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ABSTRACT OF THE DOCTORAL THESIS

DISCOVERY-BASED LEARNING IN SCIENCE THROUGH THE USE OF ONLINE RESOURCES IN PRIMARY EDUCATION

Author: Doctoral Candidate Paula-Maria Rusu (current name: Buda)
Doctoral Supervisor: Prof. Dr. Maria-Eliza Dulamă

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DECLARATION OF ACADEMIC INTEGRITY

I, the undersigned, Buda Paula-Maria, as a doctoral candidate at Babeș-Bolyai University, hereby declare:

• The doctoral thesis entitled *"Discovery-Based Learning in Science through the Use of Online Resources in Primary Education"* represents the result of my own research activity and is an original work. The thesis has been conducted in accordance with the principles of academic integrity, including honesty, responsibility, scientific rigor, and adherence to research ethics. All sources used in the preparation of the thesis are properly acknowledged and cited throughout the work, in compliance with academic standards.

• The similarity check was conducted within the Doctoral School *"Didactics. Tradition, Development, Innovation"*, using a specialized similarity detection platform (Turnitin), and the results fall within the limits accepted by current academic regulations.

• The thesis is written in accordance with the provisions of the *Publication Manual of the American Psychological Association (7th ed.),* respecting all formatting standards, with the exception of line spacing, which is set at 1.5.

• The published studies are consistent with the research topic and are properly mentioned and cited within the thesis.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANCOVA	—	Analysis of Covariance
ANOVA	—	Analysis of Variance
APA	—	American Psychological Association
Ca.	—	Circa
d	—	Effect Size (Cohen's d)
DBL	—	Discovery-Based Learning
df	—	Degrees of Freedom
et al.	—	et al.
F	—	F-value
GC	—	Control Group
GDPR	—	General Data Protection Regulation
GE^1	—	Experimental Group 1
GE^2	—	Experimental Group 2
GE^3		Experimental Group 3
HC3	—	Heteroskedasticity-Consistent Robust Standard Error Estimator, Variant 3 (HC3)
H	—	Hypothesis
CI	—	Confidence Interval
M	—	Mean
M_aj	—	Adjusted Mean
M_b	—	Mean of Boys
MEN	—	Ministry of National Education
M_g	—	Mean of Girls
M_r	—	Mean of Students from Rural Areas
M_u	—	Mean of Students from Urban Areas
MΔ	—	Mean of Difference Scores

n	—	Number
N	—	Number
n-gain	—	Normalized Gain Mean
P	—	p-value (Level of Significance)
p.	—	Page
p-aj	—	Adjusted p-value (for multiple comparisons)
PET	—	Primary Education Teachers
pp.	—	Pages
r	—	Correlation Coefficient (Guttman Split-Half)
RED	—	Open Educational Resources
SD	—	Standard Deviation
SE	—	Standard Error
SEM	—	Standard Error of the Mean
SS	—	Sum of Squares
T	—	Independent-Samples T-test
vs.	—	Versus
α	—	Internal Consistency Coefficient / Reliability (Cronbach's alpha)
Δ	—	Difference Between Two Measurements

CHAPTER I. INTRODUCTION

1.1 Research Premises and Context

Discovery-based learning in science, using online resources, carried out by primary school students, is currently influenced by the development of technology and science at the global level, by access to technology and the internet, by students' curiosity, interest, and motivation, by parents' behavior and competence, and, in the formal context, additionally by teachers' beliefs, availability, and competence.

The approach adopted in this doctoral thesis regarding discovery-based learning in science, using online resources in primary education, is initiated based on the observation of children's tendency to use the internet and other multimedia resources excessively, to the detriment of other age-appropriate activities, with negative effects on cognitive and emotional capacities, mental health, and interpersonal relationships. Considering that digital and scientific education are achieved through the cooperation between school, students, and parents, this thesis analyzes the opinions of teachers and students regarding discovery-based learning using online resources and tests the effects of guided discovery-based learning activities.

1.2 The Concept of Discovery-Based Learning

Regarding learning, Sink (2014) distinguishes three perspectives. Behavioral theories (behaviorism), which focus on observable behavior, suggest that learning occurs when a person strengthens or weakens an association between a stimulus and a response. Cognitive theories, which focus on knowledge acquisition, suggest that learning occurs when a person processes information, stores it in long-term memory, and retrieves it. In constructivist theories, learning is described as an active process of constructing knowledge in working memory.

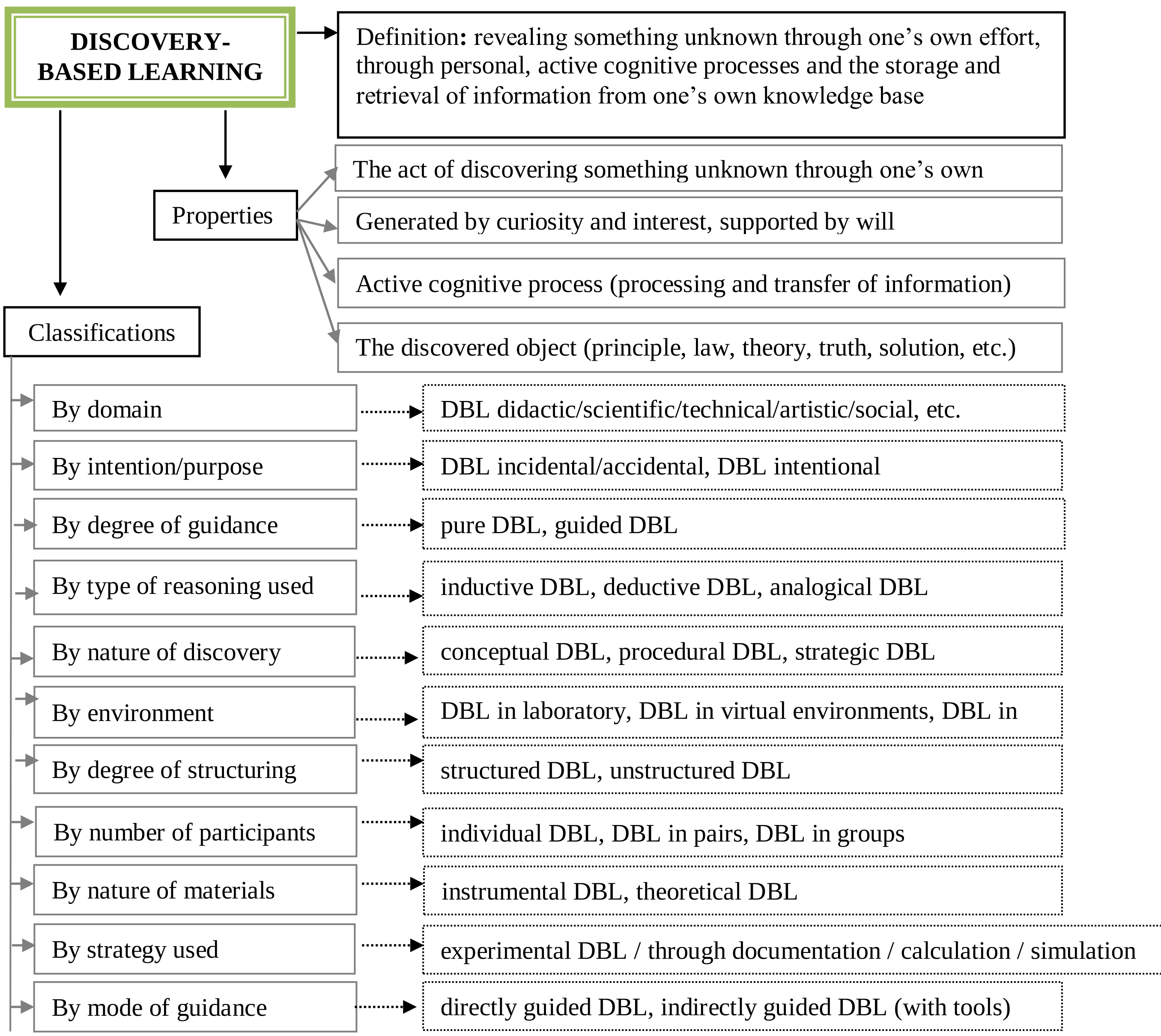
Although there are many studies on discovery-based learning, the literature does not provide a precise definition (Klahr & Nigam, 2004), but it is suggested that discovery-based learning occurs when the learner independently identifies the target information and understands it at a conceptual level in situations where certain materials are provided, but the target information itself is not explicitly given (Alfieri et al., 2011). Mayer (2004, p. 15) analyzed research on the discovery of problem-solving rules and found that, across all studies, guided discovery was more effective in learning and in students' transfer performance compared to pure discovery. Discovery-based learning requires extensive search processes that place demands on the limited capacity of working memory; otherwise, learning does not occur (Rittle-Johnson, 2006).

Based on the literature, we consider that discovery-based learning is a pathway (method, type of learning, strategy, or procedure) through which the learner reveals something unknown through personal effort, through active cognitive processes of searching, processing, and integrating information into their existing knowledge base, and retrieving it for use in new contexts.

A discovery-based learning activity, or the process of discovery-based learning carried out by a student or another individual, can be classified according to various criteria into different categories. Figure 1.1 presents such a classification: by domain (didactic, scientific, technical, artistic, social, etc.); by intention or purpose (incidental/accidental, intentional); by degree of guidance (pure, guided); by type of reasoning used (inductive, deductive, analogical); by environment (laboratory, virtual environments, nature, etc.); by degree of structuring (structured, unstructured); by number of participants (individual, pairs, groups); by nature of materials (instrumental, theoretical); by strategy used (experimental, through documentation, mathematical calculation, simulation); by mode of guidance (directly guided, indirectly guided, using tools such as worksheets and study guides); and by nature of discovery (conceptual, procedural, strategic). In relation to online resources, students can engage in discovery-based learning in almost all the contexts presented above.

Figure 1.1

The Concept of Discovery-Based Learning



1.3 Theories on Discovery-Based Learning Using Online Resources

In our research, we are interested in how discovery-based learning occurs as a process unfolding within an individual's cognitive system (Castro-Alonso, 2013), as a result of an experience or exercise through which knowledge is acquired, skills and attitudes are developed, and behavior is modified (Côté, 1987).

Discovery-based learning using online resources is explained through several categories of theories: theories of motivation, theories of curiosity, cognitive theories, theories of attention, theories related to viewing effects, cognitive development theory, and scaffolding theories. Within the category of motivation theories, relevant frameworks include the theory of human motivation, self-determination theory, theories of intrinsic and extrinsic motivation, the social cognitive theory of motivation, and the ARCS model of motivation. Curiosity is explained through curiosity theory, the optimal arousal model, the optimal stimulation model, the knowledge gap theory, and the interest/deprivation model of curiosity, which suggest that students seek new information either out of interest or to reduce uncertainty and the feeling of deprivation.

Information processing is explained through dual coding theory, working memory theory, cognitive load theory, and the cognitive theory of multimedia learning, together with principles such as the multimedia principle, coherence principle, signaling principle, spatial and temporal contiguity principles, redundancy principle, segmentation principle, modality principle, personalization principle, voice principle, image principle, concreteness principle, anchoring principle, worked example principle, guided discovery principle, explanation principle, questioning principle, elaboration principle, and testing principle. In addition, reactive attention theory, active attention theory, and coherence theory of attention explain the focusing of attention on multimedia materials. Theories related to viewing effects highlight both the potential to stimulate interest, imagination, and learning, as well as the risk of passivity, while cognitive development theory and scaffolding theories emphasize the role of the Zone of Proximal Development, mediation, internalization, and various types of scaffolding in supporting discovery-based learning.

1.4 State of the Field

Overall, the studies analyzed highlight that discovery-based learning using online resources at the primary education level is influenced both by teachers' practices and competencies and by the way students use the digital environment. The results of teacher-centered studies show that primary education teachers generally hold favorable views toward discovery-based learning and the use of online resources; however, in practice, learning activities are often organized and guided by the teacher, and online resources are more frequently used for teaching and explaining content rather than for exploration, collaboration, and active learning carried out by students.

Studies focusing on students indicate that they frequently use the online environment in their daily lives, especially for games, entertainment, and communication, while the use of digital resources for educational purposes is perceived as less frequent. Nevertheless, research in which multimedia resources, digital applications, interactive worksheets, or structured discovery activities were integrated shows improvements in students' understanding of scientific content, engagement, and motivation, particularly when these activities were accompanied by teacher guidance. In this context, the literature suggests that the challenges in implementing discovery-based learning using online resources are not determined solely by access to technology, but also by the need to support teachers in designing instructional scenarios, developing digital and pedagogical competencies, and harnessing students' interest in the digital environment for active learning in science.

1.5 Research Relevance

The relevance of the research lies in the fact that it explores in depth an area that is insufficiently clarified in the literature, namely discovery-based learning using online resources in science education at the primary level. The study provides both theoretical and practical evidence regarding primary education teachers' opinions and practices, students' perceptions and experiences, as well as the effectiveness of different ways of organizing discovery-based learning. Its importance is further emphasized by the limited number of studies explicitly focused on the primary level, as most research addresses other levels of education, the general use of technology, or isolated aspects such as digital competencies, platforms, or applications.

At the same time, the research is relevant because it offers models and examples of good practice for designing science learning activities, both in the classroom and at home, with the support of online resources. By comparing different strategies, resources, and guidance tools, the studies included in the thesis highlight the conditions under which discovery-based learning can become more effective. In this way, the research contributes to filling a gap in the literature and provides useful reference points for teachers in designing more well-grounded instructional interventions.

CHAPTER II

OBJECTIVES AND GENERAL RESEARCH METHODOLOGY

2.1 Research Objectives

2.1.1 General Objectives

This thesis aims to investigate the use of discovery-based learning in the study of science at the primary education level in Romania, from theoretical, methodological, and practical perspectives.

2.1.2 Specific Objectives

The general objectives of the research are achieved through the five studies included in the thesis: Study 1 analyzes primary education teachers' opinions regarding the use of discovery-based learning with the support of online resources in science; Study 2 investigates primary school students' perceptions and practices related to discovery-based learning using online resources; and Studies 3, 4, and 5 measure the effectiveness of different ways of organizing discovery-based learning in the subject "Natural Sciences," namely the use of the "PlantNet" application, worksheets, and guidance tools.

2.2 General Methodology

From a methodological perspective, the thesis includes five studies: two quantitative studies conducted through survey research based on questionnaires and three quasi-experimental studies. All five studies are carried out in strict accordance with the requirements of scientific research methodology specific to the field of educational sciences, as well as with regulations concerning legality, ethics, and data protection. All necessary conditions are ensured for the proper conduct of the studies and for achieving all research objectives.

CHAPTER III

ORIGINAL RESEARCH CONTRIBUTIONS

3.1 Study 1: Primary Education Teachers' Opinions and Practices Regarding Discovery-Based Learning Using Online Resources

3.1.1 Introduction

From the perspective of discovery-based learning, the analysis of previous studies shows that, in general, primary education teachers have access to technology and online resources in the school environment, that students have access to electronic devices and internet connectivity at home, and that both teachers and students possess the digital competencies necessary to use online resources in science learning and to utilize various applications freely available on the internet.

The purpose of the research is to investigate primary education teachers' perceptions of discovery-based learning using online resources in science and how this type of learning is influenced by factors related to students, teachers, and technology.

The research questions are as follows:

1. What importance do student-related factors have in discovery-based learning using online resources?

2. What importance do teacher-related factors have in discovery-based learning using online resources?

3. What importance do technological factors have in discovery-based learning using online resources?

4. What challenges do teachers face in discovery-based learning using online resources?

3.1.2 Method

Participants. The selection of primary education teachers for participation in the study was based on two criteria: holding the position of a primary education teacher and being employed as such within the education system. A total of 144 primary education teachers participated in this research, presenting diverse characteristics in terms of gender, age, level of education, teaching experience, teaching certification level, the environment in which the school is located, county of origin, and the grade level they teach.

Data Collection. The data were collected through a questionnaire between August 16, 2022, and August 1, 2024. Participants were voluntarily involved in the survey using a non-probability sampling method known as "snowball sampling." Data protection was ensured in accordance with the GDPR (2016), and all legal and ethical requirements specific to research methodology were respected throughout the study.

Instrument. The questionnaire was developed by the researcher based on her observations and professional experience in working with students, as well as on information from the literature regarding discovery-based learning. It was reviewed by two experts and statistically validated. The questionnaire includes three sections. Section I, "The Use of Technology in Discovery-Based Learning," comprises 7 items. Section II, "Problems and the Importance of Student-Related Factors in Discovery-Based Learning," comprises 78 items. Section III, "Problems and the Importance of Teacher-Related Factors in Discovery-Based Learning," comprises 135 items. For each item in the three sections, respondents were asked to assign a score from 1 to 5 on a Likert-type scale. Section IV includes "Participant Information": gender, age, educational level, teaching experience, teaching certification level, the environment in which the school is located, county, and the grade level taught.

Data Analysis

To assess the internal consistency of the instrument, Cronbach's alpha coefficient was calculated, along with the Spearman–Brown and Guttman Split-Half coefficients, by dividing the items into two equivalent halves (odd-numbered and even-numbered items), in order to determine whether the obtained scores have similar consistency.

3.1.3 Results and Discussions

Preliminary Results at the Level of the Instrument Used. The very high values of Cronbach's alpha coefficient for the entire instrument (α = .997) and for each section (α ranging between .896 and .996), as well as the Spearman–Brown and Guttman Split-Half coefficients (r = .999), indicate excellent internal consistency and reliability of the questionnaire, confirming that the items are homogeneous, well-formulated, and consistently measure the same theoretical constructs related to discovery-based learning using online resources.

Main Results and Discussions

Primary Education Teachers' Conceptions of the Importance of Student-Related Factors in Discovery-Based Learning Using Online Resources. The high mean values for students' internal conditions (*M* = 4.01–4.31; *SD* ≈ 1.1), cognitive structure (*M* = 3.74–3.98; *SD* = 1.15–1.24), cognitive and investigative abilities (*M* = 3.63–4.24; *SD* ≈ 1.07–1.24), student competencies (*M* = 4.06–4.17; *SD* ≈ 1.08–1.12), and types of thinking (*M* = 4.07–4.21; *SD* ≈ 1.05–1.11) indicate that primary education teachers consider these elements essential for the success of discovery-based learning using online resources; age has a moderate importance (*M* = 3.49; *SD* = 1.39), while cognitive guidance/scaffolding is considered necessary (*M* = 4.03; *SD* = 1.07) in primary education.

Primary Education Teachers' Perceptions of the Importance of Teacher-Related Factors in Discovery-Based Learning Using Online Resources. The mean values indicate that primary education teachers consider teacher competence essential in discovery-based learning using online resources, with digital competence having the highest importance (M = 4.10), followed by competence in science didactics (M = 3.98) and competence in science (M = 3.95), with moderate standard deviations (SD ≈ 1.14 – 1.20). Discovery-based learning is perceived as more suitable for scientific disciplines (M = 3.82 – 4.19) and is used mainly during the teaching of new knowledge (M ≈ 3.81), having formative purposes related to interest, motivation, research competence, and deep learning (M = 3.64 – 4.16).

Primary education teachers consider feedback necessary (M = 4.17) and emphasize the importance of teacher guidance, while full autonomy is less valued (M ≈ 3.52 – 3.53). The characteristics, procedures, and actions associated with discovery-based learning generally have values between M = 3.67 – 4.12, while capturing attention through visual and playful means (M = 3.89 – 4.17) and facilitating understanding through practical activities (M = 4.13) and guidance (M = 4.09) confirm the teacher's role as organizer and facilitator of discovery-based learning.

Primary Education Teachers' Perceptions of Problems in Discovery-Based Learning Using Online Resources. The low mean values for access to technology and the internet (*M* = 2.40 – 2.77) indicate that digital infrastructure is no longer perceived as a major obstacle. Costs are perceived as moderate (*M* = 2.76 – 3.16), but are not considered barriers. Time represents the main challenge (*M* = 3.35 – 3.83), and the number of students influences the effectiveness of activities (*M* = 2.75 – 3.25). The absence of guidance is perceived as a significant difficulty (*M* = 3.78), and covering the full curriculum through discovery-based learning is considered challenging (*M* = 3.36), although the formative value of this approach is acknowledged.

3.1.4 Conclusions

Primary education teachers have accurate perceptions in relation to both reality and the existing literature. The driving force of discovery-based learning using online resources in primary education is represented by students' curiosity, interest, intrinsic motivation, needs, and passion. Students' age is not perceived as a relevant factor in the success of discovery-based learning, likely because primary school students "discover" or rediscover information, procedures, and concepts daily through online resources, even if their discoveries are empirical rather than "scientific."

A detailed analysis of the factors reveals that the main challenges identified by primary education teachers are organizational and pedagogical in nature rather than technological. While access to technology and costs are perceived as minor issues, time management, class size, instructional guidance, and the coverage of curricular content represent real obstacles to the consistent implementation of discovery-based learning.

Research Limitations. The limitations of the research are related to the size and structure of the sample (*N* = 144, predominance of female participants and urban environments, and lower representation in some counties), the lack of data analysis according to primary education teachers' characteristics, and the possible subjective nature of both the responses and the formulation of the items. However, the excellent internal consistency of the instrument (α = .997; *r* = .999) confirms the stability and coherence of the measurement of the targeted construct.

Directions for Future Research. In future research, this original questionnaire could be administered at both national and international levels, through the balanced involvement of a larger number of primary education teachers. The formulation and grouping of items could be improved to more accurately measure the factors influencing the use of discovery-based learning using online resources in science, and the studies could be extended to other subjects and educational levels.

3.2 Study 2: Primary School Students' Perceptions of Discovery-Based Learning Using Online Resources

3.2.1 Introduction

In discovery-based learning using online resources, students' conceptions and practices in relation to technology, as well as to searching, verifying, and using materials available on the internet, are particularly important. In Romania, two studies have been identified in which data were collected from primary school students regarding media consumption (Rus & Negru, 2025) and the viewing and production of films (Doroșin Ilie, 2025). In organizing optimal educational contexts in which students learn through discovery using online resources, both at home and in the classroom, primary education teachers' conceptions of how students use digital devices, the internet, and available online resources are also important. These studies conducted in Romania reveal certain differences between teachers' perceptions of students' internet use and students' own perceptions of how they use technology and online resources from the perspective of discovery-based learning in science.

Purpose of the Research. It is to investigate the perceptions and practices of primary school students (Grades 3 and 4) regarding discovery-based learning using online resources, in relation to individual factors (gender, grade level) and contextual factors (environment of origin).

Research Questions. These are as follows:

1. What is the frequency of students' use of different digital devices for searching and processing online information?

2. For what purposes do students use the internet in their learning and exploratory activities?

3. How frequently do students search for and use various types of educational materials available online?

4. Which platforms, websites, and applications do students use most frequently to search for information and educational materials?

5. How frequently do students receive recommendations from others regarding online resources?

6. What strategies do students most frequently use in the process of searching for information on the internet?

7. What is the level of students' interest in searching for online materials in the field of science?

8. How do students verify and validate the accuracy and relevance of the information found online?

9. What are students' attitudes toward discovery-based learning using online resources?

10. How do students use the materials they discover on the internet in their science learning activities?

11. What differences exist between Grade 3 and Grade 4 students regarding the frequency of technology use, purposes, strategies, interests, attitudes, and the way they use information discovered through online resources?

12. What differences exist between boys and girls regarding the frequency of technology use, purposes, strategies, interests, attitudes, and the way they use information discovered through online resources?

13. What differences exist between students from urban and rural environments regarding the frequency of technology use, purposes, strategies, interests, attitudes, and the way they use information discovered through online resources?

3.2.2 Method

Participants. A total of 180 students from Grades 3 and 4 participated in this research, coming from six educational institutions located in both urban and rural areas, in the counties of Sălaj and Bistrița-Năsăud.

Data Collection. The data were collected through a questionnaire between October 20, 2025, and October 24, 2025. Data protection was ensured in accordance with the GDPR (2016), and all legal and ethical requirements specific to research methodology were respected.

Instrument. The questionnaire was developed by the researcher based on her observations and professional experience in working with students, as well as on information from the literature regarding discovery-based learning. It was reviewed by two experts and statistically validated. The instrument includes ten sections.

Data Analysis

Preliminary Analyses at the Level of the Instrument Used To assess the internal reliability of the questionnaire administered to students, Cronbach's alpha coefficient (α), the Spearman–Brown coefficient ($r_s b$), and the Guttman Split-Half coefficient were calculated.

Main Analyses at the Level of the Research Questions. For each item of the questionnaire, the mean and standard deviation were calculated separately according to the variables grade level, environment of origin, and gender; therefore, the data analysis is descriptive in nature.

3.2.3 Results and Discussions

Preliminary Results and Discussions at the Level of the Instrument Used. The value of Cronbach's alpha coefficient ($\alpha = 0.964$), together with the Spearman–Brown ($r_s b = 0.965$) and Guttman Split-Half ($r = 0.965$) coefficients, indicates a very high internal consistency and confirms that the items are homogeneous, consistently measure the same theoretical construct, and produce stable and reproducible results, thus demonstrating the reliability and good psychometric quality of the questionnaire used in the research.

Main Results and Discussions – at the Level of the Research Questions. The results show that students most frequently use smartphones ($M = 3.6$), while laptops ($M = 2.02$), tablets ($M = 1.67$), and desktop computers ($M = 1.64$) are rarely used, confirming that online learning is predominantly based on mobile devices. Smartphone use is higher in Grade 4 ($M = 3.68$) than in Grade 3 ($M = 3.54$), in urban areas ($M = 3.85$) compared to rural areas ($M = 3.42$), and among girls ($M = 3.74$) compared to boys ($M = 3.50$). The main purpose of using online resources is entertainment ($M = 3.33$), followed by satisfying curiosity ($M = 3.07$), while use for school-related tasks is less frequent (science homework: $M = 2.12$; school homework: $M = 2.11$). Students most frequently search for games ($M = 3.70$), videos ($M = 3.61$), and music ($M = 3.38$), while written texts are used less often ($M = 2.27$).

In terms of platforms, students most frequently use YouTube ($M = 3.79$), followed by Netflix ($M = 2.72$), TikTok ($M = 2.44$), and Pinterest ($M = 2.43$), while Google ($M = 2.38$) and ChatGPT ($M = 2.26$) are used less frequently. Parents most often recommend materials ($M = 3.56$), while teachers do so less frequently ($M = 2.80$). Students often search guided by parents

(M = 3.41) and teachers (M = 3.24), but they also demonstrate autonomy (learning applications independently: M = 3.20; installing them independently: M = 3.15). Interest in science is higher for animals (M = 3.14) and the surrounding world (M = 2.99). The verification of information relies mainly on sources recommended by parents (M = 3.61) and teachers (M = 3.34), complemented by searching in multiple sources (M = 3.08) and discussions with parents (M = 3.51). Students show persistence in searching (M = 3.44), experience satisfaction when discovering information (M = 3.08), and use the information through reviewing (M = 3.13), rereading (M = 3.11), note-taking (M = 3.08), and application (M = 3.21), most often discussing it within the family (M = 3.52), while passive behavior is rare (M = 2.19).

3.2.4 Conclusions

The results show that primary school students most frequently use smartphones and rely on online resources predominantly for recreational purposes (entertainment and leisure). However, the mean values related to curiosity, the desire for information, procedural learning, and interest in science suggest a potential for discovery-based learning using online resources, with a predominant use of dynamic and interactive visual materials and with instructional guidance/scaffolding to support the gradual development of strategies for searching, verifying, and critically using information.

Educational Implications. These include the integration of visual and interactive online resources into science lessons through guided discovery-based learning activities, the development of students' skills in searching for and verifying information, the valorization of their natural interest in exploration and experimentation, the strengthening of the role of primary education teachers as digital mediators, and the involvement of the family in supporting a responsible and formative use of online resources.

Research Limitations. The study presents certain limitations related to the formulation and grouping of items according to the researcher's own perspective on discovery-based learning, the risk of subjective scoring through self-reporting, the conduct of the study on a sample from a limited geographical area (Sălaj County), the lack of analysis of differences according to the level of already developed digital competencies, and the inclusion of a limited number of direct observations regarding how students actually search for and process information in real time.

Directions for Future Research. These include extending the application of the questionnaire at national and international levels, conducting comparative studies across regions, socio-cultural environments, and educational levels, applying the instrument to other subjects, and incorporating direct observations or recordings of real-time processes of online searching and analysis in discovery-based learning.

3.3 Study 3: The Effectiveness of Using the "PlantNet" Application in Discovery-Based Learning of Students' Knowledge

3.3.1 Introduction

On Earth, there are over 300,000 species of flowering plants, and identifying most of them is an impossible task for the general public and a challenging one even for professionals. Studies show that flora strongly captures people's attention (Balas & Momsen, 2014) and that, although people are surrounded by plants, they do not recognize plant species very well (Kaasinen, 2019). Researchers use the term "plant blindness" to describe or define an individual's inability to see or notice plants in their environment (Lindemann-Matthies & Bose, 2008; Wandersee & Schussler, 1999, 2001).

In the last decade, there has been an increasing interest in automating the process of plant identification (Wäldchen et al., 2018). Through automated plant identification systems, this process is simplified and accelerated, allowing non-specialists to identify plants (Bilyk et al., 2023). In our study, we are interested in having primary school students use the PlantNet application to identify plants. The impact of using the PlantNet application for plant identification in primary education has been analyzed in several studies, with results indicating increased motivation and improved knowledge of plant species.

Objectives, Variables, and Hypotheses. The purpose of this research is to investigate the effectiveness of using the "PlantNet" application in discovery-based learning of knowledge about plants in the subject "Natural Sciences" and to compare its effects with discovery-based learning through the observation of illustrative drawings.

The independent variable (IV) of our study is the learning method. This variable has two levels: the use of the "PlantNet" application and the observation of illustrative drawings. The dependent variable (DV) is the volume of students' knowledge, operationalized as the number of correct responses out of 10 items, measured at pre-test and post-test. The control variables are represented by the pre-test (initial level of knowledge), the actual time allocated to the activity, and students' prior experience in using smartphones and similar applications.

The research hypotheses are as follows:

H¹ – Students who use the PlantNet application will obtain significantly higher post-test scores compared to the pre-test, indicating an increase in knowledge volume (progress hypothesis; within-group).

H² – Students who use illustrative drawings will obtain significantly higher post-test scores compared to the pre-test, indicating an increase in knowledge volume (progress hypothesis; within-group).

H³ – Students who use the PlantNet application will obtain significantly higher post-test scores than students who learn through observing illustrative drawings (difference hypothesis; between-group).

3.3.2 Method

Participants. The study involved 101 third-grade students, with a mean age of 9 years, of both genders, from three schools in the city of Bistrița. They were organized into two experimental groups (GE^1 = 49; GE^2 = 52) based on their initial test results, with voluntary participation and in compliance with ethical regulations (GDPR, 2016).

Procedure. The research design was as follows: two groups (GE^1 – the PlantNet group *vs*. GE^2 – the Drawings group); pre-test – intervention – post-test conducted over a period of 70 minutes. The formative activity took place in the classroom, within the subject "Natural Sciences," under the guidance of the primary education teacher. During both the pre-test and post-test, students from both groups were asked to identify ten plants based on samples of plant organs displayed on a panel. During the intervention, students in GE^1 identified plants using the PlantNet application by photographing plant parts (leaves, fruits, bark) and recording the plant names, while students in GE^2 identified the same plants by observing illustrative drawings.

Instruments. Data were collected using an initial test, a pre-test, and a post-test developed by the researcher, with a maximum score of 10 points.

Data Analysis

Preliminary Analyses. The data obtained from students at the pre-test and post-test were statistically analyzed using Excel and SPSS, testing the normality of the distribution through the Kolmogorov–Smirnov test and verifying the comparability of the two experimental groups prior to the intervention, at the pre-test stage, by applying the independent-samples *t*-test.

Main Analyses – Hypothesis Testing. The sample size ($n \geq 40$ per group), similar dispersion, and the use of continuous data justify the application of *t*-tests in the statistical analysis. To compare performance between pre-test and post-test and to determine within-group progress, paired-samples *t*-tests were applied, while for comparing post-test scores between GE^{1} and GE^{2}, independent-samples *t*-tests and an analysis of covariance (*ANCOVA*) with pre-test scores as a control variable were used. When the assumption of homogeneity of variances was not met, Welch's *t*-test was applied. To determine the magnitude of differences, effect sizes (Cohen's *d* and partial η^2) were calculated, at a significance level of $p < 0.05$.

Secondary Analyses – Calculation of Students' Degree of Plant Blindness. At both pre-test and post-test, each student was asked to identify 10 plants, and the degree of plant blindness was determined based on the proportion of unidentified plants out of the total of ten possible identifications. Three levels of plant blindness were established: a low level when 0–3 plants were not identified (below 40%), a medium level when 4–7 plants were not identified (40–70%), and a high level when 8–10 plants were not identified (above 70%).

3.3.3 Results

Preliminary Results. The means of groups GE^{1} and GE^{2} on the initial test are similar, the difference of 0.16 being not statistically significant ($p > 0.05$), indicating that the groups have a similar initial level and are comparable. At the pre-test, the means are very close (GE^{1}: $M = 1.47$; GE^{2}: $M = 1.55$), with similar standard deviations, and the independent-samples *t*-test does not indicate statistically significant differences ($t = –0.59$, $p = .555$, $p > 0.05$). At the post-test, the mean is higher for GE^{2} ($M = 6.45$; $SD = 1.77$) than for GE^{1} ($M = 5.90$; $SD = 2.25$), although the distributions show deviations from normality ($p < 0.05$), more pronounced in GE^{2}.

Table 3.15

Kolmogorov–Smirnov Test Results

Depend variable / Testing moment	GE^1 (PlantNet) N = 49				GE^2 (drawings) N = 52			
	M	*SD*	*Z*	*p*	*M*	*SD*	*z*	*p*
Initial test	8.39	1.10	0.1898	0.047	8.24	1.24	0.1516	0.158
Pre-test	1.47	0.68	0.354	< 0.001	1.55	0.67	0.396	< 0.001
Post-test	5.90	2.25	0.206	0.026	6.45	1.77	0.280	< 0.001

Main Results – Hypothesis Testing. The statistical analysis confirms hypotheses H^1 and H^2, showing that both students in GE^1 (PlantNet) and those in GE^2 (Drawings) obtained significantly higher post-test scores compared to the pre-test. However, hypothesis H^3 is not supported, as the differences between the two groups at the post-test are not statistically significant, the effect of the "learning method" factor being very small.

Secondary Results – Students' Degree of Plant Blindness. At the pre-test, students in both groups correctly identified only a few plants (especially spruce and oak), and the scores of girls and boys were very similar, with girls having slightly higher means. At the post-test, over 86% of students correctly identified pine, oak, and spruce, and the scores increased substantially ($M \approx 6$ points), with small differences between girls and boys (in GE^1: $M_b = 6.00$ vs. $M_g = 5.79$; in GE^2: $M_g = 6.52$ vs. $M_b = 6.38$). The results regarding plant blindness show that, at the pre-test, students exhibited a high level of plant blindness, while at the post-test, the majority shifted to a medium or low level of plant blindness in both groups.

Table 3.23

Distribution of Students by Categories of Plant Blindness

Group	Testing moment	Low (0–3 unrecognized plants)		Medium (4–7 unrecognized plants)		High (8–10 unrecognized plants)	
		No.	%	No.	%	No.	%
GE^1	Pre-test	0	0	0	0	49	100
(N = 49)	Post-test	18	36.7	30	61.2	1	2
GE^2	Pre-test	0	0	0	0	51	100
(N = 51)	Post-test	26	51.0	24	47.1	1	2.0

3.3.4 Discussions and Conclusions

Discussion on the Choice of Topic. he content addressed in this activity, included in the *"School Curriculum for the subject 'Natural Sciences, Grades 3 and 4'"*, was selected based on the availability of natural teaching resources (plant samples), digital resources (the PlantNet application), and traditional resources (illustrative drawings), the nature and level of difficulty of the content (plant organs: leaf, flower, fruit, bark), the presence of the ten plant species in the urban environment, and the high level of plant blindness, allowing students to review, deepen, and discover new information.

Discussion on Hypothesis Testing. The first two hypotheses are confirmed, as the statistical analysis indicates a significant increase in scores from pre-test to post-test for both students in GE^1 who used the PlantNet application and students in GE^2 who used illustrative drawings. Hypothesis H^3 is not supported, as students in GE^1 obtained lower post-test scores than those in GE^2; however, the difference between groups is small and not statistically significant (Hedges' $g = -0.27$).

Discussion on Students' Degree of Plant Blindness. The statistical analysis shows that, at the pre-test, students in both groups exhibited a high level of plant blindness, while at the post-test the degree of plant blindness decreased in both groups, more noticeably in GE^2 (Drawings) than in GE^1 (PlantNet), due to the application of the signaling, spatial contiguity, and coherence principles.

Discussion on Discovery-Based Learning Activities. The activity of identifying plants using the PlantNet application follows the principle of guided discovery, engaging students in an inductive process of discovery-based learning, from concrete to abstract. It transforms them into active participants who analyze, compare, and make decisions based on matching rates, and ultimately supports the development of critical thinking and skills for verifying information from online sources.

Educational Implications. Students should learn how to search for and verify information in the online environment and to use applications responsibly in order to benefit appropriately from their educational potential.

Research Limitations. The selection of participants only from the urban environment, from a single city, as well as the fact that students did not choose the plants themselves and did not use the PlantNet application in nature but in the classroom, may be considered limitations, although they contributed to the standardization of conditions and the control of knowledge.

Directions for Future Research. Future studies could involve students from different grade levels and residential environments, conduct comparative research, allow students to photograph plants in nature—selected either by the teacher or by themselves according to different criteria—and include a questionnaire regarding satisfaction with the use of the PlantNet application and the difficulties encountered.

3.4 Study 4: The Effectiveness of Guided Discovery Learning Compared to Learning through Observation and Reception

3.4.1 Introduction

During students' interaction with online resources, they are exposed to multiple types of media that they observe and listen to. The ability to observe plays an important role in the early years of life (Covill & Pattie, 2002). To improve their observation skills and to distinguish relevant aspects of the observed objects or phenomena, children need contexts in which they can observe carefully (Tomkins & Tunnicliffe, 2007), explore using all their senses, notice details, sort, group, and classify (Johnston, 2011), and use tools, specific knowledge, and experience to construct reasoning (Eberbach & Crowley, 2009), either independently or together with adults (Johnston, 2011). In the case of dynamic visual materials (animated films, videos, etc.), children are exposed to a sequence of images that quickly disappear from their visual field; therefore, these are not adequately processed in sensory and working memory.

In discovery-based learning using online resources in science, for the development of scientific observation skills and scientific thinking, children should be aware of the purpose of the observation activity and the expected learning outcomes (Morris, 2007), receive support from others (Pahome, 2023b), and use appropriate tools (de Bóo, 2006). Observation worksheets are tools that help students actively engage in the learning process, observe, analyze, compare, and interpret information (Pahome, 2023b), and construct their knowledge in an autonomous manner, with the indirect support of the teacher (Kuhlthau, 2010).

***Purpose, Variables, and Hypotheses*.** The purpose of this research is to investigate the effectiveness of using worksheets in discovery-based learning of knowledge through online resources in the subject "Natural Sciences" and to compare its effects with learning through reception and observation of illustrative drawings within a PowerPoint presentation.

The independent variable (IV) of the study is the learning method. This variable has two levels: the use of worksheets with online resources and the reception of the teacher's presentation combined with the observation of images from a PowerPoint presentation.

The dependent variable (DV) is the volume of students' knowledge, operationalized as the number of correct responses out of 10 items, measured at pre-test and post-test. The control variables include the pre-test (initial level of knowledge), the actual time allocated to the activity, and students' prior experience in searching for online resources.

The research hypotheses are as follows:

H^1 – Students who use worksheets and online resources at home will obtain significantly higher post-test scores compared to the pre-test, indicating an increase in knowledge volume.

H^2 – Students who listen to the teacher's explanation and observe images in a PowerPoint presentation will obtain significantly higher post-test scores compared to the pre-test, indicating an increase in knowledge volume.

H^3 – Students who use worksheets and online resources at home will obtain significantly higher post-test scores than students who listen to an explanation and observe images in a PowerPoint presentation.

H^4 – Students who use worksheets and online resources at home will show significant improvements in most item categories across all three topics.

H^5 – Students who listen to the teacher's explanation and observe images in a PowerPoint presentation will show significant improvements in most item categories across all three topics.

H^6 – There will be significant differences between students who use worksheets and online resources at home and those who listen to an explanation and observe images in a PowerPoint presentation for most item categories across the three topics.

3.4.2 Method

Participants. The research was conducted between March and May, during the 2022–2023 school year, in six schools from Bistrița-Năsăud County (two urban and four rural), selected based on criteria related to location, availability of equipment, and internet access.

A total of 124 first-grade students (mean age: 8 years) participated in the study, forming two groups (GE^1 = 61 students; GE^2 = 63 students) based on the results obtained on the initial test. All ethical requirements and data confidentiality regulations were respected, in accordance with GDPR (2016), and the participation of students, teachers, and parents was voluntary.

Procedure. The research design followed a pre-test – formative intervention – post-test structure, with two experimental groups: GE^1, which learned through discovery using worksheets and online resources (the intervention conducted at home, with parental support in searching for information, without influencing the choice of answers), and GE^2, which learned at school through reception (listening to a text) and observing images presented in PowerPoint.

Students participated in three activities within the subject "Mathematics and Environmental Exploration," each activity including a pre-experimental stage (pre-test), a formative intervention stage, and a post-experimental stage (post-test); the post-test was administered to GE^2 on the same day and to GE^1 on the following day.

Instruments. Data collection was carried out using an initial test, three pre-tests, and three post-tests developed by the researcher, aligned with the intended learning objectives and the content studied, with a maximum score of 10 points.

Data Analysis

Preliminary Analyses. To test the equivalence of the two experimental groups (GE^1 and GE^2) before the intervention, comparative statistical analyses were conducted. The normality of the distribution of results was tested using the Kolmogorov–Smirnov test, and the independent-samples *t*-test was applied at the pre-test stage to verify whether the groups were equivalent prior to the formative intervention.

Main Analyses – Hypothesis Testing. At the level of the initial test, the data were normally distributed, but for the other pre-tests and post-tests, the data were non-parametric in nine out of twelve cases. For comparisons between pre-tests and post-tests within each group, the Wilcoxon test was used. To assess the magnitude of the learning effect for each group, beyond statistical significance, Cohen's *d* was calculated. For comparisons between GE^1 and GE^2, the Mann–Whitney U test was applied.

3.4.3 Results

Preliminary Results. The analysis of the initial test results shows that the means of the two groups, GE^1 (M = 8.38) and GE^2 (M = 8.44), are similar, with comparable standard deviations (GE^1: SD = 1.23; GE^2: SD = 1.31). The distributions meet the assumption of normality ($p > 0.05$), and the independent-samples *t*-test ($t = -0.281$, $p = 0.780$) indicates that there are no statistically significant differences between initial performances; therefore, the groups are equivalent before the formative intervention.

Across the three interventions and the two testing moments, p values < 0.05 in the Kolmogorov–Smirnov test indicate that, in most cases, the score distributions do not meet the assumption of normality; therefore, non-parametric tests are required for subsequent comparative data analysis.

Table 3.25

Kolmogorov–Smirnov Test Results for Pre-test and Post-test across the Three Topics, for GE^1 and GE^2

Testing moment	Subject	GE^1 (with worksheet) (N = 61)				GE^2 (with PowerPoint presentation) (N = 63)			
		M	*SD*	*Z*	*p*	*M*	*SD*	*Z*	*p*
Initial assessment	Science (Grade I)	8.38	1.23	0.125	0.272	8.44	1.31	0.131	0.213
Pre-test	Water transformations	4.90	2.24	0.213	0.006	4.90	2.11	0.143	0.139
	Geometric shapes	5.43	1.95	0.304	< .001	5.37	1.62	0.240	< .001
	Sound propagation	4.59	1.50	0.187	0.024	4.89	1.56	0.211	0.006
Post-test	Water transformations	7.44	1.74	0.137	0.184	7.35	1.76	0.216	0.005
	Geometric shapes	8.30	2.19	0.249	< .001	8.29	1.97	0.236	< .001
	Sound propagation	6.97	1.56	0.279	< .001	7.19	1.49	0.167	0.053

Main Results – Hypothesis Testing. The results show that in both GE^1 and GE^2 scores increased significantly from pre-test to post-test across all three topics, with statistically significant differences ($p < .001$) and large to very large effect sizes (d ranging from 1.36 to 1.98 for GE^1; d and from 1.42 to 2.66 for GE^2), thus confirming hypotheses H^1 and H^2 and indicating a substantial increase in the volume of knowledge under both learning conditions. The comparison between GE^1 and GE^2 using the Mann–Whitney U test shows that there are no statistically significant differences between the groups for any of the three topics ($p > 0.05$; Δ close to 0), the progress being balanced, which does not support H^3.

Hypotheses H^4 and H^5 are largely confirmed, as students in both groups showed significant progress in definitions, identification of phenomena, and, partially, in inferences, with effect sizes ranging from moderate to very large (d between 0.43 and 1.56), with some exceptions for the topic "Sound Propagation." Hypothesis H^6 is only partially supported, as significant differences between GE^1 and GE^2 appeared only in certain subcomponents of the topic "Sound Propagation," while for the other topics, performance levels were similar.

Table 3.30

Comparative Results by Item Groups at Pre-tests and Post-tests for GE1 vs. GE2 (Independent-Samples t-test and Cohen's d)

Topic	Category	Items	Mean GE^1	Mean GE^2	*t*	*p*	Cohen *d*
Transformations of Water	Definitions	1, 2, 3, 6, 7	3.75	3.38	1.54	0.126	0.28
	Identification of phenomena	4, 5	1.46	1.49	–0.27	0.788	–0.05
	Inferences	8, 9, 10	2.28	2.48	–1.87	0.063	–0.34
Geometric Shapes	Definitions	1, 2, 7, 8	3.08	3.16	–0.40	0.690	–0.07
	Identification of phenomena	3, 4, 5, 6	3.46	3.24	1.16	0.250	0.21
	Inferences	9, 10	1.75	1.89	–1.70	0.092	–0.31
Sound Propagation	Definitions	1, 2, 7, 8	2.13	3.16	–5.73	< .001	–1.03
	Identification of phenomena	3, 4, 5	2.30	1.60	5.47	< .001	0.99
	Inferences	6, 9, 10	2.54	2.49	0.41	0.686	0.07

3.4.4 Discussions and Conclusions

Discussion on the Choice of Topic. For the experimental activities, three topics included in the *"School Curriculum for the subject Mathematics and Environmental Exploration"*, appropriate for Grade 1, were selected based on the nature and level of difficulty of the content, the availability of online teaching resources, and students' prior knowledge.

Discussion on Hypothesis Testing. The statistical analysis indicates a significant increase in scores from pre-test to post-test for students in both GE^1 and GE^2, confirming hypotheses H^1 and H^2, with very large effect sizes across all three topics. The progress was visible, consistent, and balanced in both groups, while the differences between GE^1 and GE^2 were small and not statistically significant; therefore, hypothesis H^3 is not supported.

Hypotheses H^4 and H^5 are confirmed in most cases, while H^6 is supported only for certain categories of items within the topic "Sound Propagation." Overall, the results show that both forms of organizing learning were effective and led to a real and measurable increase in the volume of knowledge.

Research Limitations. Although the results support the effectiveness of the interventions and students' cognitive progress, they must be interpreted considering the possible influence of prior knowledge, uncontrolled variables in the family environment, and parental mediation, as well as the fact that the post-test was administered at different times in the two groups, the lack of a long-term retention measure, and the relatively small number of students, which limits the generalization of the conclusions.

Directions for Future Research. Based on the results and the identified limitations, the research could be extended by introducing a re-test to assess retention, by replicating the intervention under controlled school conditions and administering tests under identical conditions, by using different cognitive scaffolding tools, and by conducting studies on larger and more diverse samples, in order to analyze not only how much students learn, but also how they learn and what strategies they use in discovery-based learning.

3.5 Study 5: The Effectiveness of Using the Study Guide and Worksheet in Discovery-Based Learning from Online Resources

3.5.1 Introduction

In science studies conducted at the primary education level, students have used various online resources: videos (Elian & Hamaidi, 2018; Doroșin Ilie, 2025; Koto, 2020; Khan et al., 2025; Ilie et al., 2023), digital materials (Ugwuanyi, 2022), texts/online sources (Ilie et al., 2023), silent films (Ilie & Cristea, 2020a), films (Ilie et al., 2021; Ilie et al., 2020b), and animated films (Vereș et al., 2021; Vereș et al., 2020a; Vereș & Magdaș, 2020a). Studies in which children aged 6–12 learn through discovery or inquiry show the benefits of these instructional strategies or models. Guided discovery learning is more effective than pure discovery because it helps students construct knowledge, assign meaning to new information, and integrate new information into their existing knowledge base (Shulman & Keisler, 1966). The review of the literature highlights the necessity of guiding discovery-based learning in science carried out by primary school students.

In this study, we considered that the results of the quasi-experimental study in which first-grade students learned through discovery using online resources and worksheets may have been influenced by parental intervention and their prior knowledge regarding the three topics ("Water Transformations," "Geometric Shapes," "Sound Propagation"). Therefore, in this study, we involve fourth-grade students, who have greater autonomy in learning, and we propose a topic that is less familiar to students, as it is not included in the official curriculum.

Purpose, Variables, and Hypotheses. The first purpose of this research is to investigate the effectiveness of the optional use of the study guide and the mandatory use of the worksheet in the process of discovery-based learning of knowledge about the hummingbird, using online resources proposed by the teacher and selected by students, within the subject "Natural Sciences." In this study, the effects of using these two instruments in discovery-based learning are compared with the effects of discovery-based learning without the use of such instruments.

The independent variable of the quasi-experimental study is the condition or method of discovery-based learning. This variable has three levels: the optional use of the study guide (GE1); the mandatory use of the worksheet (GE2); and learning without a study guide or worksheet (GE3). The dependent variable consists of the volume of students' knowledge measured through a knowledge test on the hummingbird, operationalized as the number of correct responses (maximum score = 10), assessed at pre-test and post-test. The control variables (covariates) are represented by the pre-test (students' initial level of knowledge, expressed through the pre-test score) and students' prior experience in using digital technology and online resources.

The research hypotheses are as follows:

H^1 – Students who use the study guide in an optional manner (GE^1) will obtain significantly higher post-test scores than pre-test scores.

H^2 – Students who are required to use the worksheet (GE^2) will obtain significantly higher post-test scores than pre-test scores.

H^3 – Students who learn without a study guide and without a worksheet (GE^3) will obtain significantly higher post-test scores than pre-test scores.

H^4 – Students who are required to use the worksheet (GE2) will obtain significantly higher post-test scores, controlling for pre-test level, compared to students who use the study guide in an optional manner (GE^1).

H^5 – Students who are required to use the worksheet (GE^2) will obtain significantly higher post-test scores, controlling for pre-test level, compared to students who learn without a study guide and without a worksheet (GE^3).

H^6 – Students who use the study guide in an optional manner (GE^1) will obtain significantly higher post-test scores, controlling for pre-test level, compared to students who learn without a study guide and without a worksheet (GE^3).

The second purpose of the research is to investigate how students perceived the learning activity about the hummingbird, by analyzing their level of satisfaction, the degree of autonomous engagement in the study, the discussions held with other people about the topic, as well as the aspects considered most interesting or unclear by the students.

The research also aims to identify differences in students' opinions (responses) according to gender and experimental condition (GE^1 – study guide, GE^2 – worksheet, GE^3 – without instrument), based on quantitative indicators (means, standard deviations, percentages) obtained from the responses to the questionnaire items.

To achieve the second purpose of the research, the following research questions were formulated:

RQ^1 – What is the level of satisfaction and enjoyment of primary school students regarding the activity about the hummingbird, and to what extent does it differ according to gender (boys/girls) and experimental condition (GE^1 – study guide, GE^2 – worksheet, GE^3 – without instrument)? (*items 1–10*)

RQ^2 – To what extent did the activity stimulate primary school students to autonomously explore additional resources (online sources), and how does this exploration differ according to gender and experimental group? *(items 11–12)*

RQ^3 – To what extent did the activity stimulate primary school students to autonomously explore additional resources (online sources), and how does this exploration differ according to gender and experimental group? *(item 13)*

RQ^4 – Which aspects of the activity were most appreciated by primary school students, and how do these preferences differ according to gender and groups (experimental condition)? *(open-ended item 14)*

RQ^5 – What information about the hummingbird was perceived by primary school students as the most interesting, and how does this interest vary according to gender and groups? *(open-ended item 15)*

RQ⁶ – Which aspects about the hummingbird remained unclear for primary school students after the activity, and to what extent do these uncertainties differ according to gender, experimental condition, and type of knowledge? *(open-ended item 16)*

3.5.2 Method

Participants. The research was conducted during the 2024 − 2025 school year, in May June, in three schools located in urban areas, in the counties of Sălaj, Neamț, and Dâmbovița. A total of 146 fourth-grade students participated in the study, with a mean age of 10 years, of both genders, in compliance with legal requirements and informed consent procedures, in accordance with GDPR (2016). The students were organized into three experimental groups: (GE^1 = 40; GE^2 = 52 and GE^3 = 54).

Procedure. The research design followed a pre-test – formative intervention – post-test structure, with three experimental groups: GE1 – discovery-based learning with the optional use of the study guide; GE2 – discovery-based learning with the mandatory use of the worksheet; GE3 – discovery-based learning without the use of a study guide or worksheet. All experimental groups went through three stages: the pre-experimental stage, in which the pre-test was administered in the classroom; the formative intervention stage, conducted at students' homes, in which they studied the topic "The Hummingbird" through discovery, based on web pages and video resources recommended by the teacher, according to the condition assigned to each group (GE1, GE2, GE3); and the post-experimental stage, in which the post-test (identical in structure to the pre-test) and a questionnaire were administered in the classroom. Students completed the tests and the questionnaire in printed format. The questionnaire aimed to capture students' perceptions of the learning experience based on online resources and the way they explored and evaluated the information discovered on the internet.

Instruments. Data collection was carried out using a pre-test, a post-test, and a questionnaire developed by the researcher, aligned with the intended learning objectives and the content studied, with a maximum score of 10 points. The study guide included 12 questions about the hummingbird, while the worksheet consisted of a gap-fill text comprising 39 sentences.

Data Analysis

Preliminary Analyses. The data obtained from the pre-test and post-test were statistically analyzed using Excel and SPSS. To verify whether the groups were comparable before the intervention, the independent-samples *t*-test (Welch's version) was applied, and descriptive statistics were calculated for each group (*M*, *SD*, *SEM*, skewness, kurtosis). The normality of data distribution was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests, and the homogeneity of variances was tested using Levene's test. For the application of ANCOVA, the homogeneity of variances and the homogeneity of regression slopes were verified, descriptive statistics for the post-test were calculated (*M*, *SD*, *M*adj, *SE*, 95% CI), and the normality of the difference scores (Δ = post-test – pre-test) was tested using the Shapiro–Wilk test.

Main Analyses at the Level of the Research Questions. For items 1–10 of the questionnaire, the mean and standard deviation were calculated for each group (GE^1 – study guide, GE^2 – worksheet, GE^3 – without instrument) and for the gender variable; therefore, the data analysis is descriptive in nature. For items 11–12, which are closed-ended (Yes/No), the number of students who selected the answer "Yes" and their proportion (%) were calculated. For item 13, which includes a list of three predefined categories (parents, classmates, friends), the number of students who selected each category and their proportion (%) were calculated. Items 14, 15, and 16 are open-ended questions. The responses to these questions were coded and grouped into content categories according to the purpose of the research.

3.5.3 Results

Preliminary Results. The descriptive statistical analysis shows that at the pre-test, the means of the three groups are similar, the standard errors are small (*SEM* ranging from 0.086 to 0.135), and the skewness and kurtosis values are close to 0, while the Shapiro–Wilk and Kolmogorov–Smirnov tests indicate an approximately normal distribution ($p > .05$). Levene's test at the pre-test ($F(2, 143) = 2.30$, $p = .104$) indicates homogeneous variances, and Welch's *t*-test shows no significant differences between groups; Cohen's *d* values are small or negligible (0.09; −0.02; −0.12). At the post-test, the variances are unequal ($W = 7.27$, $p < .001$), but the homogeneity of regression slopes is met ($W = 1.41$, $p = .248$); therefore, *ANCOVA* with *HC3* robust standard errors can be applied, and parametric tests can be used for the main analyses.

Main Results – Hypothesis Testing. The descriptive statistical analysis shows that, at the post-test, the means of GE^1 ($M = 7.92$) and GE^2 ($M = 7.89$) are similar and higher than that of GE^3 ($M = 6.45$), and the adjusted means are also similar (M_aj ≈ 7.90 *vs*. 6.44). The standard error is small ($SE = 0.13$–0.15), indicating stable estimates and allowing valid comparisons through *ANCOVA*. The Shapiro–Wilk test indicates normal distribution for GE^1 and GE^3 ($p > .05$), while for GE^2 the differences are not normally distributed ($p = .009$), which is why the Wilcoxon test was also applied, indicating a significant increase at the post-test ($W = 5.00$, $p < .001$), with a very large effect ($Z = 6.23$, $r = .87$).

Table 3.36

Descriptive Statistics of Post-test Scores and Gain Scores (Δ = Post–Pre)

Group	*N*	*M*	*SD*	*M_aj*	*SE*	*IC* 95%	*M(Δ)*	*AS(Δ)*
GE^1	40	7.92	0.70	7.91	0.15	[6.05, 9.78]	2.62	1.00
GE^2	52	7.89	1.23	7.90	0.13	[6.04, 9.76]	2.65	1.21
GE^3	54	6.45	0.78	6.44	0.13	[4.58, 8.30]	1.13	1.00

Within-Group Analysis: Progress from Pre-Test to Post-Test (Hypotheses H^1–H^3)

The paired-samples *t*-test shows that all three groups recorded statistically significant increases between pre-test and post-test ($p < .001$). In GE^1 (study guide), the progress is very large, $t(39) = 16.53$, $d = 2.62$. In GE^2 (worksheet), the progress is similar in magnitude, $t(51) = 15.79$, and the Wilcoxon test confirms the difference ($W = 5.00$, $p < .001$), with a very large effect ($d = 2.19$; $r = .865$). In GE^3 (without instrument), the progress is significant but more modest, $t(53) = 8.29$, $d = 1.13$. Discovery-based learning with supporting instruments (study guide, worksheet) produced effects nearly twice as large as discovery-based learning without a supporting instrument.

Table 3.38

Results of the Paired Samples t-test (Dependent) (Pre-test vs. Post-test) and Cohen's dz

Group	*N*	*M*_Dif	*AS*_Dif	*t*(df)	*p*	*SE*_dif	*IC*95%	Cohen_ *dz*
GE^1	40	2.62	1.00	16.53(39)	< .001	0.158	[2.30, 2.94]	2.62
GE^2	52	2.65	1.21	15.79 (51)	< .001	0.168	[2.32, 2.99]	2.19
GE^3	54	1.13	1.00	8.29 (53)	< .001	0.136	[0.86, 1.40]	1.13

Between-Group Analysis: Testing Hypotheses H^4–H^5.

The analysis of covariance (*ANCOVA*) indicates a significant effect of the learning condition on post-test performance, after controlling for the initial score, $F(2, 142) = 42.13$, $p <$

.001, with a large effect size (partial $\eta^2 = .37$). The difference between the worksheet and the study guide is not significant, $t(142) = -0.07$, $p = .95$, $d = 0.01$, but both groups obtained significantly higher results than the group without an instrument (GE^2 vs. GE^3: $t(142) = 8.06$, $p < .001$, $d = 1.57$; GE^1 vs. GE^3: $t(142) = 7.59$, $p < .001$, $d = 1.58$). The *ANOVA* on the gain score confirms the effect of the learning condition, $F(2, 143) = 33.15$, $p < .001$, and the Tukey post-hoc tests show that the use of a supporting instrument (study guide or worksheet) leads to significantly greater improvements than learning without an instrument, with no differences between the two instruments ($p = .987$).

Main Results at the Level of the Research Questions. he results indicate a very high level of appreciation for the activity on the hummingbird ($M = 4.23 – 4.73$), with students particularly valuing the learning of interesting information ($M = 4.73$) and new information ($M = 4.58$), the clarity of tasks ($M = 4.66$) and autonomy in exploring resources ($M = 4.52$). Girls consistently reported higher scores than boys, and students in the worksheet group showed the highest levels of appreciation, followed by those using the study guide, while the group without an instrument recorded the lowest scores. More than half of the students searched for additional web sources (53.42%), and 46.58% watched additional videos, indicating a moderate tendency toward further exploration. Many students discussed the hummingbird with classmates (65.75%) and with parents (64.38%). The most interesting aspects were perceived to be physical characteristics (37.59%) and flight speed, while the most frequent uncertainties concerned size (19.23%), reproduction (16.35%), and feeding (14.42%). Overall, students showed interest in the scientific content, formulated both factual and conceptual questions, and demonstrated cognitive engagement in analyzing and understanding the information.

3.5.4 Discussions and Conclusions

Discussion on the Choice of Topic. The hummingbird was selected as the topic because students are generally unfamiliar with it or have limited prior knowledge about this bird, they are interested in learning about animals, and the uniqueness of its characteristics (size, flight, feeding) has a high potential to stimulate and satisfy students' curiosity.

Discussion on the Design of the Pre-Test and Post-Test. Both the pre-test and post-test included 40 True/False items, aligned with the information provided in the online sources, the worksheet, and the study guide. These items were designed to stimulate curiosity, generate cognitive conflict, and promote critical thinking by combining true and false information within the statements.

Discussion on the Design of Instruments for Guiding Discovery-Based Learning. The worksheet (39 incomplete sentences) provides a high level of guidance and a high degree of difficulty, requiring the mandatory completion of information discovered in online sources, while the study guide (12 questions) offers a moderate level of guidance and greater autonomy in selecting information. Both instruments represent forms of scaffolding—explicit, context-specific, strategic, and affective—through which students are supported in discovery-based learning.

Discussion on the Effectiveness of Instruments in Discovery-Based Learning ((Hypotheses H^1–H^3)*.* The results show that instructional support tools—the worksheet and the study guide—strongly influenced discovery-based learning using online resources: the worksheet ($M\Delta$ = 2.65; d = 2.19; r = .865) and the study guide ($M\Delta$ = 2.62; d = 2.62) generated nearly double the progress compared to learning without an instrument ($M\Delta$ = 1.13; d = 1.13). This indicates that cognitive scaffolding, whether directive or orientative, guides attention, reduces cognitive overload, and facilitates active processing and retention of information in long-term memory, whereas in its absence, progress is lower.

Discussion on Students' Perceptions of the Discovery-Based Learning Activity. The means of the ten items indicate a very high level of satisfaction and appreciation of the activity. More than 50% of students searched for additional web sources, nearly half watched additional videos, over 60% discussed the topic with classmates and parents, and 52.05% stated that they enjoyed discovering and learning new information. Approximately 40% were impressed by the physical characteristics of the hummingbird, and the 60 questions formulated (13 factual and 47 conceptual) indicate that the activity stimulated curiosity; however, discovery-based learning conducted individually at home using online resources does not fully satisfy the need for deeper understanding and requires subsequent mediation in formal contexts.

Research Limitations. The results may be influenced by the selection of participants from only one class in each school, the implementation of discovery-based learning at home (with uncontrolled variables and possible parental support), the differences between instruments (12 questions in the study guide and 39 sentences in the worksheet), the exclusive use of True/False items, which primarily assess factual knowledge, the absence of a re-test to assess learning retention, and the relatively small number of students involved ($GE^1 = 40$, $GE^2 = 50$, $GE^3 = 54$), all of which limit the generalizability of the findings.

Directions for Future Research. To confirm and generalize the conclusions, further studies are needed with larger samples of students from different environments and countries, the organization of the intervention in controlled school settings, and the comparison of discovery-based learning conducted at home and in the classroom. Additionally, re-testing at 2–12 weeks is recommended to assess the stability of learning, as well as measuring additional variables (motivation, engagement, digital competence, time on task, navigation strategies) and comparing other forms of cognitive scaffolding (immediate feedback, digital games, artificial intelligence applications).

CHAPTER IV

CONCLUSIONS AND RESEARCH IMPLICATIONS

4.1 Theoretical Implications

The theoretical implications of the research consist in the conceptual clarification of discovery-based learning as a type of learning that can be associated with a procedure, method, strategy, or instructional model, depending on the context and the level of guidance, as well as in highlighting the role of scaffolding in supporting the active cognitive processes involved in discovery-based learning based on online resources.

4.2 Practical Implications

The practical implications of the research consist in providing concrete guidelines for designing and organizing discovery-based learning using online resources in science, by adapting the level of instructional guidance (worksheet, study guide, or absence of instruments), integrating the PlantNet application, and effectively using the selected tools, so that the process of knowledge construction is supported efficiently according to students’ age and level of autonomy.

4.3 Research Limitations

The investigated samples are not nationally representative (limited geographical distribution, predominance of the urban environment or of a particular gender, and a relatively small number of participants in Studies 3, 4, and 5), which reduces the possibility of generalizing the conclusions. In Studies 1 and 2, the use of self-report questionnaires may lead to underestimation or overestimation of actual behaviors, and the formulation of the items reflects the researcher's own perspective on discovery-based learning using online resources. In the quasi-experimental studies, the control of contextual variables was limited, especially in interventions conducted at home, where parental support and differing working conditions may have influenced the results. The instruments and assessment conditions (type of items, selected content, different moments of post-test administration) may limit the complete capture of the cognitive processes involved in discovery-based learning and may affect the comparability of the results. The absence of a long-term retention measure does not allow conclusions regarding the stability and durability of the acquired knowledge.

4.4 Directions for Future Research

To confirm and generalize the conclusions, future research could be extended at national and international levels, involving a larger number of participants from different environments (urban/rural, different socio-economic and cultural backgrounds). The instruments developed in this thesis may be improved and applied to other subjects and educational levels, as well as in comparative studies between regions and different educational contexts. In the quasi-experimental studies, re-tests at 4–12 weeks could be introduced in order to assess medium- and long-term retention, and the interventions could be replicated in controlled school settings, comparing learning conducted at home with learning conducted in the classroom. To deepen the understanding of discovery-based learning, future research may analyze not only the volume of acquired knowledge, but also the way students learn and the strategies they use, as well as the effectiveness of different forms of cognitive scaffolding and levels of learning autonomy.

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