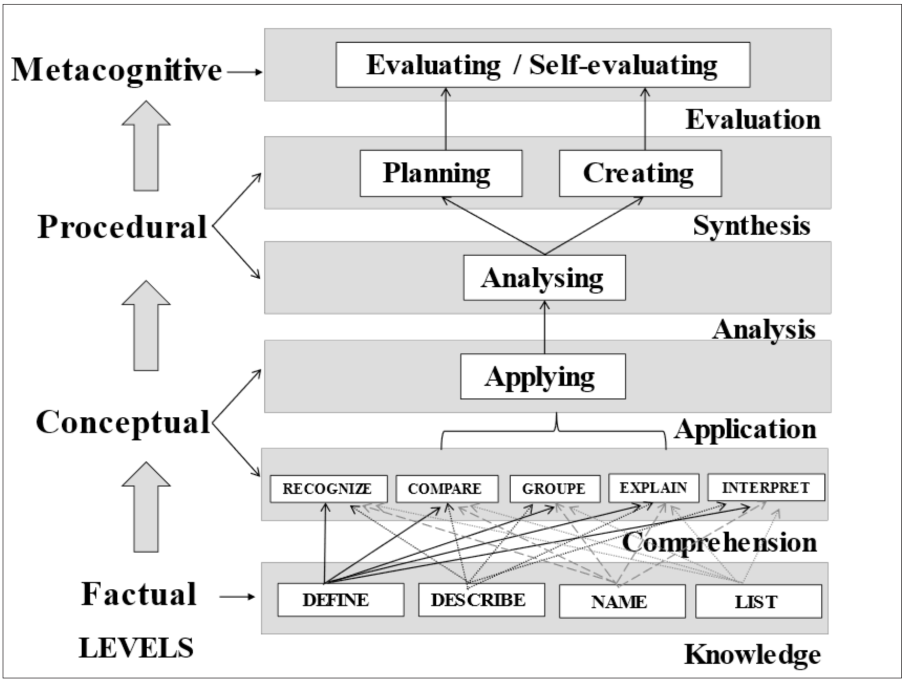


Figure 1. B. Bloom's revised taxonomy –
adapted from Anderson and Krathwohl (2001)

At its core, the task has its own interpretation in the subject fields of the sciences related to Methodology of Biology Education, such as logic, psychology and pedagogy. This means that definition occurs in different micro-territories of the task area, which influences choice – both its generic affiliation and the signs of its type specificity. The concepts which are most often applied when decoding the essence of the task are: problem situation, goal, situation model: (a) the task is the goal of the activity, given under certain conditions and requiring adequate means to achieve it; (b) the task is a model of a problem situation; (c) a study task is a symbolic model of a study situation (Müller & Brown 2022). The construction and implementation of tasks for a pedagogical purpose (educational and cognitive tasks) provides the opportunity to "shorten" the process of gaining experience (variants and possibilities of the person to deal with different situations, including problem ones).

The "experience" of various task mechanisms is "cleaned", presented in a model form, controlled, from the point of view of a sought-after solution with a certain formative effect for the person. This applies both to tasks close to real-life situations and to tasks remote from real life (artificial tasks). Task-solving is a factor in building new mental constructs which could not otherwise be formed. Their positive effect on the development of metacognitive (reflective) skills in the context of a purposefully organised learning process has been proven in a number of studies (Dimova 2011; Kuhn 2000; Millar & Osborne 1998; Vasilev et al. 2010; Zohar & Peled 2008; Zohar & David 2008).

Examining the task in the context of metacognitive knowledge is impossible without revealing its relations with mutually dependent phenomena such as metacognitive regulation, planning, monitoring and assessment (Figure 2).

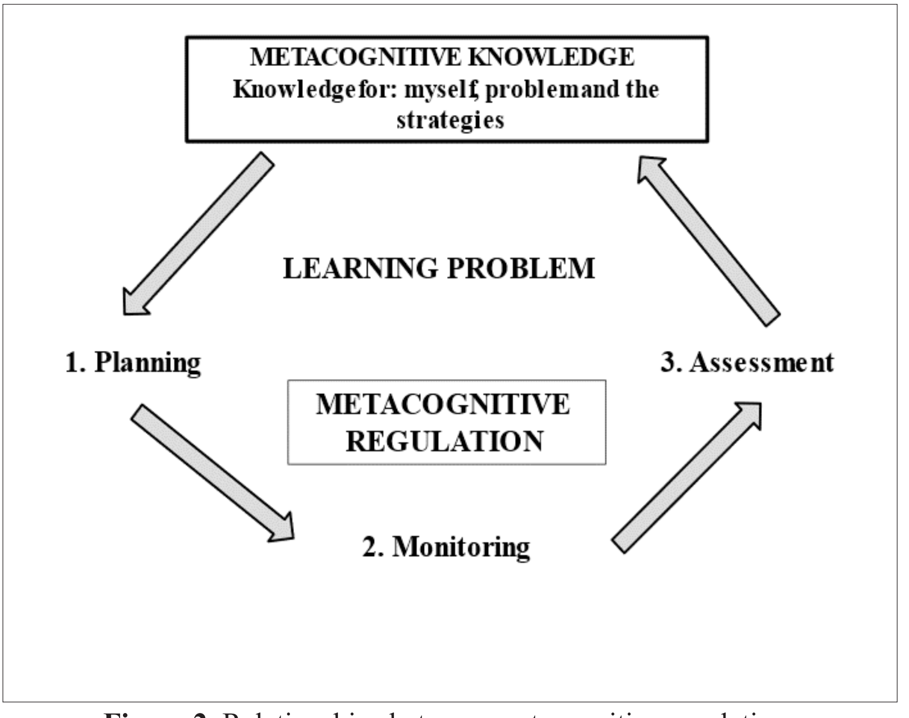


Figure 2. Relationships between metacognitive regulation, planning, monitoring, and assessment

The Experiment as a Training Method

The experiment is a method of studying objects, processes or phenomena under specially created controllable conditions. Most often, the goal is to test a proposed hypothesis of a cause-and-effect relationship in the studied reality. The researcher (learner) influences the object by purposefully changing the external conditions, observing and measuring certain parameters of this object (Peng 2020). There are two types of experiment according to the object of knowledge (Figure 3).

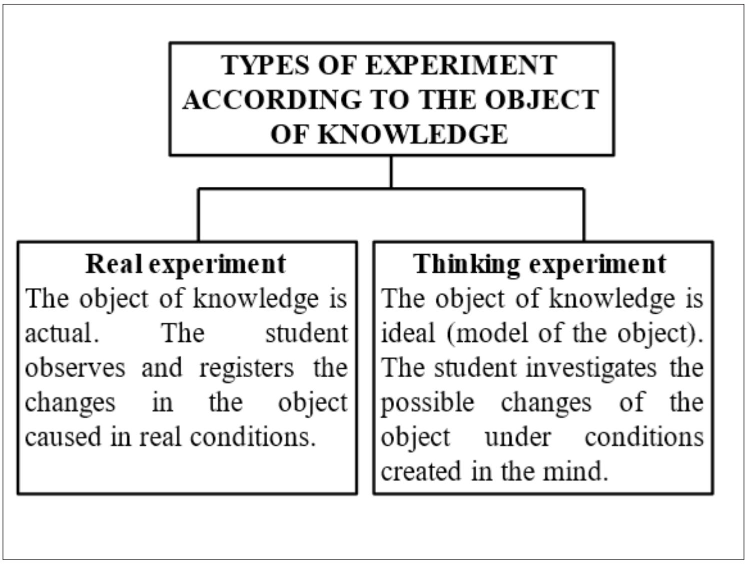


Figure 3. Types of experiment according to the object of knowledge

The purposeful setting up of an experimental activity by the teacher as an independent study by the students stimulates the formation of metacognitive knowledge and promotes the development of a number of metacognitive (reflective) skills – planning, monitoring and assessment of one's own cognitive activity.

Basic steps of a controlled experiment:

1. Formulation of a research question;
2. Formulation of a hypothesis (possible answer/explanation) to the question;
3. Proposing a supposition (a result we expect if the hypothesis is true);
4. Experimental testing of the hypothesis;
5. Defining a control and an experimental group;
6. Defining and controlling variables: independent (factors which are manipulated) and dependent (the outcome of the manipulation);
7. Repetition;
8. Collection and analysis of results;
9. Formulation of conclusions.

The knowledge of the main steps (strategies) of the controlled experiment, i.e. "Why?", "How?", and "When?" these strategies are used, is viewed as metacognitive knowledge (Table 1).

Table 1. Elements of metacognitive knowledge

Metacognitive knowledge	Elements of metacognitive knowledge		
	"Why?"	"How?"	"When?"
Formulating of a research question (FRQ)	Understanding that RQ is a type of question providing answers which can explain, describe or predict phenomena.	RQ includes clearly defined and measurable variables (dependent and independent), as well as the relationship between them.	In any scientific (and educational) research.
Formulating of a research hypothesis (FRH)	Understanding that RH is a possible answer to the defined question and determines the direction of the research.	RH includes a possible answer/solution to RQ, the definitions of the variables and the possible relationship between them.	In most scientific (and educational) research.
Controlling variables (CV)	Understanding that CV is necessary to prove the validity of the conclusions.	Most often involves comparing at least two cases in which all Vs are identical except for the V being manipulated.	When looking for a causal relationship in a studied phenomenon.

In the context of contemporary secondary school biology teaching, the development of metacognitive knowledge and skills is viewed through the lens of studied problem solving and learning through inquiry. At the same time, a number of authors noted that metacognitive development is given a secondary role not only in national, but also in other international educational standards.

Research Design

Research Question

A number of researchers offer examples of the application of various cognitive strategies for development of metacognitive skills. Fundamental in the present study is the *control-of-variables strategy* (CVS), theoretically substantiated and empirically confirmed by recent research in the field of school biology education (Zohar & David 2008; Zohar & Peled 2008).

The conceptual analysis presented in the previous sections delineates the main research question pertained to our investigation: *What is the effect of non-formal educational activities conducted at the Children's University Foundation on the development of metacognitive skills?*

Context of the Study and Participants

Children's University Foundation is an initiative by teachers, scientists and entrepreneurs aiming to inspire students of all ages to discover and develop their talents in various fields of science, art and crafts. To achieve this goal, the Foundation lays down attractive teaching methods which skilfully balance the needs of young people for live communication, skilful work with new technologies and bold venture into research and creative activities. In a dynamic world of constant technological improvement, erratic personal fulfilment and chaotic social uncertainty, young people need discreet but persistent support to look into their own potential and build upon their talents. To inspire them to fearlessly and relentlessly pursue their dreams, the *Children's University* offers them a "career" as practicing researchers, educators, master craftsmen, etc. (Hadjiali et al. 2018).

The study sample consisted of 48 secondary students from 5th to 7th grade (aged 11–14 years). They all attended public primary or secondary schools located in Sofia and Gabrovo. The sample was divided into two groups – experimental and control, assigned to each research condition: non-formal metacognitive training and no metacognitive training. The experimental group comprised of 22 students (grade 5 to 7) from various primary and secondary schools in Sofia, and the control group – included 26 students (grade 5 to 7) from High School of Science and Mathematics "Academic Ivan Gyuzelev" in Gabrovo. Students in the experimental condition attended a non-formal training course "Introduction to Biology" at the Children's University Foundation designed to support their metacognitive skills. Students from the control group did not have any formal or non-formal training in metacognitive skills.

Between the two groups there was an equal distribution of academic performance, identified in summative assessments (students' grades on subjects "Human and Nature" and "Biology and Health education") during the school year up to the time of this investigation. Further, all participants study the compulsory subjects "Human and Nature" (grade 5 to 6) and "Biology and Health education" (grade 7) with the same number of hours (2 to 3 hours per week) in formal educational settings. It is important to note, that students from both groups had never been explicitly taught metacognitive skills and specifically control-of-variables strategy, as noted per informal conversations with science teachers at the selected schools (personal communication).

Intervention

The main stage of the research was implemented during the 2021 – 2022 academic year. At this stage, the formative pedagogical experiment, which aims to empirically prove the credibility of the constructed theoretical concept, was carried out. The scientific and theoretical study of the problem of non-formal education in a pedagogical and strictly methodological aspect which was carried out allowed us to hypothetically postulate *that non-formal educational activities have a positive effect on developing of metacognitive skills in biology education*.

The experimental version of instruction included non-formal training with application of learning tasks designed to support students' metacognitive skills, while the control version of instruction is organised in accordance with regulatory framework of training in “Human and nature” (5th -6th grade) and “Biology and health education” (7th grade) without explicitly teaching of metacognitive skills.

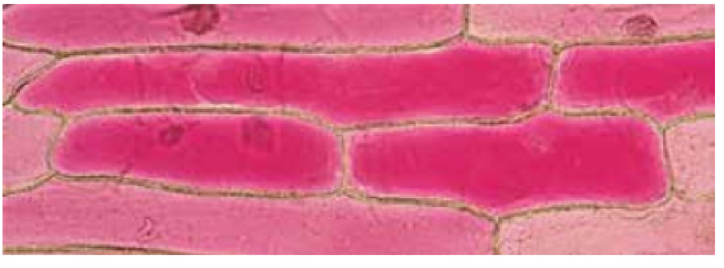
The *final stage* of the experiment was conducted at the end of June 2022. During this stage of the experimental impact, students from both contrast groups had to solve problems (main diagnostic tool), which were two (2) in number and contained different numbers of subtasks.

Examples of tasks for development of *metacognitive skills*:

Task 1. Applying the control-of-variables strategy: study of the osmotic behaviour of plant cells.

The students are presented with an experiment conducted by their peers – Ivan and Maria. Points 1 through 7 describe the stages of the experiment:

1. They place a drop of water on a glass slide.
2. Using a scalpel and tweezers, they remove a thin layer from the red-coloured side of the red onion skin.
3. They place the piece of tissue in the drop of water and cover it with a glass slide.
4. They observe the microscope slide successively at different magnifications, starting with the lowest.
5. The results from the microscopic observation are recorded via a schematic drawing.



6. They repeat steps 1, 2 and 3 and place 2 – 3 drops of 10% solution of NaCl at the edge of the coverslip and then draw off the saline solution with a piece of filter paper from the opposite end of the coverslip.
7. They wait 2 – 3 minutes and observe the preparation at different magnifications. The results from the microscopic observation are recorded via a schematic drawing.

Help Ivan and Maria answer the following research questions (A – F):

A) What happens to the cells after they are placed in a 10% solution of NaCl? (1 p.)

B) What is the process observed by Ivan and Maria called? (1 p.)

C) Do the cells change size? Explain why. (1 p.)

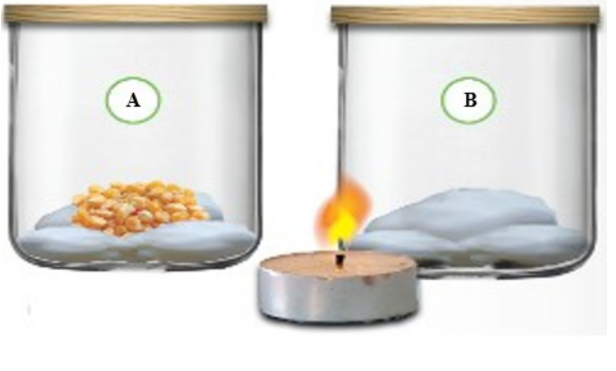
D) Does the red colour of the cytoplasm change its intensity? Explain why. (1 p.)

E) Can you reverse the process they observed at baseline? Explain how you will do this! (1 p.)

F) Suggest a sample design of a school experiment to answer the following research question: *What will happen if you put red onion in boiling water for 5 min. and then repeat the experiment? Will you observe the same results? Explain why* (5 p.).

Task 2. Placing emphasis on the development of skills for metacognitive regulation of the activity (planning, monitoring and assessment of the activity)

A). Design and conduct an experiment with which to demonstrate that during respiration plant seeds use oxygen from the air and release carbon dioxide, by having available: - two glass vessels (A and B) with well-fitting stoppers; – cotton wool; – corn seeds; – a candle affixed onto wire.



Describe in sequence the stages of the experiment and the main conclusions you've reached. (5 p.).

B). Can you suggest and describe the sequential steps of an experiment to demonstrate the release of carbon dioxide in human breathing. (5 p.)

The maximum number of points that each student can get when solving the problems is 20 points.

Results and Discussion

The results from the solution of Task 1. (Applying the control-of-variables strategy) (Table 2) give grounds for the following analyses and comments. The students from the experimental version of instruction did much better with finding the solution of all the subtasks of the main task. The group of those who correctly defined and described the process they observed (B. 95.45%) and explained the reasons for the change in the staining intensity of the cells (D. 86.36%) is represented by the highest percentage value (total point credits). In the control group, the ones represented by the highest percentage are those who stated that "cells change their size" (50%) and most often provided the wrong answer to the question – *What happens to the cells after they are placed in a 10% solution of NaCl?* (A. 42.31%).

Table 2. Results from the solution of Task 1, which requires applying the control-of-variables strategy

	EG N=22 (f and %)			KG N=26 (f and %)		
	Total point credits	Partial point credits	Wrong or no answer	Total point credits	Partial point credits	Wrong or no answer
A) What happens to the cells after they are placed in a 10% solution of NaCl?	15 (68.18%)	5 (22.73%)	2 (9.09%)	5 (19.23%)	10 (38.46%)	11 (42.31%)
B) What is the process observed by Ivan and Maria called?	21 (95.45%)	0 (0.00%)	1 (4.55%)	7 (26.92%)	15 (57.69%)	4 (15.38%)

C) Do the cells change size? Explain why.	12 (54.55%)	7 (31.82%)	3 (13.64%)	2 (7.68%)	11 (42.31%)	13 (50.00%)
D) Does the red colour of the cytoplasm change its intensity? Explain why.	19 (86.36%)	2 (9.09%)	1 (4.55%)	7 (26.92%)	17 (65.38%)	2 (7.68%)
E) Can you reverse the process they observed at baseline? Explain how you will do this!	16 (72.73%)	2 (9.09%)	4 (18.18%)	6 (23.08%)	10 (38.46%)	10 (38.46%)
F) What will happen if you put red onion in boiling water for 5 min. and then repeat the experiment? Will you observe the same results? Explain why.	18 (81.82%)	3 (13.64%)	1 (4.55%)	9 (34.62%)	9 (34.62%)	8 (30.77%)

The results from the descriptive statistics (Table 3) show that the average number of points in EG is 8.5682, while in KG it is relatively lower (4.8462).

Table 3. Descriptive statistics results, Task 1

	N	Mean	Median	Mode	SD	Variance	Minim.	Max.
EG	22	8.5682	10.0000	10.00	2.65157	7.031	0.00	10.00
KG	26	4.8462	4.7500	5.00	3.52922	12.455	0.00	10.00

The distribution (in %) of the students' answers from the two groups for Task 2. (Table 4) unequivocally shows that the students from the experimental group successfully design and conduct an experiment to prove that during respiration plant seeds and humans use oxygen from the air and release carbon dioxide (A. 54.55%; B. 63.64%), while in the control group the percentage of those who receive total point credits was significantly lower (A. 26.92%; B. 23.08%). The average number of points of the students from the EG is 7.1591 and from the KG - 4.8077 (Table 5).

Table 4. Results from the solution of Task 2, which requires metacognitive regulation of the activity (planning, monitoring and assessment of the activity)

	EG N=22 (f and %)			KG N=26 (f and %)		
	Total point credits	Partial point credits	Wrong or no answer	Total point credits	Partial point credits	Wrong or no answer
A) Design and conduct an experiment to demonstrate that during respiration, plant seeds use oxygen from the air and release carbon dioxide.	12 (54.55%)	6 (27.27%)	4 (18.18%)	7 (26.92%)	12 (46.15%)	7 (26.92%)
B) Can you suggest and describe the sequential steps of an experiment to demonstrate the release of carbon dioxide in human breathing.	14 (63.64%)	5 (22.73%)	3 (13.64%)	6 (23.08%)	12 (46.15%)	8 (30.77%)

Table 5. Descriptive statistics results, Task 2

	N	Mean	Median	Mode	SD	Variance	Minim.	Max.
EG	22	7.1591	10.0000	10.00	3.72375	13.866	0.00	10.00
KG	26	4.8077	5.0000	5.00	3.66900	13.462	0.00	10.00

The statistical analysis of the results from the empirical study in this part is aimed at solving the following question: *Is there a statistically significant difference between the distributions of the random variables X and Y which characterise numerically the achievements of the students in the two extreme groups?*

The solution of this question is connected with the empirical verification of the following statistical hypotheses:

Null hypothesis H_0: The distribution of the random variable X in the experimental group is not significantly different from the distribution of the random variable Y in the control group.

Alternative hypothesis H_1: The distributions of the random variables X and Y in the experimental and the control group differ significantly.

The verification of the statistical hypotheses was carried out using a parametric test – *Paired Samples T-Test,* and a non-parametric test – *Mann-Whitney Test,* for two independent samples.

The data from the descriptive statistics and the tests (Paired Samples T-Test and Mann-Whitney Test) show that the empirical values of t and *Z-criterion* are incompatible with the null hypothesis (Table 6). We accept the alternative hypothesis – *The distributions of the random variables X and Y in the experimental and the control group differ significantly*. The conclusion is reached that the students from the experimental group attending the course "Introduction to Biology" at the Children's University Foundation do better with solving tasks aimed at developing metacognitive skills in the teaching biology.

Table 6. Results from the statistical hypothesis verification tests

Statistical tests	Applying the *control-of-variables* strategy	Metacognitive regulation of the activity (*planning, monitoring and assessment of the activity*)
	EG/KG	**EG/KG**
Paired Samples T-Test **H_0: $\mu_1^2 = \mu_2^2$** **H_1: $\mu_1^2 \neq \mu_2^2$**	t = 6.333 df - 21 p=0.000 $p < 0.05$ **H_0- rejected**	t = 3.245 df - 21 p=0.004 $p < 0.05$ **H_0- rejected**
Mann-Whitney Test **H_0: /u/ < u_α** **H_1: /u/ ≥ u_α**	Mann-Whitney (U)= 159.000 Wilcoxon (W)= 510.000 Z= (-3.112) p=0.000 $p < 0.05$ **H_0 – rejected**	Mann-Whitney (U)= 185.000 Wilcoxon (W)= 536.000 Z= (-2.193) p=0.028 $p < 0.05$ **H_0 – rejected**

Conclusion

The results from our study showed that the quality of metacognitive skills exhibited by the experimental group exceeded that of a control group, highlighting the power of non-formal science learning in developing of middle school students' metacognition. It may be claimed that science inquiry carried out during the course

"Introduction to Biology" at the Children's University Foundation provides a promising and fruitful environment that engaged students in more metacognitive regulation than in typical classroom settings. It is our assumption that the program of these course provided specific learning goals and content for students in a supportive learning context that enabled them to use their metacognitive knowledge and skills in an optimal manner.

Consistent with a number of previous studies, the present research highlights the importance of promoting metacognition in science learning (Linn & Bat-Sheva 2006; Schraw et al. 2006; Stanton et al. 2021; Zohar & David 2008) and specifically in non-school settings (Schraw et al. 2011). As in the school classroom, the course "Introduction to Biology" used a structured curriculum to enhance student learning. However, it differed from a traditional classroom in that it was hands on, experiential, and based in a novel setting. These new characteristics of the learning environment probably required students to use a broader array of metacognitive skills than a traditional classroom learning experience. Like others scholars (Schraw et al. 2011), we assume that students faced more conditional knowledge demands due to the new learning environment and engaged in more self-monitoring and self-assessment than in typical classroom settings. We also suppose that students were more motivated to use their existing metacognitive skills and to share them in closer collaboration with other students than they might have been in a traditional classroom. Future studies may, therefore, benefit from a comparison of metacognitive skills and their quality characteristics, inside and outside classroom using the same students.

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Dr. Isa Hadjiali, Assoc. Prof.
ORCID iD: 0000-0001-8677-1663
Department of Methodology of Biology Education
Sofia University
Sofia, Bulgaria
E-mail: hadzhiali@biofac.uni-sofia.bg

Dr. Teodora Kolarova, Assoc. Prof.
ORCID iD: 0009-0004-9731-7430
Department of Botany and Didactics of Biology
University of Plovdiv "Paisii Hilendarski"
Plovdiv, Bulgaria
E-mail: teokolarova@uni-plovdiv.bg