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ABSTRACT OF DOCTORAL THESIS

FORMATION OF REPRESENTATIONS IN PRIMARY EDUCATION, IN SCIENCE

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DECLARATION

I, the undersigned, Daniela Pahome, as a doctoral student at "Babeș – Bolyai" University, declare the following:

The doctoral thesis titled "Formation of Representations in Primary Education, in Sciences" has been completed with strict adherence to the four values of academic integrity – honesty, responsibility, replicability, and validity of knowledge.

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LIST OF ABBREVIATIONS AND ACRONYMS

APA — American Psychological Association
GE — Experimental Group
GL — Work Group
p. — page
pp. — pages
PISA — Programme for International Student Assessment
TIMSS — Trends In International Mathematics And Science Study
ZPD — Zona Proximei Dezvoltări

Keywords: mental representation, external representation, mental model, cognitive process, learning, mental image, teaching method, teaching strategy, sciences, primary education

CHAPTER I

THEORETICAL FRAMEWORK

1.1 Introduction and Research Problem

Scientific education of citizens is considered a necessity in contemporary society (Mujika & Aranzabal, 2015). Scientific knowledge helps us understand the world we live in correctly, precisely, and comprehensively, while scientific skills enable us to adapt optimally to this world and contribute to its development. To date, there have been numerous studies investigating the teaching and learning of science, but the number of studies addressing science learning in primary education is limited, and they do not explicitly explore students' representations.

At the global level, there are several problems and deficiencies in science education. A first problem is revealed by the international assessments "Trends in International Mathematics and Science Study" [TIMSS] and "Programme for International Student Assessment" [PISA]. The two international programs provide an overview of student results, as a result of teaching and learning. On these tests, the results of Romanian students have been consistently unsatisfactory (Ciascai & Dulamă, 2013).

The TIMSS assessments are administered to fourth and eighth-grade students once every four years. In 2019, eighth-grade students in Romania scored 470 points in science, compared to the international average of 500 points (Mullis et al., 2020). In the field of science, in 2007, students achieved a minimum score of 458 points (Martin et al., 2008). These results indicate that the level of students' science competencies is similar to that of 25 years ago. It is concerning that 22% of students are functionally illiterate in science, below the international average of 13%. In Romania, 4% of students excel in science, below the international average of 5%, and nearly a quarter of students do not meet the minimum performance criteria. Additionally, the TIMSS 2019 results reveal unfavorable percentages for Romania, both in terms of students' self-confidence and the socio-economic situation of students' families (Mullis et al., 2020).

The PISA assessments are applied to 15-year-old students around the world once every three years. The tests assess reading, mathematics, and science skills. The results of the 2018 PISA assessment show that the international average in science has fallen from 493 points in 2015 to 489 points in 2018. This trend was also recorded in Romania, where the average fell from 435 points in 2015 to 426 points in 2018. It was found that students recognize and identify some explanations of simple scientific phenomena, but they cannot find, without support or guidance, causal relationships or other scientific correlations. 56% of students tested in Romania were at level 2 of competence or higher. These students "recognize the correct explanation of a familiar scientific phenomenon" and can use their knowledge to evaluate certain data to support a conclusion. Only 1% of students performed very well in science (level 5 or 6). These students can apply their scientific knowledge independently and creatively in a variety of situations, including unfamiliar ones.

Other issues and deficiencies are identified at the level of school programs and textbooks. In Romania, in the study conducted by Ciascai & Dulamă (2013) regarding science programs for primary education, it is suggested that one possible cause of the poor results obtained by Romanian students in international science tests may be these official curriculum documents. In another study of the "Mathematics and Exploration of the Environment for Kindergarten, Grade 1 and 2" curriculum, imprecision and lack of rigor in the presentation of content are noted, which creates difficulties in the design and organization of teaching activities, in the allocation of time resources, and in the decision on the level of content depth. Researchers conclude that these problems can lead to a superficial understanding of large amounts of information, and to their memorization instead of deep learning (Dulamă & Magdaș, 2014).

Other studies highlight deficiencies in primary school mathematics and science textbooks (Buzilă et al., 2017; Lalău, 2014; Magdas & Drîngu, 2016; Magdaș et al., 2017), and these can also influence science learning and students' results. In another study, some of the surveyed teachers argue that the textbooks for "Mathematics and Environmental Exploration" offer little motivation for learning, exploring the environment in everyday contexts, holistic understanding of reality, the scientific rigor required for environmental science, and the depth of environmental science knowledge (Magdaș et al., 2017).

International studies support that teachers play an essential role in science education, but also identify a variety of problems and deficiencies. The study conducted by the Organization for Economic Cooperation and Development [OECD] (2005) highlights three problematic aspects related to science teachers: the inappropriate selection of teachers; the lack of flexibility and incentives in the teaching career; the initial and continuous training of teachers. Diaz (2017) also notes that the lack of promotion opportunities can lead to stagnation and low motivation, which can negatively affect the quality of teaching.

The PISA study (ME, 2019) reveals that 49.4% of teachers instructing in the evaluated schools in Romania have completed master's courses (with the participating countries' average being 43.9%). The data from the study indicate a weak correlation between the teachers' level of education and students' outcomes. In this study, it is argued that students' results are influenced by the teachers' attitude towards teaching and the enthusiasm demonstrated in their instructional activities. It was found that in most countries, including Romania, students who perceived that their teacher taught with passion and interest achieved better results.

The studies mentioned above highlight deficiencies at the level of curricular materials (school curricula and textbooks in mathematics and science), gaps and problems in the initial and continuous training of teachers in science teaching, the need for support materials for science teaching (guides, lesson plans), the lack of material resources in schools, and unsatisfactory student results. We assume that all these deficiencies and problems have an impact on student learning in general and in science in particular.

As solutions for the professional development of primary school teachers, several studies in Romania suggest the organization of open lessons, discussions, and methodological activities, training programs (Magdas & Drîngu, 2016), the creation of informative materials, methodological guides, or teacher manuals (Magdas & Drîngu, 2016; Magdaș et al., 2017), a focus in textbooks on practical activities such as observation, experimentation, investigation, problem-solving, fun and interdisciplinary activities (Lalău, 2014).

In summary, globally, it is noted that in recent years, researchers have not focused their attention on the formation of students' representations in science, which is a complex and inadequately investigated subject. Our interest in investigating the formation of students' representations in science can be explained on the one hand by the gaps and issues highlighted in studies and, on the other hand, by the needs, suggestions, and recommendations of researchers who have explored aspects of science learning in primary education.

Our research aims to address some of the expectations of teachers, such as:

(1) the need to understand the methods and strategies that most strongly influence students' learning in science in primary education (Magdas & Drîngu, 2016; Magdaș et al., 2017), including the formation of representations, for their use in classroom practice;

(2) the need to understand teaching materials and effective ways to use them to have the strongest impact on students' learning in science in primary education (Magdas & Drîngu, 2016; Magdaș et al., 2017), including the formation of representations.

1.2 Theoretical Landmarks Regarding Representations

In dictionaries and other works, the term "representation" is attributed multiple meanings. On the one hand, representation is analyzed as a process, and on the other hand, as a product. Both as a process and as a product, representation can be located either in a person's mind, in which case we refer to internal or mental representations, or in the external environment of the person, in which case we refer to external representations (Zlate, 1999).

Mental representation is defined as: "a hypothetical entity that represents a thought, an evocation, or something similar during cognitive operations" (APA, 2015, p. 641); "a cognitive entity that reflects, in the mental system of an individual, a fraction of the universe outside this system" (Bloch, 2007, p. 753); Active and dynamic constructions of the human mind, which vary depending on individual experiences and can be influenced by social and cultural factors (Bruner, 1974); "a secondary-order product (image), opposed to primacy or the construction of the image of the actual and present object, in the absence of it and even without the existence being obligatory" (Popescu-Neveanu, 1978, p. 617); "a projection into the cognitive system of external reality" (Miclea, 1999, p. 159); projections of reality, in the subject's internal environment, in the form of schematic images, linguistic labels, symbols (Anderson, 2015; Mih, 2018); simplified and abstracted knowledge as symbols, structured in such a way as to facilitate the pursuit of goals and plans in a complex environment (Martinez, 2013); "interiorized models that the subject builds from its environment and through its actions on this environment" (Bloch, 2007, p. 753). It is noted that there is still no consensus on what mental representations might be (APA, 2015).

Zlate (1999) specifies that representation begins with perception but extends to the level of abstract concepts. Functionally, representation exists in the absence of the object; therefore, mental imagery has approximations but facilitates generality. Unlike perception, which reproduces all the characteristics of the object, representations mentally reproduce the important ones. Representation involves processing the information perceived about the subject, namely selecting those with a high degree of generality and assembling them into stable structures and systems of images. Representation is not just a "past and reproduced" perception but a "past, processed, enriched" perception, reworked, and then reproduced (p. 193).

The general properties of representations are "figurativeness," "operativeness," and "panoramicity" (Zlate, 1999, p. 214). Individualizing properties of representation include "intensity," "stability," "degree of completeness," "degree of relevance," "degree of generality," and "character of the designative connection" (Golu, 2005; Popescu-Neveanu, 2013). Jodelet (1988, pp. 362-365) emphasizes that representation, possessing the property of reflecting the external world, does not passively reproduce the outside world inside but does so in an integrated, symbolic, meaningful, constructive, autonomous, creative, and social manner.

The process of representation is described as: a cognitive process by which a person forms a mental image of an entity (object, event, person) (Piaget, 1954); "a process by which something absent is described or expressed" (Cambridge, n.d.), it is made present (Ingold, 2020), visible (Merriam-Webster, n.d.); "an informational-operational mechanism for the primary processing of information" (Zlate, 1999, p.183); a way of encoding and storing information about reality in memory (Hebart, 2020; Lee, 2018; Sternberg & Sternberg, 2012); a mode of encoding input into the cognitive system in various forms: semantic, imagistic, serial, or through activation values (Miclea, 1999); the process by which correspondence is established between two elements and which "results in one replacing or 'presenting differently' the other" (Doron & Parot, 1991/2006, p. 670).

Zlate (1999) summarizes several mechanisms through which representations are formed, for example: through processing (combining, recombining) and systematizing sensory attributes; by selecting the attributes of objects based on the meaning assigned by the individual; through words, representations are organized into systems, fixed in the person's consciousness, acquire meaning and generalized character; through the actions of the individual.

The process of forming representations is influenced by: attention, motivation, emotions, and social context (Tytler et al., 2020). These factors can influence the completeness, relevance, and stability of representations (Wixted & Thompson-Schill, 2018).

Golu (2005, p. 357) presents a classification of representations based on several criteria. According to the dominant sensory mode in structuring informational content, there are several categories of representations: visual, auditory, tactile, kinesthetic, auditory, olfactory, gustatory. According to cognitive reference domains, there are scientific, technical, artistic, religious representations. According to the degree of generality, there are individual representations, species representations, and genus (class) representations. According to the degree of complexity, there are simple representations and complex representations. According to the generative source, there are memory representations and imagination representations. According to the mode of generation, there are intentional or voluntary representations and unintentional or involuntary representations. According to the static-dynamic dimension, there are static representations and dynamic representations. According to the degree of abstraction, there are representations with a moderate degree of abstraction and representations with a high degree of abstraction. Zlate (1999) emphasizes that there are no pure representations, and in fact, representations are multimodal.

Eysenck & Keane (1992) (cited in Zlate, 1999, p. 208) present two categories of representations: internal representations, which exist in the subject's mind, and external representations. External representations consist of signs or symbols that represent objects of knowledge in the absence of that object (Zlate, 1999). In the category of external representations, there are distinctions between pictorial representations and linguistic representations. External representations are seen and shared by other individuals (Tippett, 2016).

In the sciences, scientific knowledge is constructed and communicated in various visual and symbolic forms (maps, graphs, drawings, diagrams, formulas, models), and language plays a complex role (Lemke, 1998). A representation can be considered a scientific model when it embodies the essential characteristics of objects or events, making it integrative, predictive, and explanatory (Gilbert, 2007, 2010). Models are physically represented in various ways or formats: scale models, equations, maps, computer simulations, diagrams (Tippett, 2016).

1.3. Theories Underlying Science Learning

The Cognitive Theory of Multimedia Learning

This theory suggests that people learn more deeply when words and images are used together than when words alone are used, representing the multimedia principle (Mayer, 2005a). Multimedia is the combination of text and images, and multimedia learning occurs when mental representations are constructed from both words and images (Mayer, 2005b). In multimedia, words can be written or spoken, and images can take various forms (graphics, photographs, animations, videos).

CTML is based on three hypotheses (Mayer & Moreno, 1998; Mayer, 2003): (1) based on the Working Memory Theory (Baddeley, 1986) and the Dual Coding Theory (Paivio, 1990), it is highlighted that working memory has two channels; (2) based on the Cognitive Load Theory (Sweller, 1988,1994), it is assumed that each subsystem of working memory has limited capacity; (3) it is also considered that people actively process and construct knowledge in meaningful ways when they pay attention to relevant material, when they organize it into a coherent mental structure, and when they integrate it with their prior knowledge (Mayer, 1996, 1999). Mayer (2009) identified twelve principles of multimedia instruction, which have been further developed in numerous studies. Mayer (2005b) also suggested other principles for multimedia learning, which are not evidence-based and should be demonstrated in future research.

Cognitive Development Theory, as Viewed by Vygotsky

Vygotsky (Vygotsky, 1962, 1978) argues that a child's cognitive development occurs through social interactions. For science learning, the processes of mediation and internalization described by Vygotsky, along with the concept of the Zone of Proximal Development (ZPD), are relevant. Mediation is the process by which a child constructs cognitive tools and develops mental functions with the assistance of another person. The process of internalizing external activities, resulting in the formation of mental structures and cognitive development, occurs in three stages: the child's involvement in an organized activity guided by another person, the child verbalizing their thoughts aloud during problem-solving, and the internalization or mental representation of the performed activity. The ZPD (Vygotsky, 1962, 1978) represents the zone in which a child can learn something unknown. This zone essentially represents the difference between what a child can accomplish or solve independently at a certain moment or stage in their intellectual development and what they can achieve when supported by another person.

Theories Regarding Scaffolded Learning and Teaching Approaches

The term scaffold was introduced by Wood et al. (1976). A scaffold is defined as "the process that enables a child or novice to solve a problem, complete a task, or achieve a goal that would be beyond his unassisted efforts" (Wood et al., 1976, p. 90). With this support, children can reach higher levels of performance than they could without scaffolding. Essentially, scaffolding functions as a mediator within the child's zone of proximal development (Vygotsky 1978).

Scaffolds have been more recently defined as "tools, strategies, or guides that support students in achieving higher levels of understanding" (Devolder et al., 2012, p. 4). Based on their functions, four types of scaffolds have been identified: conceptual, metacognitive, procedural, and strategic (Hannafin et al. 1999; Hill & Hannafin 2001). Yelland and Masters (2007) use the term "cognitive scaffolds" for tools or techniques that assist individuals in developing conceptual and procedural understanding.

Scaffolds have also been differentiated by their delivery method, leading to distinctions between hard or soft scaffolds (Saye & Brush 2002; Sharma & Hannafin 2007), static or dynamic scaffolds (Kim & Hannafin 2010), embedded or non-embedded scaffolds (Narciss et al, 2007), fixed or adaptive scaffolds, and direct or indirect scaffolds.

When implementing scaffolds, Smit et al. (2013) argue that it's essential to diagnose students' prior knowledge, provide support within their zone of proximal development, and gradually withdraw teacher support, allowing students to engage in the learning process independently.

Theories Supporting the Strategy of Learning Through Drawing

The "Generative Theory of Drawing Construction" is derived from the "Generative Learning Theory" (Mayer, 2014; Wittrock, 1992) and explains the conversion of provided text into a drawing (Van Meter & Garner, 2005).

1.4 Current State of the Field

Teachers' Conceptions of Teaching

In the educational process, it is considered that there is a strong relationship between conceptions of teaching, teaching practice, and student learning (Taylor & Booth, 2015). Conceptions of teaching refer to the nature of the content to be taught and how that content should be taught and learned (Da-Silva et al, 2006). Teachers' beliefs influence their practice and can be either a facilitator or a barrier to learning (Admiral et al, 2017). The teacher and the quality of teaching have a strong effect on maximizing student outcomes (Darling-Hammond & Youngs, 2002).

Teachers' conceptions of teaching have been explored in educational studies (Boulton-Lewis et al., 2001; Chan & Elliott, 2004; Chen, 2014; Virtanen & Lindblom-Ylänne, 2010) and are associated with their teaching experience and personal epistemologies (Tsai, 2007). When it comes to teaching in the sciences or disciplines within the field of sciences, there are fewer studies that have delved into teachers' conceptions (Alt, 2018; Da-Silva et al., 2006; Koballa et al., 2005). Conceptions of teaching are examined and categorized in studies from various perspectives, including dimensions, preferred teaching and learning modalities of teachers, the roles of both teachers and students, orientations, and recommendations (Chan & Elliott, 2004; Koballa et al., 2005).

In the study conducted by Boulton-Lewis et al. (2001), four categories of teaching conceptions were established. From the perspective of these conceptions, teachers focused their teaching on: content transmission; skill development; facilitating understanding; cognitive, behavioral, and affective transformation as a result of stimuli provided by teachers to engage them in learning activities.

Worldwide research has shown two traditions regarding teaching: "teacher-centered teaching" and "student-centered teaching" (Cuban, 2007; Lindblom-Ylänne et al., 2006; Samuelowicz & Bain, 2001). Teaching is described by Fenstermacher & Soltis (2004) through three conceptually incompatible metaphors: executive, facilitative, and liberationist.

Regarding teaching methodologies, Trigwell & Prosser (2004) identified five teaching strategies: (1) teacher-focused strategy, centered on transmitting facts and skills, expecting students to remember facts and solve problems; (2) teacher-focused strategy helping students acquire the concepts of the discipline and the relationships between them and solving problems; (3) interactive strategy carried out between teachers and students, where students acquire concepts and their relationships through an active teaching-learning process; (4) student-focused strategy, where they are helped to develop their vision or conception of the world; (5) student-focused strategy where they reconstruct their knowledge, vision, or conception of the world, without teachers transmitting their own conceptions to the students.

In the view of Onwuegbuzie et al. (2007), there are two types of teaching approaches: progressive teaching and transmissive teaching. Other researchers categorize conceptions of teaching and learning into two categories: quantitative and qualitative (Chan, 2011). Chen (2014) explores and describes the traditional Chinese teaching model, characterized by the transmission of knowledge through an imitative, repetitive, and memorization-based process (Hughes & Yuan, 2005).

Zhang & Liu (2013), Donnelly et al. (2014), and Wang et al. (2015) differentiate traditional teaching from constructivist teaching.

In other studies, researchers have examined teaching from the perspective of technology use (Vanderlinde & van Braak, 2010). In Romania, research has focused on teachers' opinions and conceptions regarding digital textbooks (Magdaș & Drîngu, 2016; Manasia et al., 2013)

Research on the Use of Observation in Science Teaching and Learning

Observation is addressed in educational research and science education as an action and cognitive process, as a skill and competence, as a teaching method, as a technique, or as a stage in scientific research. The impact of observation on science learning has been studied in a limited number of studies (Kos & Jerman, 2015). In most studies, observation is integrated within other methods (observational-comparative method, laboratory method, experimental method) (Meneghetti et al., 2017) or instructional models: learning through observation and discovery (Barbacovi et al., 2018), the Prediction-Observation-Explanation (POE) model (Zhao et al., 2021). Some studies focus on the visual materials used in observation (Eş, 2014).

Studies report the outcomes of observation-based learning activities involving students aged 6-11 years. Eberbach & Crowley (2009) compared children's bird observation with expert biology observation. Eş (2014) investigated the (re)presentation of concepts related to fruits and vegetables in primary school science textbooks, students' knowledge, and teachers' opinions about these concepts, as well as the teaching materials used in preschool education. Grancher et al. (2015) propose two approaches to exploring the living world, both of which include observation.

Kos & Jerman (2015) conducted research involving two groups of children aged 5 and 10. They were tasked with observing 37 flowering plants. Barbacovi et al. (2018) employed observation, along with other teaching strategies, in an experiment conducted with second-grade students, focusing on corn germination and the study of the plant life cycle.

Meneghetti et al. (2017) conducted research with fourth-grade students regarding mushrooms, aiming to compare the effects of the traditional method with the laboratory method. Jäggi & Stutz (2020) set up an ant farm in the classroom. The hands-on experience and all the activities undertaken had a positive impact on shaping their a priori representations.

Damerau et al. (2022) examined the effect of anatomical models in science education on primary school students' conceptions of human internal organs. One group used anatomical models (haptic models) and conducted experiments related to nutrition, while another group used two-dimensional anatomical illustrations of internal organs. The intervention led to a change in students' conceptions.

Research on the Use of Experiments in Science Teaching and Learning

Conducting experiments by students is essential in science teaching and learning, as well as in integrated disciplines within this field (biology, physics, chemistry). Globally, the number of studies focusing on conducting pedagogical experiments involving young students is relatively limited. The studies identified exhibit a diversity of approaches to experimentation. Some studies describe experiments carried out by children at school, similar to those conducted autonomously at home, where they are asked to explain what happened or will happen (Tin, 2017, 2022). Other studies describe experiments integrated into structured learning environments, methods, activities, or instructional models, organized into stages: problem-based and structured learning environment (Leuchter et al., 2014), experimental method applied in an observation and discovery-based learning activity (Barbacovi et al., 2018), scientific investigation based on experimentation and observation, a "prediction, observation, interpretation" scenario (Tin, 2019), laboratory activity based on the scientific method (Bolzon et al., 2022).

From the multitude of studies, those were selected where pedagogical experiments involving young students, primary school teachers, or future primary school teachers are described, and the chosen research topics are addressed: "Seed Germination" (Barbacovi et al., 2018; Bolzon et al., 2022; Jewell, 2002; Ürek, 2020; Vidal & Membiela, 2014), "States of Water Aggregation" ((Black et al., 2011; Jung et al., 2020; Paik, 2015; Tin, 2019, 2022), "Buoyancy of Solid Objects in Water" (Leuchter et al., 2014; Tin, 2017; Van Schaik et al., 2020).

In these studies, various aspects were explored, including representations of plants among future primary school teachers (Jewel, 2002). In the study conducted by Vidal & Membiela (2014) on seed germination, practical activities were carried out with groups of three or four student teachers. This study highlights that germination is more conceptually complex than commonly believed. The authors of the study mention that the literature reports several issues, including misconceptions among students, teachers, and in school textbooks.

Research on the Use of Drawing in Science Teaching and Learning

Globally, numerous studies in science education focus on the analysis of children's drawings for various research purposes: exploring conceptual understanding (Anderson et al., 2014); investigating the extent of knowledge acquired through formative intervention (Wilson & Bradbury, 2016a, b); representing the world of plants (Comeau et al., 2019; Villarroel, 2016, 2018; Villanueva et al., 2021; Wilson & Bradbury, 2016a, b); depicting landscapes and the environment (Eija et al., 2012; Eugenio-Gozalbo et al., 2020; Tamoutseli & Polyzou, 2010). Other studies have examined the representation of landscapes and the environment in children's drawings (Eija et al., 2012; Eugenio-Gozalbo et al., 2020; Tamoutseli & Polyzou, 2010).

In other studies, the use of drawing as a research tool in science education has been analyzed (Chang et al., 2020), differences between technology-based drawing and paper-and-pencil drawing (Cromley et al., 2020), the effect of instructions for reading a text with scientific illustrations (Jian, 2018a), strategies for reading illustrations and integrating text and illustrations (Jian, 2018b), the use of drawing for learning (Fiorella & Zhang, 2018; Haney et al., 2004), and the opinions of preschool and primary school teachers regarding the role of drawing in science teaching (Areljung et al., 2021).

Areljung et al. (2021) interviewed preschool and primary school teachers regarding the role of drawing in science teaching. It was found that few of the participating teachers in the study specifically associate drawing with science learning. They viewed drawing, rather, as a variation in teaching and learning. Observing classroom activities, researchers concluded that drawing holds a relatively weak position as a means of communicating and learning science, with the emphasis in teaching placed on writing or "producing a product." However, the researchers discovered that there are still examples where teachers explicitly use drawing in science learning.

1.5 Research Relevance

Relevance of Teacher Conceptions Research

The relevance of this study lies in collecting consistent data on the ways representations are formed in students in the field of science. These data contribute to a deeper understanding of what should be achieved in the study of science in Romania, in comparison to the situation in other countries. Additionally, our study fills a gap in the literature.

Relevance of Observational Effect Research in Representation Formation

Our study is relevant for the following reasons: we aim to test the effect of observation on the formation of students' representations in three conditions (through direct observation of objects, observing them in drawings, and in photographs); we seek to demonstrate the role of observation sheets as scaffolds that facilitate and systematize observation; the self-designed instruments and materials used in the research, along with the rigorous description of the study, could enable the replication of the research and the implementation of these teaching activities in various contexts.

Relevance of Research on the Effect of Experimentation on Representation Formation

Our research is important as we aim to compare the effects of experiments on the formation of students' representations compared to the effects of activities where they listen to presentations, teacher explanations, and observe experiments through drawings and photographs. The significance of the study is justified by our intention to conduct an innovative activity by blending two instructional models: Gagné's (1970) instructional model and the traditional model. Furthermore, it is essential to explore the impact of experimental activity sheets and observation sheets that provide support to primary school students in conducting experiments.

Relevance of Research on the Effect of Drawing on Representation Formation

Our research holds value for several reasons. Firstly, we seek to explore the effects of using the drawing-based learning strategy on students' representations and compare them with those of using the text-centered learning strategy (Fiorella & Zhang, 2018). Secondly, we aim to assess students before and after the intervention through drawing tasks and similar written tasks, using verbalization to gain a clearer understanding of their representations. We believe that our study offers an original and useful perspective on the use of drawing and drawings in science learning and that the materials designed and the detailed description of the research could serve as references for other teachers and for the replication of the study.

CHAPTER II

RESEARCH OBJECTIVES AND GENERAL METHODOLOGY

2.1. Research Objectives

General Objectives

This thesis aimed to address theoretical, methodological, and practical aspects related to the development of scientific representations in primary education students. Therefore, this research had two main objectives: (1) to investigate primary education methodist teachers' conceptions of representations and their teaching practices used in fostering scientific representations in primary education; (2) to examine the effects of specific teaching methods and strategies on the development of scientific representations in primary education.

Specific Objectives

To achieve the first main objective, we conducted interview-based surveys to analyze the conceptions of primary education methodist teachers (PEMTs) regarding representations and their teaching practices used in developing scientific representations in students. These teachers are involved in assessing the teaching activities of other primary education teachers, which has led to diversified experiences and the development of a broader perspective on teaching, learning, and assessment in Romanian schools. We aimed to capture PEMTs' conceptions concerning four relevant aspects for the research: the concept of representations; the selection, use, and effectiveness of teaching aids and materials for developing scientific representations; the effectiveness and frequency of using specific teaching methods in fostering scientific representations; the proper, efficient, systematic, and lasting development of scientific representations in primary cycle students.

The second main objective was accomplished through studies 2, 3, and 4.

Study 2 aimed to analyze the effects of learning activities based on direct observation of environmental components, in comparison to the effects of learning activities based on observing the same components in static visual representations (photographs and drawings).

Study 3 focused on analyzing the impact of learning activities based on experimentation on students' development of scientific representations, compared to the impact of learning activities based on listening to the teacher's explanations and observing experiments in static visual representations (photographs and drawings).

The objective of study 4 was to investigate the efficiency of drawing based on the observation of static visual materials (photographs, drawings, and diagrams), in comparison to observing static representations (photographs, drawings, and diagrams). These activities were organized in conjunction with and in addition to teaching activities based on listening to and studying texts illustrated with photographs, drawings, and diagrams.

These interventions serve to demonstrate the role and effectiveness of specific teaching methods and strategies compared to others and to provide support materials for improving teaching activities to other primary education teachers.

2.2 General Research Methodology

In this research, a qualitative study was conducted, utilizing interview-based surveys and three quasi-experimental studies.

In Study 1, to collect data regarding primary education methodist teachers' (PEMTs) conceptions of developing representations in young school-aged students in the field of science, individual interviews were used. The selection of the 10 teachers was done through purposive sampling, typical for phenomenological research. Data collection was carried out using a self-designed interview guide, validated by two experts. Data analysis involved several stages, including data identification, data sorting based on similarities and differences, data classification, category generation and description, and reliability verification. Throughout the entire study, ethical and legal requirements regarding the protection of participants' personal data were upheld.

The other studies (2, 3, 4) were quasi-experimental studies with a pre-test-post-test design and two or three experimental groups. Class equivalence was established based on knowledge tests in the field of science acquired in either Grade 1 (studies 2, 4) or Grade 3 (study 3).

The experimental groups consisted of 40-51 students. In all three studies, the experimental activities comprised three stages: the pre-experimental stage - administering pre-tests; the formative intervention stage; the post-experimental stage - administering post-tests.

CHAPTER III
ORIGINAL RESEARCH CONTRIBUTIONS

3.1 Study 1: Primary Education Methodist Teachers' Conceptions Regarding the Construction of Representations in Young School-Aged Students in Science

3.1.1 Introduction

Conceptions of teaching among primary education teachers have been explored in few studies (Alt, 2018; Vanderlinde & van Braak, 2010; Wang, Tsai & Wei, 2015). Wang, Tsai & Wei (2015) categorized teaching conceptions among primary education teachers into two models: the traditional model, where students are seen as passive recipients of knowledge, and the constructivist model, where teachers assist students in becoming critical thinkers.

Studies conducted in Romania on the conceptions and perceptions of primary school teachers have focused on digital textbooks in various subjects and educational cycles, including primary school (Manasia et al, 2013), textbooks in various subjects in primary school (Lalău, 2014), digital textbooks in primary school (Magdaș & Drîngu, 2016), and the digital textbook of "Mathematics and Environmental Exploration: Grade 2" (Buzilă et al, 2017; Magdaș et al, 2017).

Results concerning digital textbooks and their use suggest a shift in teachers' perceptions, from initial reluctance, lack of information, insufficient familiarity, and training to effectively integrate them into teaching (Manasia et al., 2013; Magdaș & Drîngu, 2016), to becoming familiar with the textbook, understanding its roles, and overcoming technical difficulties in its use (Magdaș et al., 2017).

Because teachers' conceptions of teaching, learning, and instructional resources influence their choices, decisions, and teaching actions, it is important for these conceptions to be carefully investigated and understood. Teachers' beliefs about representations, instructional resources, and the most suitable methods for their development could determine teachers' actions in the classroom, shaping the organization of teaching, learning, and assessment.

In this context, we chose to gather qualitative data through semi-structured interviews because participants can construct elaborate discourse to respond to questions, and thematic analysis allows the identification of common structures (Creswell & Creswell, 2018; Popa et al., 2009) and the clarification of aspects of interest for research (Bocoș et al., 2021).

Purpose and Research Questions

The purpose of the study is to investigate the conceptions of primary education methodist teachers (PEMTs) regarding representations and their teaching practices used in developing scientific representations in primary education. These teachers are engaged in assessing the teaching activities of other teachers working at this level of education, which has facilitated diversified experiences.

The following research questions were formulated for the conduct of the study:

(1) What do primary education methodist teachers (PEMTs) understand by representations?

(2) What are the conceptions of PEMTs regarding the selection, use, and effectiveness of teaching aids/instructional materials for developing scientific representations in primary education students?

(3) What are the conceptions of PEMTs regarding the effectiveness and frequency of using specific teaching methods in developing scientific representations in primary education students?

(4) What are the conceptions of PEMTs regarding the development of scientific representations in primary education students?

3.1.2 Method

Participants

To obtain a rich variation of conceptions reported in interviews, we used purposive sampling, typical for phenomenological research. Participant selection for the interviews was based on the following criteria: (a) involvement in the educational system during the 2021-2022 school year; (b) holding the position of primary education methodist teacher (PEMT); (c) having more than three years of experience in evaluating lessons and other teaching activities at the primary education level.

PEMTs were informed about the research purpose, participation conditions, and the use of collected data. We obtained informed consent from PEMTs through a "Consent Form." We ensured the confidentiality of participants' personal data and adhered to all ethical and legal requirements during the study.

Data Collection

Data was collected between December and February 2022. A "Interview Guide" was used as the instrument for collecting phenomenological data, developed by the researcher based on recommendations from the specialized literature (Popa et al., 2009). The questions in the "Interview Guide" were subjected to analysis by two experts in the fields of psychology and science education and were subsequently validated. In alignment with the research purpose and questions, the interview guide comprised 13 open-ended questions, grouped into four content categories: the concept of representation (I1); teaching aids/instructional materials (I2, I3, I4, I5); strategies, teaching methods, and instructional models (I6, I7); the process of developing representations (I8, I9, I10, I11, I12, I13). The ideas of PEMTs regarding representations and their development were collected in written format.

Data analysis

The interviewees were assigned codes in the format 11, assigned before recording (I - interviewee, 1 - order in the database). In the phenomenological data analysis, the following steps were taken: (a) The interviews were read several times to identify the primary ideas about the PMÎP conceptions about representations and how they are formed in students; (b) these primary ideas, based on reflection, were highlighted by the similarities and differences between them; (c) on the basis of the similarities, differences and the meaning of each primary idea, the categories were distinguished; (d) the categories were described; (e) hierarchical relationships were established within the categories (Åkerlind, 2005; Bowden, 2000). The collection of data with a deep focus on the research aspects, the detailed descriptions of the interviewees, the repeated review of the data analysis by the researcher, the coding evaluated by experts in psychology, education sciences and with experience in qualitative data analysis, the analysis and feedback from experts have contributed to the validity of the study. The provision of evidence of the coherence of the research process, the application of a recognized methodology, transparent documentation, careful collection of data through interviews, the development of descriptive categories ensured the reliability of the study.

3.1.3 Results

Categories of PEMTs' Conceptions about Representation

By comparing the discrepancies and similarities among PEMTs' discourses, conceptions about representations, as illustrated through the phenomenological method, are structured into three main directions or major categories of conceptions: representation as a process, as a capacity, and representation as a product.

Categories of PEMTs' Conceptions about Instructional Resources Used in Developing Scientific Representations in Students

After analyzing the instructional resources mentioned in the discourses as utilized by PEMTs in fostering scientific representations in students, four major categories ("Object-based Resources," "Audio-Visual Resources," "Static Visual Materials," "Dynamic Visual Materials") reflecting PEMTs' conceptions were generated, and within these, 15 subcategories were included. At the collective level, the categories and subcategories reveal a wide array of instructional resources used by PEMTs in developing scientific representations. At the individual level, the results indicate differences among PEMTs, with some of them employing a broader range of instructional resources than others. PEMTs make more extensive use of "Static Visual Materials," while "Dynamic Visual Materials" are less frequently utilized.

Categories of PEMTs' Conceptions about the Effectiveness of Instructional Resources Used in Developing Students' Representations in Science

Three major categories ("Object-based Resources," "Static Visual Materials," "Dynamic Visual Materials") and 7 subcategories reflecting PEMTs' conceptions were generated. The most effective instructional resources in developing representations in science were considered to be those in the categories of "Object-based Resources" and "Dynamic Visual Materials." The most effective instructional resources were deemed to be "Photographs," followed by "Natural Objects and Materials," "Artificial Objects and Materials," and "Drawings and Paintings," mentioned by the majority of PEMTs (50-60%). "Static Visual Materials" were considered to be the least effective in developing students' representations in science. 10% of PEMTs considered "materials that students do not manipulate" to be the least effective.

Categories of PEMTs' Conceptions about the Selection of Instructional Resources Used in Science

Seven major categories were generated: "Characteristics of Instructional Resources," "Represented Content," "Purpose/Objectives," "Methodology," "Organization Format," "Students," and "Time." At the collective level, a wide array of criteria used by PEMTs in selecting instructional resources to develop representations in science is revealed. At the individual level, the results indicate differences among PEMTs, with some considering a broader range of criteria than others. The number of criteria considered varies as follows: 11 criteria (10%), 8 criteria (10%), 3 criteria (10%), 2 criteria (30%), one criterion (40%). The following criteria were most frequently considered by PEMTs: "Activity Objectives" (50%), "Nature, Specificity of Content" (40%). The other criteria were considered by 1-2 PEMTs.

Categories of PEMTs' Conceptions about the Use of Instructional Materials in Fostering High-Quality Representations in Science

Two major categories reflecting PEMTs' conceptions were generated. At the collective level, two methods of using instructional materials in fostering high-quality representations in science among students are revealed: a traditional method centered on the teacher and a modern method centered on the student. At the individual level, the results indicate differences among PEMTs, with 40% of them using them traditionally, 60% using them in a modern way, one PEMT using both methods, and one PEMT's discourse being unclear.

Categories of PEMTs' Conceptions about Teaching Methods Used in Developing Representations in Science

Regarding the teaching methods employed by PEMTs in developing scientific representations in students, four major categories ("Expository Methods," "Dialogue-Based Methods," "Exploration Methods," "Action-Based Methods") reflecting PEMTs' conceptions and 11 subcategories were generated. At the collective level, a wide array of teaching methods used more frequently in fostering scientific representations is revealed. 40% of PEMTs mention 4-7 methods, while 60% mention 1-3 methods. The most frequently used methods in developing scientific representations were "Expository Methods" ("Explanation," "Demonstration," "Presentation"), "Dialogue-Based Methods" ("Conversation"), and "Action-Based Methods" ("Exercise"). The methods "Conversation" (90%), "Exercise" (60%), and "Explanation" (50%) were the most commonly employed.

Categories of PEMTs' Conceptions about the Effectiveness of Teaching Strategies and Methods in Developing Scientific Representations in Students

Regarding the most effective teaching methods in developing scientific representations in students, four major categories ("Expository Methods," "Dialogue-Based Methods," "Exploration Methods," "Action-Based Methods") and 11 subcategories were generated. The most effective methods in fostering scientific representations were considered to be "Exploration Methods" ("Observation," "Experiment"), "Action-Based Methods" ("Games," "Exercises," "Practical Activities"), and "Dialogue-Based Methods" ("Conversation"). The most effective methods were "Observation" (70%), "Games" (60%), and "Experiment" (40%).

Categories of PEMTs' Conceptions about Instructional Models Used in Developing Scientific Representations in Students

Ten major categories associated with ten instructional models were generated: the traditional model, "Sequential Knowledge Acquisition Model"; the "Evocation-Meaning Making-Reflection" model; the "I Know-I Want to Know-I Have Learned" model; the discovery learning model; the "Flipped Classroom" model; the exploration and discovery learning model; the inquiry-based learning model; the problematization-based model; the problem-solving-based model. At the collective level, a wide array of instructional models used by PEMTs in developing scientific representations is revealed. One PEMT enumerated 7 instructional models. 80% of PEMTs listed the stages of an instructional model.

Categories of PEMTs' Conceptions about Ways to Exploit Students' Representations in Acquiring New Knowledge

Activities in which PEMTs exploit students' representations in acquiring new knowledge have been categorized into four major categories ("Expository Activities," "Dialogue-Based Activities," "Action-Based Activities," "Assessment Activities") and 10 subcategories.

At the individual level, the results indicate differences among PEMTs, with some mentioning a broader range of teaching activities than others. 40% of PEMTs list 3-4 types of activities, while 60% of PEMTs mention 1-2 methods.

PEMTs considered that they make the most use of students' representations in acquiring new knowledge in "Dialogue-Based Activities" and "Action-Based Activities." The activities mentioned by most PEMTs (4 nominations) are those that use "Illustrations," "Discussions," and "Conversations."

Categories of PEMTs' Conceptions about Methods Used for Students to Learn to Form Their Own Representations

The methods and techniques used by PEMTs to help students learn to form their own representations have been categorized into four major categories ("Expository Methods," "Exploration Methods," "Action-Based Methods," "Dialogue-Based Methods") and 11 subcategories. PEMTs considered that they use "Action-Based Methods" and "Exploration Methods" the most to help students learn to form their own representations. The methods mentioned by most PEMTs (40-50%) are "Individual Study/Guided Learning" and "Exercises."

Categories of PEMTs' Conceptions about Methods Used to Correct Students' Misrepresentations/Incorrect Conceptions in Science

Five major categories ("Expository Methods," "Action-Based Methods," "Dialogue-Based Methods," "Exploration Methods") and 10 subcategories have been generated. 10% of PEMTs specified 7 methods, 20% specified 3-4 methods, and 70% specified 1-2 methods. PEMTs considered that they use discussions the most for this purpose, followed by examples and explanations.

Categories of PEMTs' Conceptions about Strategies Used for Systematizing Representations

Four major categories: "Schematization," "Synthesis," "Verbal/Oral Systematization," "Application," and 5 subcategories have been generated. Collectively, PEMTs considered that they use a set of methods to help students systematize their representations: "Graphic Organizers," "Recapitulation," "Conversation," "Peer Discussions," "Solving Given Tasks." At an individual level, "Graphic Organizers" have the highest weight (50%).

Categories of PEMTs' Conceptions about Procedures/Methods/Strategies Used for Students to Retain Representations in Memory

Six major categories: "Recall," "Contextualization," "Understanding," "Repetition," "Application," "Evaluation," and 11 subcategories have been generated. Collectively, PEMTs considered that they use an array of methods to help students retain representations in memory, activating a series of information organization procedures, repetition procedures, and association procedures. Recapitulation has the highest weight (40%), followed equally by games (30%) and exercises (30%).

3.1.4 Discussions and Conclusions

PEMTs' Conceptions of Representations

PEMTs' responses reveal a wide array of ideas about representations, reflecting the diversity of definitions in psychology and the meanings attributed to this term: process, capacity, internal product, or external product. The summary presentation, incomplete in attributes, without differentiation between essential and non-essential, gives the impression that teachers have empirical knowledge about representations. These results are similar to those obtained from the study conducted by Danish et al. (2020). These findings could be explained by the fact that both initial and continuous teacher training pays little attention to representations and their formation in students. Another explanation could be that official curriculum documents (school programs, textbooks) do not emphasize the formation of representations. Therefore, we assume that teachers will be less concerned with the formation of representations in students, both from a theoretical and practical perspective.

PEMTs' Conceptions of Using Teaching Aids in Developing Scientific Representations in Students

Regarding the teaching aids used in developing scientific representations, PEMTs' responses indicate the use of a wide range of such didactic materials, which are categorized into several groups but do not cover all possibilities from the literature (Dulamă & Roșcovan, 2007). The results are similar to those in other studies where it is found that teachers widely use learning objects to work with students on developing their mental representations (Sotirova, 2020).

At an individual level, the results indicate an imbalance: only 20% of participants use various means categorized into 9-12 subcategories, while the majority (70%) use a limited range of means, categorized into 1-3 subcategories. The fact that more PEMTs specify that they use drawings and photographs (70%), films (40%), natural and artificial objects and materials, models and molds (30%) suggests an orientation towards using easily accessible and usable materials. Sotirova (2020) found that 58% of primary school teachers use computers for presenting images, etc.

Regarding the effectiveness of teaching aids in developing scientific representations, PEMTs' responses reveal consistency with the previously mentioned findings. The most effective were considered to be photographs (60%), drawings, paintings, natural and artificial objects and materials (50%), films, and online games (40%).

In choosing teaching aids to be used in developing scientific representations, PEMTs use a wide variety of criteria or reasons: objectives; characteristics of teaching aids/educational materials; the represented content; the organization of activities; student characteristics; time. At an individual level, the responses indicate an imbalance: 20% of PEMTs take into account 8-11 criteria in selecting teaching aids, while 80% of them select based on 1-3 criteria. The criteria that most PEMTs consider in choosing teaching aids are the activity's objectives (50%) and the nature/specificity of the content (40%), while only 10-20% of PEMTs consider the other criteria. In Danish's study (2020), the most frequently used selection criteria were student ability, followed by teacher preference, curriculum relevance, and student relevance, understanding of representation, and teacher preference.

PEMTs' responses regarding the use of teaching materials in developing high-quality scientific representations in students indicate two approaches: a modern, student-centered approach (60%) and a traditional, teacher-centered approach (40%). The modern approach is characterized by activism, information seeking, the pursuit of learning satisfaction, initiative, problem-solving, and self-directed learning (Paloș, 2012, p. 20), while the traditional approach is characterized by passivity, information reception, "covering a deficit," responsiveness to external stimuli, knowledge and skill transfer, and the need for a teacher (Paloș, 2012, p. 20).

The PMÎP's conceptions of the teaching strategies/methods used in shaping students' representations in science

Regarding the teaching strategies/methods used in shaping students' representations in science, it is notable that PMÎP primarily refers to teaching methods, a term well-established in the Romanian education system (Cerghit, 2006). Although PMÎP encompasses a wide range of methods, they have been categorized into existing categories in domestic literature: "expository methods," "dialogue-based methods," "exploratory methods," and "action-based methods" (Cerghit, 2006). The fact that "expository methods" were most frequently employed (24 mentions) in shaping representations in science suggests a transmissive teaching approach emphasizing the dissemination of knowledge to learners (Onwuegbuzie et al., 2007), a quantitative conception focused on the quantity of knowledge acquired and reproduced, the teacher's role as a transmitter of information and an evaluator, and the student's role as a recipient (Chan & Elliott, 2004). The predominant use of expository methods indicates teacher-centered instruction, where the teacher controls what, when, and under what conditions the subject matter is taught (Cuban, 2007).

An important and essential aspect of teaching science in primary education is the use of explanation by 50% of PMÎP. Among the "dialogue-based methods," the fact that 90% of PMÎP use conversation, the most frequently employed method, is of great importance. Among the "action-based methods," exercises are used the most (60%). We expected observation, experimentation, and educational games to be more commonly used in shaping representations. Although observation was mentioned by only 3 PMÎP, and experimentation and educational games were not mentioned, we believe that these methods are used in science lessons, albeit less frequently. In science education, experimentation is one of the frequently used and appreciated methods, as are educational games. It is evident that PMÎP employ various teaching strategies to ensure learning, similar to teachers in other countries (Goodrum et al., 2001). These strategies and methods are also used in other educational disciplines.

The PMÎP's Conceptions of the Process of Developing Representations in Students in Science

The fact that the process of developing representations in students in science is structured according to ten instructional models indicates a methodologically diverse teaching approach, aligned with the theoretical and methodological models described in the literature. While at the method level, the conceptions suggest teacher-centered instruction, at the level of instructional models, the analyzed conceptions indicate student-centered instruction. Many PMÎP (50%) mentioned the traditional model and sequential knowledge acquisition (SKA) (proposed by Gagné, 1968), a model promoted, preferred, and preserved in Romania over the past decades in all educational disciplines, both in initial and continuous education. The results indicate the use of constructivist teaching models (similar to Wang et al., 2015) "Evocation-Meaning-Making-Reflection" (ERR) (30%) and "I Know-I Want to Know-I Learned."

Regarding the ways of harnessing students' representations in acquiring new knowledge, our expectations focused on conceptions related to using students' prior knowledge to integrate it with new information. The results indicate a wide variety of activities in which teachers claim to leverage students' representations, indicating an anchoring of science learning in the constructivist paradigm of teaching and instruction (similar conclusions to those found by Wang et al., 2015). Students' representations are most often utilized in dialogue-based activities (60%), in "Exemplifications," "Discussions," and "Conversations" (40%). Although 60% of PMÎP mention 1-2 activities in which they leverage representations, it is presumed that in reality, they use them intuitively, naturally, implicitly, in more activities, but without their intention and practice being explicitly correlated with this purpose.

Conceptions regarding the methods and teaching procedures used to help students learn to develop their own representations indicate an orientation towards experiential learning that can be carried out individually, in real-life contexts, through "Individual Study/Guided Learning" (50%), "Exercises" (40%), "Observation" (30%), "Experiments," "Practical Activities," "Case Studies," "Watching Films," as well as collectively with others, through "Conversation" followed by "reflection."

Various strategies are described for correcting students' misconceptions or incorrect representations, with some being teacher-centered (explicitly pointing out the error, providing correct explanations for aspects represented incorrectly in the students' minds or physically, making comparisons, offering examples to facilitate comparisons, giving suggestions and hints), while others are student-centered (discussions among students, conducting exercises to identify gaps, mistakes, or inconsistencies, repeating exercises until the error is corrected, redoing an exercise/problem/drawing). Some strategies are based on heuristic conversation aimed at guiding students in discovering or deducing their mistakes.

Mental organization of representations is crucial to facilitate their further enrichment through new learning. PMÎP conceptions indicate the use of graphic organizers (50%) as a way to ensure the mental organization of knowledge from their own knowledge base. In PMÎP's conception, other strategies for organizing representations are oral, either through conversation or discussions among students, referring to the "directed learning" described by Gagné (1968). Solving tasks given by the teacher is also considered a useful strategy in organizing representations by 30% of PMÎP. The role of recapitulation lessons in organizing representations is also emphasized.

At the end of the study, several conclusions emerge:

Based on the analysis of discourse and its interpretation, the study provides an overall picture of PMÎP's conceptions of representations and their teaching practices used in shaping representations in science at the primary level. Regarding the term "representation," the conceptions indicate varied and partially related ideas, which are only partially aligned with the scientific content of the concept of representation. Therefore, this understanding of representations could have an impact on science learning.

Conceptions related to teaching materials, overall, indicate a wide range of diverse resources, but at the individual level, most PMÎP predominantly use a few resources, with textbooks and their included materials playing a significant role. The use of teaching materials in science learning is positively influenced by PMÎP's conceptions of their effectiveness.

Regarding teaching strategies/methods, PMÎP's conceptions indicate that exploratory and action-based methods are considered effective. However, in terms of their frequency of use, conceptions tend to focus on expository methods, which are teacher-centered, and dialogue-based methods.

PMÎP's conceptions of shaping scientific representations in science, systematically and thoroughly, individually, and correcting students' misconceptions suggest methods used in many educational disciplines without highlighting specific approaches. The occasional mention of using observation, experimentation, games, and drawing in shaping scientific representations in science provides a promising premise for the experimental research proposed in this thesis.

The fact that responses were collected in writing could be considered a limitation of the research because it did not use questions to gather additional data to delve deeper into the investigated aspects. Additionally, data collection through written discourse by interviewees may be influenced by theoretical statements presented in the literature of psychology and science education. Another limitation could be that, although the individual interview-based survey was based on the principle of collaboration, the relevance of the responses depended on the interviewees' willingness to provide details and their central or peripheral position regarding the study's issues, depending on their personal perspectives.

Given the absence of other studies regarding PMÎP's or teachers' perceptions of students' representation formation in science, the research can be extended by using the interview guide in other studies and by further exploring the investigated aspects. The research included original methodological aspects, such as categorizing PMÎP's responses into data tables, aiming to provide a transparent approach to the researcher's logic and to facilitate interpretation and understanding by others. The "Study Guide" is an original resource and can serve as a reference

3.2 Study 2: The Effects of Observation-Based Learning Activities on the Formation of Students' Representations in Science

3.2.1. Introduction

In the process of learning science, we are interested in several meanings related to observation: as an action and cognitive process, as a teaching method, and as a scientific research method. The ability to observe is important in the early years of life and in primary science (Covill & Pattie, 2002; de Bóo, 2006; Harlen, 2000; Johnston 2009). Children observe the world daily to learn about it (Rogoff et al, 2003), using multiple senses simultaneously (Johnston, 2011, 2013), observing, as a general ability, meaning more than seeing objects and describing surface features (Chinn & Malhotra, 2002).

Gradually, children begin to notice similarities and differences between objects, observe patterns, identify sequences and events in their surroundings, and interpret observations (Johnston, 2011). Discovering patterns and organizing them as a result of observing the world is essential for scientific activity (Klemm & Neuhaus, 2017). However, children observe phenomena without developing new knowledge or associating their observations with scientific reasoning and explanations (Ford, 2008). As they grow, children's observational skills develop (Johnston, 2011; Kos & Jerman, 2015), and they move from simple explanations of observations to complex interpretations (Johnston, 2009).

Knowing the importance of observation in children's cognitive development, teachers should provide contexts and opportunities for them to improve their observational skills, such as: time for careful observation (Eberbach & Crowley, 2009; Tomkins & Tunnicliffe, 2007), encouragement (Johnston, 2013; Kos & Jerman, 2015), observation and conversation with adults (Eberbach & Crowley, 2017; Johnston, 2011), interaction with other people (Johnston, 2009; Tomkins & Tunnicliffe, 2001), sketching and drawing (Eberbach & Crowley, 2009), journal writing (Tomkins & Tunnicliffe, 2007), questioning (Eberbach & Crowley, 2009; Johnston, 2011, 2013; Tomkins & Tunnicliffe, 2001; Van der Graaf et al, 2019). Children need opportunities to explore with their senses, observe details, sort, group, and classify (Johnston, 2011), get clues to understand, and stimulate their further questioning and interest (Tomkins & Tunnicliffe, 2007).

Observation is affected by children's knowledge or conceptions (Johnston, 2009; Tomkins and Tunnicliffe, 2001), which influence how they approach and interpret observations. Children can only develop their observational skills when they have specific knowledge, tools, and experience to support their reasoning (Eberbach & Crowley, 2009). They should learn to distinguish between what is relevant and irrelevant to the objects or phenomena observed.

Gelman & Brenneman (2012) highlight the role of observation in the construction of scientific knowledge. In the construction of empirical evidence, observation must meet several criteria: it must be systematic (Gelman & Brenneman, 2012), active, and have a purpose, i.e., it must be intentional (Monteira & Jiménez-Aleixandre, 2016). In intentional observation, the following are taken into account: what the student is asked to observe; what prior knowledge the observation activity presupposes; what the expected learning outcomes are, i.e., the purpose of the observation activity (Morris, 2007). Observation as a research tool (Merriam, 2009) serves a research purpose, is deliberately planned, and systematically recorded.

Our study is part of the context of the provisions in the official documents in Romania. In the Mathematics and Environment Exploration Curriculum (MEN, 2013, p. 2), the importance of contextualizing learning in the surrounding reality is specified because it increases the depth of understanding of the concepts and procedures used. Although studies highlight the benefits of direct observation on the formation of students' representations (Gallina et al., 2019) and that, in the curriculum, the implementation of activities based on direct observation is recommended, we find that, in textbooks and curricular materials, images in the form of drawings (static visual materials) predominate, to the detriment of direct observation activities. Thus, we notice the existence of a contradiction between the regulations in official documents (Palade et al., 2020), the recommendations in official documents regarding the realization of knowledge and exploration of the environment in real contexts (Singer, 2019), the recommendations of specialists and practitioners in science didactics (Dulamă, 2012; Pahome 2021), textbooks and practices found in schools (see the conclusions of study 1).

Purpose, variables and hypotheses

The purpose of the study is to study the effects of learning activities based on observation in the environment (direct) on the formation of students' representations in science (Mathematics and Environment Exploration), compared to the effects of learning activities based on observation in static visual representations (photographs and drawings).

The variables of our study are as follows: direct observation, indirect observation through photographs, indirect observation through drawings (independent variables), the volume and completeness of representations, and the degree of generality of representations (dependent variables).

The following research hypotheses were formulated for the implementation of the study:

I1 – The volume and degree of completeness of the representations created by students after direct observation of environmental components is greater than in the case of representations created on the basis of observation of the same environmental components through photographs and/or drawings.

I2 – The degree of generality of the representations created by students after direct observation of environmental components is greater than in the case of representations created on the basis of observation of the same environmental components through photographs and/or drawings.

I3 - Direct observation of environmental components leads to the creation of more complex and more precise representations compared to observation of the same environmental components in photographs and drawings.

3.2.2. Method

Participants

The study took place in the period December-February 2020 and September-December 2021, in the school year 2021-2022 in three schools in the city of Târgoviște. The selection of schools was based on the following criteria: recommendation of the specialist inspector, location in an urban environment, the existence of parallel classes, and the attendance of students.

The study was conducted with 153 students from six second-grade classes, with an average age of 8-9 years, of both genders (86 female). The students were divided into the three experimental conditions at the classroom level, as follows: experimental group 1 (GE1) - 51 students (two classes) observed environmental components directly, experimental group 2 (GE2) - 51 students (two classes) observed environmental components in photographs, experimental group 3 (GE3) - 51 students (two classes) observed environmental components in drawings.

We informed the students about the research objective and the conditions of participation: participation in pretests, in the activities planned in the formative intervention, and in posttests.

We ensured the confidentiality of the students' personal data and we respected all the ethical and legal requirements imposed in the conduct of the study. The parents of the students expressed their written consent for the participation of the students in the study. The didactic activities included in the study were supported by the researcher in all classes, in the presence of the classroom teachers, at the end of the school day.

Procedure

Prior to the experiment, students completed a science knowledge test. Based on the results of this test, we verified the equivalence of the classes. Students in the three groups participated in three activities. Each activity included three stages, conducted on distinct days of the week: pre-experimental stage – administration of the pre-test (10 minutes) and analysis of the results; formative intervention stage (50 minutes); post-experimental stage (Wednesday) – administration of the post-test (10 minutes)

Didactic activities

In the formative intervention stage, students in all classes worked in small groups of 4-5 students, based on observation sheets. Students were constantly monitored by the research professor. The professor read the items one by one, and students checked the box after the answer option they considered correct for each observed aspect. If they could not establish the answer, they drew a horizontal line across the row. After the observation time expired, based on the students' responses, we corrected the confusions, and students completed the unmarked answers on the observation sheet.

On the topic of "The Spruce", each student in GE1 received a spruce seedling, a spruce cone, a scale removed from the cone, and 2-3 spruce seeds. Later, in the same activity, the groups observed the mature trees in the schoolyard and compared the properties of the component parts with those of the seedling. Each student in GE2 received photos of the spruce seedling and mature trees, the cone and spruce seeds. Students in GE3 received drawings with the same content. Students, in groups of 4-5 students, based on observation, completed an observation sheet.

On the topic of "The Food Chopper", students in GE1 received 5 manual food choppers and food. Each student in GE2 received a photo of the food chopper, and students in GE3 received drawings of the object. Students in GE1 disassembled and reassembled the food chopper, established the characteristics of the components based on the observation sheet, and chopped food. Students in GE2 and GE3 established the properties of the components of the household object mentioned and completed observation sheets identical to those received by students in group GE1. On the topic of "The Military Truck", students in GE1 received three scale models of the military truck and wooden bodies for loading the truck bed. Each student in GE2 received two photos of the scale model of the truck, and participants in GE3 received drawings of the scale model. Students in all three groups established, based on the observation sheet, the characteristics of the truck's components. Students in GE1 disassembled and reassembled the components (made of plastic or metal) during breaks as a recreational activity. Students in GE2 and GE3 observed the photos and drawings of the scale model of the truck, in A2 format, displayed in the classrooms.

Instruments

The collection of data necessary to evaluate students' knowledge and representations was carried out through several instruments developed by the researcher: 3 pre-tests, 3 post-tests, and 3 observation sheets.

The initial test. The test consisted of 20 items. The maximum score was 100 points. The items required the mobilization of knowledge from the field of science, acquired in first grade.

Pre-tests and post-tests. To diagnose the level of knowledge of students on the three topics addressed, we designed and applied 3 pre-tests: "The Spruce", "The Manual Food Chopper", and "The Military Truck". The maximum score for each test is 100 points. The post-tests are similar to the pre-tests in terms of the number of items and relevance to the relationship with the dependent variables.

Observation sheets. For each topic and activity in the formative intervention, we designed an observation sheet, with a tabular structure that includes 50 aspects to be observed. The properties are specified and associated with boxes where the student can check if they observed that characteristic.

Data analysis

Preliminary analyses – at the level of the initial test

We used the Kruskal-Wallis H test for non-parametric data.

Principal analyses – Testing the hypotheses

We conducted Quades's ANCOVA analyses for non-parametric data to test each of the three hypotheses of the study.

3.2.3 Results

Preliminary results

The mean ranks of the three groups of students are as follows: MRobs.directă = 70.69 (Nobs.directă = 51); MRobs.foto = 76.62 (Nobs.foto = 51) and MRobs.desen = 83.70 (Nobs.desen = 51). The results of the Kruskal-Wallis H test show that there are no significant differences between the three groups of students (H(3) = 2.677; p = .262). As such, the groups are equivalent and can be used in the quasi-experimental study.

Main results – Testing the hypotheses

To test hypothesis 1, the results of the Quades's ANCOVA analysis showed significant differences between the three experimental conditions, in all three teaching activities analyzed. The results are presented in detail in the body of the thesis. Following the Quades's ANCOVA analysis, we proceeded to calculate the Tukey post-hoc test.

In the case of the *Spruce,* we found significant differences between all three experimental conditions, compared two by two, between *Direct observation* and *Obs. – photo* (p = .000), between *Direct observation* and *Obs. – drawing* (p = .001), but also between *Obs. . – photo* and *Obs. – drawing*, p = .011. The results show that the most effective method of teaching the spruce was direct observation, followed by observation through drawings. The least effective was observation based on photos.

In the case of the *Meat grinder,* we find significant differences between direct observation and the other two experimental conditions (*Direct observation* vs. *Obs. – photo*, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000), but not between the latter two (*Obs. – photo* vs. *Obs. – drawing*, p = .662). In this case as well, direct observation seems to be the most effective method of forming representations.

In the case of the *Truck,* statistically significant differences were identified between the experimental condition direct observation and the other two conditions with which it was compared (*Direct observation* vs. *Obs. – photo*, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000), in favor of direct observation. There were no statistically significant differences between the conditions *Observation through photography* and *Observation through drawing* (p = .173).

The statistical analyses, in the case of testing hypothesis 1, confirm the hypothesis, *direct observation* is a more effective teaching method for *forming the volume and complexity of the representation*, compared to observation based on *photographs* or *drawings*.

In order to test hypothesis 2, for each topic, we performed the Tukey post-hoc test. For the subject of the *spruce*, the test identifies significant differences between direct observation and the other two teaching methods (*Direct observation* vs. *Obs. – photo*, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000), but not between the latter two (*Obs. photo* vs. *Obs. – drawing*, p = .490).

The data show that direct observation is a more effective teaching method than the other two. In the cases of the subjects *Meat grinder* and *Truck*, the data show significant differences both between direct observation and the other two teaching methods, and between the latter two. Direct observation is again the most effective method (Meat grinder: *Direct observation* vs. *Obs. – photo,* p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000; truck: *Direct observation* vs. *Obs. – photo,* p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000). In the case of the subject meat grinder, observation based on photographs is more effective than that through drawings (*Obs. – photo* vs. Obs. – drawing, p = .000), in the case of the subject truck the situation is reversed (Obs. – photo vs. *Obs. – drawing,* p = .004).

The statistical analyses conducted to test hypothesis 2 confirm the hypothesis, *direct observation* is a more effective teaching method than observation conducted through *photographs* and/or *drawings*.

To test hypothesis 3, the results of the *Quades's ANCOVA* analysis showed significant differences between the three experimental conditions in all three teaching activities under analysis. After the *Quades's ANCOVA* analysis, we proceeded to calculate the Tukey post-hoc test to identify which experimental conditions have the statistically significant differences identified by the *Quades's ANCOVA* analysis.

The data from the Tukey test show that, in the case of the *Spruce*, there are significant differences between direct observation and the other two types of observation (*Direct observation* vs. *Obs. – photo*, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000), in favor of direct observation, which proves to be a more effective teaching method for forming representations. There are no statistically significant results between *Observation by photography* and *Observation by drawing* (p = .031).

In the case of the *Meat grinder* subject, the post-hoc test shows significant differences between any of the three experimental conditions grouped two by two (*Direct observation* vs. *Obs. – photo*, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000; *Obs. – photo* vs. *Obs. – drawing*, p = .003). The most effective method proved to be direct observation, followed by observation through drawings and observation through photography. Similarly, for the truck subject, the post-hoc analysis performed by the Tukey test reveals significant differences between any of the three experimental conditions compared two by two (*Direct observation* vs. Obs. – photo, p = .000; *Direct observation* vs. *Obs. – drawing*, p = .000 and *Obs. – photo* vs. *Obs. – drawing*, p = .000). In conclusion, the analysis of the data confirms hypothesis 3, direct observation proves to be a more efficient teaching solution for forming representations compared to trying to form representations by using photographs and/or drawings.

Table 3.1 presents data on the effect size of the differences between the three experimental conditions. It can be observed that the differences between direct observation and the other two types of observation are very large, with effect sizes ranging from d = 2.13 to d = 9.79.

Table 3.1

Means, Standard Deviations, and Effect Sizes

for The Comparison Of The Three Experimental Conditions

		GE 1 - direct observation		**GE2 - observation through photography**		**GE3 - observation through drawing**		**Cohen's d effect size**		
	N	**M**	**AS**	**M**	**AS**	**M**	**AS**	**A vs. B**	**A vs. C**	**B vs. C**
Spruce										
volume and complexity	51	**42,75**	2,70	**28,53**	5,03	**31,27**	6,31	3.5	2.37	.48
generalization	51	**48,82**	2,36	**26,86**	5,10	**27,35**	4,94	5.53	5.55	.10
representation	51	**91,67**	3,70	**55,39**	5,64	**58,63**	7,42	7.61	5.64	.49
Meat grinde										
volume and complexity	51	**49,80**	1,40	**36,96**	6,17	**36,47**	8,74	2.87	2.13	.07
generalization	51	**48,43**	3,08	**15,78**	7,03	**20,69**	6,17	6.02	5.69	.74
representation	51	**98,24**	3,58	**52,75**	5,51	**57,16**	10,78	9.79	5.12	.52
Truck										
volume and complexity	51	**47,35**	4,51	**36,86**	5,19	**34,61**	5,28	2.16	2.60	.43
generalization	51	**47,94**	4,92	**24,90**	4,64	**21,57**	4,74	4.82	5.46	.87
representation	51	**95,29**	7,44	**61,76**	4,78	**56,18**	4,65	5.36	6.30	1.18

3.2.4 Discussion and Conclusions

In the case of testing hypothesis 1, at pre-test and post-test, the measurement of the volume and complexity of students' representations was associated with items that targeted: identification of the components of the observed objects in reality/ photographs/ drawings (word-image associations or label-iconic representation correspondences); providing the names of the components of the observed objects without visual support; describing, with or without visual support, the observed objects and their components; assembling the meat grinder (GE1) or specifying the assembly steps (GE2, GE3).

In the case of the formative intervention, some conditions were followed to ensure an optimal context for observation. Some of these conditions concerned the choice of subjects for observation. Three different components from the environment were selected: a living thing (the pine tree) and two inanimate objects (the food grinder and the model of a military truck). These objects are similar to each other in that they are systems in which the components are visible and easy for children to observe, even if the relationships between the components are more difficult to perceive. The fact that they have multiple components facilitated systematic observation of them, by repeating a similar procedure for identifying characteristics, an exercise through which students had the opportunity to develop their observation skills. Another condition that was respected was partial knowledge of them by students, so that they could leverage their previous representations during the formative intervention. Another condition concerned the choice of the observation procedure. In many studies, observation is included in the context of methods (comparative observational method, laboratory method, experimental method) (Meneghetti et al, 2017) or training models: learning through observation and discovery (Barbacovi et al, 2018), the Prediction-Observation-Explanation (POE) model (Zhao et al, 2021), therefore the effects of observation on the volume and complexity of representations are difficult to measure.

In this research, the strategy of guided observation using observation sheets was used. The learning strategy was integrated into a contextualized activity. Before applying the procedure, the teacher organized the groups, described the task and the observation procedure. To ensure the transfer of knowledge and the observation procedure to real-world contexts, the activity ended with discussions with the students, with conclusions, thus achieving a cyclical approach to observation. These activities leveraged some of the students' previous representations formed by observing such objects in real contexts, in everyday life, and the improved representations in this context can be leveraged in future situations.

The research results have confirmed the effectiveness of this procedure and the instruments used to guide the observation. Since the observation and the use of the instrument were strictly controlled by the teacher, we believe that the students focused on observing the specified aspects. Through these sheets, the scientific observation of the object being investigated was ensured (Gelman & Brenneman, 2012), imposing the order in which the objects and their components were observed or analyzed. This instrument had the role of explicit cognitive scaffolding, but without taking into account the differences between students, with the exception of reading skills. Another objective pursued was the active involvement of students in the process oriented towards a prefigured goal, being guided towards intentional observation (Monteira & Jiménez-Aleixandre, 2016). We assume that, if the students had observed these objects in groups, without benefiting from these instruments, they would have practiced non-scientific, subjective observation (Hodson, 1986), unfocused (Schuster & Leland, 2008). These instruments prefigured the expected learning outcomes in a structure in which the information is grouped into categories: constituent parts and their characteristics.

The statistical analyses confirm the hypothesis that *direct observation* is a more effective teaching method for the formation of the *volume and complexity of representation*, compared to *observation based on photographs or drawings*. Direct observation of the pine tree and the other two objects (meat grinder and model truck) provided GE1 students with several advantages over the other groups. First, they perceived the objects multimodally, in three-dimensional form, by direct contact with them, which facilitated more precise observation of their spatial arrangement, texture, dimensions, proportions, and details. Second, students were able to decompose the objects intended for observation into component elements with which they could operate (Seel, 2012; Tytler & Hubber, 2016).

Statistical analyses indicate that *observation based on photographs* is the least effective method for the formation of *the volume and complexity of representation*. Students in the group that observed the photographs – external representations of reality – perceived the investigated objects only through the visual analyzer, therefore they had fewer landmarks for the correct perception of size, shape, texture, details, structure, and internal components and their characteristics. It was difficult for students to convert the two-dimensional representation from the photograph into a three-dimensional one at the mental level.

Statistical data show that there are statistically significant differences between *Observation-photography* and *Obs. – drawing*, in the case of the pine tree, but not in the case of the Meat Grinder and the Truck. These results can be explained, first of all, by the fact that students probably had, before the formative intervention, a larger volume of representations about the pine tree compared to the volume of representations about the other objects, therefore students in the groups that observed photographs and drawings have leveraged these representations at post-test.

In the case of testing hypothesis 2, at pre-test and post-test, the measurement of the degree of generality of the students' representations was associated with items that targeted: identifying in reality/ photographs/ drawings, based on certain essential features, the bodies/ objects similar (pine trees, food grinders, models and trucks); classifying the observed/ analyzed bodies into the higher category; arguing/ explaining the classification of a body/ object into a category.

The statistical analyses confirm the hypothesis that *direct observation* is a more effective teaching method for increasing the degree of generality of students' representations, compared to observation based on *photographs* or *drawings*.

The worksheet had a strong effect in increasing students' ability to identify the essential features of bodies and recognize the objects analyzed in this situation and in other contexts, by specifying their component elements and characteristics for identification, as well as general characteristics of bodies.

In the case of observing the *Military truck*, observation based on drawings is more efficient than observation through photographs. By comparing the representation of the model truck in photographs and drawings, it is observed that the drawings observed by GE3 specify the names of the components and indicate their position with arrows. Establishing the relationship between the image and the name of specific components requires a great cognitive effort even for an uninitiated adult, without prior knowledge about cars. The statistical data show that, in the case of the meat grinder, observation based on photographs is more efficient than observation through drawings. The drawings and photographs provided to the students are very similar and do not contain the names of the components. Students who observed the drawings and photographs had access to the names of the components only in the worksheets.

In conclusion, in the case of hypothesis 3, the data analysis confirms that direct observation of environmental components proves to be a more effective learning strategy for the formation of more complex and more precise representations compared to trying to form representations by observing the same environmental components in drawings and photographs.

At the end of the study, a few conclusions emerge:

Regarding the three hypotheses tested, the results obtained by statistical analysis indicate their confirmation: direct observation is a more efficient training method than observation in photographs and/or drawings, effect sizes are very large, oscillating between $d = 2.13$ and $d = 9.79$. The learning strategy of guided observation through worksheets contributed more to the increase in volume, complexity, and relevance of representations on the three topics in learning activities based on direct observation of objects than in those based on observation in drawings and photographs. The strategy has beneficial effects on the internal representations of students participating in the study, effects reflected in student worksheets and posttests and presented in the literature: they build more detailed representations; they use their background of representations voluntarily and decompose the assembly into component elements with which they can operate (Seel, 2012; Tytler & Hubber, 2016).

The limitations of the study are represented by the relatively small size of the sample of participants, the content sample, and the small number of learning activities based on guided observation through worksheets – direct observation of three-dimensional objects and their representation in drawings and photographs – included in the formative intervention. These limitations can be overcome by expanding the research to a larger sample of participants, both from rural and urban areas, and involving them in more learning activities based on observation. Without considering it a limitation of this study, we suggest that the research could be expanded by including a group of students who observe objects individually or in groups, but without the benefit of the worksheet, as well as a group that studies texts, without the benefit of images.

The research can be extended by using observation-based learning strategies in other educational disciplines. The tests, and projects of the self-designed learning activities can also be useful for other teachers and other groups of students. The description of the research process and the materials included in the paper allow the research to be replicated in other groups.

3.3 Study 3: The Effects of Learning Activities Based on Experimentation on the Formation of Student Representations

3.3.1 Introduction

Experimental activity is generally considered the main teaching method in science education (Abrahams et al, 2013). Conducting experiments in science teaching and learning should help to understand and practice the scientific process (Szalay et al, 2023).

Studies highlight the importance of integrated experimental design in an educational context. Díaz-Lobo & Fernández-Novell (2015) argue that didactic experiments can help students develop a passion for science, critical thinking, and problem-solving skills, and suggest that teachers should use didactic experiments in lessons as often as possible. Globally, there are studies on the implementation of didactic experiments involving young students and investigating the topics of interest for this research: germination (Barbacovi et al, 2018; Bolzon et al, 2022; Ürek, 2020), states of water, floating (Leuchter et al, 2014; Tin, 2017; Van Schaik et al, 2020).

Researches in primary education, referring to germination, have been oriented towards the design and implementation of the experiment from the perspective of the scientific method. Barbacovi et al (2018) applied the experimental method in the study of the plant life cycle and the germination of corn by second-grade students.

Despite its simplicity, the literature reports many problems and misconceptions about seed germination in students, teachers, and textbooks. Jewell (2002) identified the characteristics of the seed model in children (small in size, round or teardrop-shaped, inedible for humans, not living things because they do not grow). Ürek (2020) found many difficulties in students regarding the effects of some factors on germination and appreciates that carrying out experiments focused on one factor does not prevent students from having misconceptions about the factors that affect germination. To eliminate students' conceptual problems, it is believed that the experiment should be designed taking into account all the factors that influence germination and that this experiment should be more detailed (Ürek, 2020).

The change of state of aggregation of water is an important concept in the understanding of energy cycles and the water cycle (Jung et al, 2020), but difficult to understand by young children (Black et al., 2011).

Studies have primarily investigated two main transitions (Black et al, 2011): the solid-gas transition and the solid-liquid transition (Jung et al 2020). Of the three states of matter, the gaseous state is the most difficult to understand due to its invisibility (Black et al., 2011). Studies on the states of aggregation of water in primary education are numerous and diverse in terms of objectives, applied training model, and experimental design. (Paik, 2015; Tin, 2019, 2022).

There are few studies conducted with primary school students on buoyancy. Leuchter et al. (2014) examined the effect of a structured, problem-based learning environment on the construction of concepts about buoyancy and sinking of solid and hollow objects by children in the early school years, as well as on scientific reasoning. In the study, researchers provided scaffolds regarding the task characteristics. Over a period of 4 weeks, children observed, compared, generated hypotheses, and recorded findings about buoyancy and sinking.

In terms of teachers, Goodman et al. (2006) stated that some of them often feel uncomfortable teaching science due to lack of knowledge or understanding. Primary school teachers tend to have limited knowledge of science and scientific pedagogical content, have low confidence and self-efficacy in teaching science, therefore many avoid teaching science content (Appleton 2007).

Senocak (2009) revealed that primary school teachers participating in the study had many misconceptions about boiling phenomena, these being based on their daily life experiences and inadequate science knowledge. Scott et al. (2007) argue that much less is known about how teachers should teach to help students learn.

Regarding future primary school teachers, Jewel (2002) found that many of them are not familiar with: the parts of the seed, the characteristics of each part, the function of seeds and their parts, and with regard to the germination process, they have gaps. In the practical activity carried out with trainee teachers, Vidal & Membiela (2014) found that many had misconceptions about biological processes and that these were corrected or completed after the teaching activity.

Aim, variables and hypotheses

The aim of the study is to investigate the impact of learning activities based on experiments on the formation of students' representations in science, compared to the impact of learning activities based on listening to the teacher's explanations and the guided observation of experiments in static visual representations (photographs and drawings) in the discipline of "Natural Sciences".

In this sense, the variables of our study are as follows: experiment, explanation, observation of static representations (independent variables), volume and completeness of representations, and degree of generality of representations (dependent variable).

For the implementation of the study, the following three research hypotheses were formulated:

H1: The volume and degree of completeness of students' representations created after using the experiment as a teaching method is greater than in the case of representations created in the context of didactic activities in which explanation and/or observation of static representations are used as teaching methods.

H2: The degree of generality of students' representations created after using the experiment as a teaching method is greater than in the case of representations created in the context of didactic activities in which explanation and/or observation of static representations are used as teaching methods.

H3: The use of the experiment as a teaching method leads to the creation of more complex and accurate representations compared to the use of explanation and/or observation of static representations as teaching methods for the formation of representations in the discipline of "Natural Sciences".

3.3.2 Method

Participants

The study was conducted in the period February-May 2022 in three schools in the county of Dambovita. The selection of schools was based on the following criteria: attendance of schools by students, recommendation of the specialist inspector, location in the urban environment, and the existence of parallel classes.

At the study participated 80 fourth grade students, aged 11-12, of both genders. To find out the students' performance prior to the experiment and to have a control variable for initial differences between groups, students took a test of accumulated knowledge in the third grade, in the subject "Natural Sciences". Based on the analysis of the results obtained at the initial test, 40 students from 2 classes formed the experimental group 1 (GE1), and another 40 students formed the experimental group 2 (GE2). The pre-existing classes were kept, the intervention taking place in the students' classrooms.

Before the beginning of the experiment, we explained the objectives of the study to the students and clarified aspects related to their way of involvement in the study (solving pre-tests, participating in the lessons included in the formative activity, solving post-tests, participating voluntarily in this study, without awarding rewards). We respected all the ethical and legal requirements imposed in the conduct of the study. We conducted the didactic activities included in the experimental study in the presence of the classroom teachers, according to their plans.

Procedure

Students in both groups participated in the following activities, extracted from the school curriculum of the Natural Sciences discipline, grade IV: "Germination in beans"; "Changing the state of aggregation of water" and "Floating of bodies in water". Each organized activity included three stages, carried out on separate days of a week: pre-experimental stage - application of the pre-test (10 minutes) and analysis of the results; formative intervention stage (50 minutes); post-experimental stage - application of the post-test (10 minutes).

Didactic activities

In the formative intervention stage, students in GE1 participated in activities based on conducting experiments, while students in GE2 participated in activities based on the teacher's explanations and guided observation of photographs and drawings.

Students in GE1 conducted biological or physical experiments in groups of 4-5 students, based on worksheets. The lessons were structured according to the model of sequential knowledge learning (Gagné, 1970).

On the topic of "Germination of bean seeds", students in GE1 participated in two lessons. In the first lesson, students identified the materials, observed the seeds based on the Observation Sheet, solved the task, and then formulated oral answers to the questions posed by the research teacher. In each group, students formulated predictions (hypotheses) on the effects over time of an environmental factor. With the help of the *Experimental Activity Sheet*, each working group (GL) conducted an experiment to test an environmental factor that influences the germination of bean seeds: GL1 - "Moisture", GL2 - "Temperature", GL3 - "Air", GL4 - "Light" and GL5 - "Germinative bed". At the end of the first lesson, the students completed a graphic organizer. In the following days, the students observed the changes in the seeds, discussed the observed aspects, and recorded their observations in the sheet they received. In the second lesson, the teacher checked the students' knowledge acquired in the previous lesson, then each group presented the experiment, predictions/hypotheses, recorded results, and the conclusion of the experiment. The students in GE2 followed the presentation of the research teacher, based on the PPT material "Germination of bean seeds" and completed a diagram and a table, identical to those used in the lesson with the students in GE1.

At the beginning of the lesson "Change of the state of aggregation of water", students in GE1, in pairs, identified situations in reality in which water was in the three states of aggregation. Students from all pairs presented their ideas orally. Subsequently, students completed a graphic organizer about the properties of water and drew the three states. In the following learning activities, students worked in small groups. In activity 1 (A1), each group formulated hypotheses about the factors that contribute to the change of the state of aggregation of water, completed the worksheet, and provided examples from nature. In activities 2, 3, 4, and 5, they made predictions about the passage of water from one state to another, observed physical phenomena (A2 - "Melting ice", A3 - "Vaporization of water", A4 - "Condensation of water", A5 - "Solidification of water"), and made conclusions. At the end of the lesson, students completed a table that summarized the names of the phenomena observed, the states of water, and the way in which each phenomenon is produced (by absorption/by release of heat). Students in GE2 followed the presentation of the researcher teacher, based on the PPT material "Changes in the state of aggregation of water", and at the end of the lesson they completed a diagram and a table, identical to those used in the lesson with students from GE1.

On the topic of the lesson "Floating of bodies in water", students in GE1, made hypotheses in response to the question "Why do bodies float in water?". Each working group carried out one of the 4 experiments on the floating of a solid body in water, in situations where only one variable was changed (volume of water, salinity of water, shape or mass of a solid body). At the end of the lesson, the students presented the results obtained from the experiments and formulated conclusions regarding the conditions for floating of a solid body in water. The students in G2 followed the presentation of the research teacher, based on the PPT material "Floating of bodies in water" and completed the same diagrams as the students in G1.

Instruments

The data collection necessary to evaluate the students' knowledge and representations was carried out through the use of self-designed instruments: 3 pre-tests, 3 post-tests, 3 observation sheets.

Initial test. The test consisted of 20 items with varying difficulty levels. For each item solved correctly, we awarded 5 points. The maximum score is 100 points.

Pre-tests and Post-tests. To diagnose the level of knowledge of students on the three topics addressed, we applied 3 pre-tests: "Bean germination", "Changes in the state of aggregation of water", "Floating of bodies". Each pre-test consists of 20 items. For each item solved correctly, we awarded 5 points. The items are correlated with the two dependent variables (50 points each). The maximum score of each test is 100 points. The 3 post-tests are similar to the pre-tests in terms of the number of items, correlations with the dependent variables and score.

Observation sheets and sheets for experimental activities. For the topic "Germination of bean seeds", in order to identify the characteristics of bean seeds, I designed a "Bean Seed Observation Sheet". For the experimental activities, I designed four sheets, customized to test the effects of the following external factors: "Humidity", "Temperature", "Air", "Light", "Germinative bed". For the topic "States of aggregation of water", I designed sheets customized for each physical phenomenon: sublimation, desublimation, melting, vaporization, condensation, solidification. For the topic "Floating of solid bodies in water", I designed an observation sheet of the behavior of solid bodies in water. In all the sheets of the experimental activities, I specified the materials used and the procedure.

Data analysis

Preliminary analyses – at the level of the initial test. To test the equivalence of the two experimental groups, we performed comparative statistical analyses. Since the data at the level of the initial test are not normally distributed, we chose to use the Mann-Whitney U test for non-parametric data.

Main analyses – hypothesis testing. Preliminary analyses of the assumptions showed that the data collected through the three pretests and the three posttests are also non-parametric, the Gaussian normal distribution being violated. Therefore, instead of ANCOVA time analyses in which we would use the pretest results as a covariate, we performed Quades' ANCOVA analyses for non-parametric data to test each of the three hypotheses of the study.

3.3.3 Results

Preliminary results

The mean ranks of the two groups of students are as follows: MRexperiment = 47.76

(Nexperiment = 40) and MRobservare = 33.24 (Nobservare = 40). The results of the Mann-Whitney U test show that there are significant differences between the two groups of students (z = -2.892; p = .004) at the level of the initial test in favor of the group that will participate in instructional-educational activities carried out through the use of the didactic experiment method. As such, the groups are not equivalent. The comparison of the two groups in the context of a scientific experiment can only be made by controlling their results at the pre-test. Therefore, pre-test results will constitute covariates in the comparisons of the two experimental groups.

Main results – hypothesis testing

The results of the Quades's ANCOVA analysis conducted to test hypothesis number 1 show that there are statistically significant differences between the two experimental groups, in all three cases of topics addressed (bean germination, change of water aggregation state and floating of bodies). All differences are in favor of GE1, which studied the topics through experiments, and that the effect sizes are large and very large: Mgrup_experiment = 47.24 vs. Mgrup_obs_exp = 38.63, η2p = .286, in the case of the subject of bean germination; Mgrup_experiment = 46.75 vs. Mgrup_obs_exp = 26.38, η2p = .665, in the case of the subject of the change of water aggregation state and Mgrup_experiment = 45.75 vs. Mgrup_obs_exp = 29.75, η2p = .698, in the case of the subject of the floating of bodies.

Therefore, in the case of hypothesis testing 1, the statistical analyses confirm the hypothesis, that the didactic experiment is a more efficient teaching method for the formation of the volume and complexity of representation, compared to the use of observation of static representations and explanation.

The results of the Quades's ANCOVA analysis for hypothesis testing 2 show that, for all three instructional situations (bean germination, change of water aggregation state and floating of bodies), we have significant differences (p = .000) between the teaching methods used. The analysis of the means of the experimental groups shows that these differences are, in all three instructional topics addressed, in favor of the group that addressed the topics through the didactic experiment method (Mgrup_experiment = 46.13 vs. Mgrup_obs_exp = 20.38, η2p = .771, in the case of the subject of bean germination; Mgrup_experiment = 46.63 vs. Mgrup_obs_exp = 35.50, η2p = .567, in the case of the subject of the change of water aggregation state and Mgrup_experiment = 45.13 vs. Mgrup_obs_exp = 29.00, η2p = .603, in the case of the subject of the floating of bodies). Therefore, the statistical analyses carried out for hypothesis testing 2 confirm the hypothesis, the didactic experiment is a more efficient instructional method compared to the observation of static representations and the explanations of the teacher.

The results of the Quades's ANCOVA analysis conducted for hypothesis testing 3 show significant differences between the two experimental conditions, in all three didactic activities analyzed (bean germination, change of water aggregation state and floating of bodies). All three statistically significant differences (p = .000) are in favor of the group that addressed the instructional topics through the didactic experiment method (Mgrup_experiment = 93.50 vs. Mgrup_obs_exp = 59.13, η2p = .760, in the case of the subject of bean germination; Mgrup_experiment = 93.38 vs. Mgrup_obs_exp = 61.88, η2p = .710, in the case of the subject of the change of water aggregation state and Mgrup_experiment = 90.88 vs. Mgrup_obs_exp = 58.75, η2p = .762, in the case of the subject of the floating of bodies).

In conclusion, the data analysis confirms hypothesis number 3. The didactic experiment proves to be a more efficient instructional and educational solution for the formation of representations, compared to the attempt to form representations by using the observation of static representations and the explanations of the teacher.

Table 3.2 presents data on the effect size of the differences between the two experimental conditions.

Table 3.2

Means, Standard Deviations, and Effect Sizes

	GE1 - experiments			**GE2 – observation and explanation**			**Effect size (partial eta squared)**
	N	**M**	**AS**	**N**	**M**	**AS**	
Bean germination							
volume and complexity	40	47,25	2,99	40	38,63	5,19	.286
generalization	40	46,13	6,65	40	20,38	8,20	.771
representation	40	93,50	6,91	40	59,13	8,08	.760
The change in the state of aggregation							
volume and complexity	40	46,75	5,38	40	26,38	5,43	.665
generalization	40	46,63	3,99	40	35,50	5,16	.567
representation	40	93,38	8,43	40	61,88	7,22	.710
Buoyancy of bodies in water							
volume and complexity	40	45,75	4,61	40	29,75	4,52	.698
generalization	40	45,13	4,31	40	29,00	4,56	.603
representation	40	90,88	7,92	40	58,75	7,40	.762

It can be observed that the differences between the two groups are very large, with effect sizes ranging from η2p = .286 to η2p = .771.

3.3.4 Discussion and Conclusions

In the case of testing Hypothesis 1, at the pre-test and post-test, the measurement of the volume and complexity of students' representations was associated with items that targeted: the specification of the characteristics of some observed bodies and the conditions under which physical phenomena and biological processes are produced or observed; the identification in drawings of the components of the observed bodies (word-image associations or label-iconic representation correspondences); the specification, without visual support, of the names of the components of the observed bodies.

In the case of the formative intervention, in order to ensure an optimal context for experimentation and for the formation of representations, certain conditions were met. Regarding the subjects intended for experimentation, germination in beans was chosen as a biological process, the change of state of water and the floating of solid bodies in water as physical phenomena. From the teacher's perspective, experiments were designed with a similar degree of complexity that can be carried out in class by students. From the students' perspective, phenomena were chosen about which they have some correct representations acquired in everyday life, but also some misconceptions (Leuchter et al, 2014; Ürek, 2020) or misunderstandings (Vidal & Membiela, 2014). Although these phenomena seem simple, some aspects are difficult to understand (Black et al., 2011), therefore students had the opportunity to capitalize on their previous experiences and representations during the formative intervention, to fill in the gaps and correct misconceptions, and to enrich their volume of representations.

In our research, experiments were integrated in the context of Gagné's instructional model (1970; Gagné & Briggs, 1974), one of the most well-known and widely used instructional models (Smith & Ragan, 2000), also presented in pedagogy (Ilie, 2009) and science education textbooks for primary education in Romania (Dulamă, 2012). The instructional model is applied in a specific way in each lesson. The events are reorganized in the traditional structure of the knowledge acquisition lesson: it starts with the organizational moment, suggested by Ilie et al (2014) to increase the efficiency of learning, continues with the acquisition of knowledge, which includes the first five activities from Gagné's model, including the experiment at GE1, and, finally, the other events take place, which can be related to the moment of consolidation of knowledge.

Activities were organized based on the specificity of the content, the necessary time resources, and the characteristics of the students. At GE1, the experiment was conducted in stable groups for all three topics. The distribution of tasks is different due to the time required to conduct the experiments. Thus, for the topics "Germination" and "Floating", each group conducts a different experiment in which it tests a specific factor or condition. For the topic "Water States", all groups conduct all experiments. In addition, for the topic "Germination", the first part of the experiment is conducted in the first lesson, the observation of the process takes place over the course of a week, and the discussion of observations, hypotheses, and the formulation of conclusions is conducted in the second lesson. Ürek (2020), referring to germination, suggested the need to test all factors. However, the large volume of content included in the school curriculum (MEM, 2014) and the actual available time resources are restrictive factors in ensuring this condition.

At GE1, “learning orientation”, also known in Romanian as “learning guidance” (for example, Dulamă, 2012), is achieved through work sheets (“observation sheets” and “experimental activity sheets”), while at GE2, it is achieved through systematic presentation, visual organization of information on the screen, and conversation. Activities to intensify retention are achieved through games (Robingo) and by summarizing information in schemes. The transfer and contextualization of knowledge is carried out through problem-solving situations, by requesting real-world examples, and through conversation, and the achievement of performance is demonstrated throughout the activity and by solving the items in post-tests. Even though the provision of feedback is scheduled to be done at a certain point, in reality, the teacher provided feedback throughout the lessons, in various forms.

In this study, the guided experimentation strategy was used at GE1 through observation sheets and experimental activity sheets. The designed and used sheets are detailed because fourth graders do not have experience in applying the scientific method and need guidance or "scaffolds" from the teacher. The work sheets list the materials and detail the procedures or tasks in the order in which they must be performed, so the sheets are strategic scaffolds (Hannafin et al, 1999). Similar to Study 2, the sheets represented for the students "cognitive scaffolds" (Yelland & Masters, 2007), static (Kim & Hannafin 2010) with the help of which they go through the procedure, engage in practical "scientific" activity, collaborate with groupmates, reflect on their own concepts and actions, ensuring metacognition (Davis, 2015). Given that students were required to pay attention, these tools have the characteristics of embedded scaffolds, integrated in the learning environment (Narciss et al, 2007). The sheets provided students with affective scaffolds by encouraging them to focus on the task and persist in it (Yelland & Masters 2007). For learning the scientific method, through explicit guidance from the sheet, students in GE1 were asked to make predictions, write them in the sheet, observe the consequences of actions and mention them in the sheet, and select and underline the correct explanation from two explanations constructed by the teacher. Unlike students in GE1, students in GE2 observed sequences from experiments in photographs and answered the teacher's questions orally. The learning process was controlled by the teacher providing the questions, including research questions.

In the case of testing hypothesis 1, statistical analyses show that there are statistically significant differences (p = .000) between the two experimental groups, for all three topics. Thus, they confirm the hypothesis that the use of experiment is a more effective teaching method for increasing the volume and complexity of representation, compared to observing static representations and using explanation.

From the perspective of representation formation, GE1 students benefited from more favorable learning conditions. They directly observed objects and phenomena, manipulated three-dimensional objects through direct contact with them, with their classmates or autonomously (Capparotto et al, 2017), and perceived them multimodally. GE1 students self-guided or self-regulated their observation process of objects and processes, unlike GE2 students who, in frontal activities, were prompted by the teacher to move on to observing another image even if they may have needed more time to decode the meaning of the content represented in the photograph. GE1 students perceived the information in a rigorous chronological order, predetermined by the teacher, which on the one hand ensured the coherence of the process performed (experiment or observation), but also of the process (germination) and the phenomena investigated (change of the state of aggregation of water, floating). Students in GE2 received information from the teacher in an order influenced by their answers to questions. The attention of students in GE1 was focused on a single aspect, while students in GE2 observed multiple images simultaneously on a slide, which can distract and disperse attention. The process of understanding what they saw was more difficult for students in GE2 because they had to convert the two-dimensional representation from the photograph to a three-dimensional one at the mental level.

In the case of testing hypothesis 2, at pre-test and post-test, the measurement of the degree of generality of students' representations was associated with items that targeted: identifying, in drawings, certain essential features of bodies/ objects; defining concepts (seed, germination, melting, freezing, vaporization, condensation, sublimation, desublimation, floating); formulating hypotheses and conclusions regarding the process or phenomena that will occur in given/existing conditions in reality; arguing/explaining a biological process and physical phenomena experimented or observed. Statistical analyses show that there are statistically significant differences (p = .000) between the two experimental groups, for all three topics and, thus, confirm the hypothesis that the *use of experiment* is a more effective teaching method for increasing the degree of generality of students' representations, compared to *observing static representations* and using *explanation*.

Experiments conducted using work sheets had a strong effect on increasing students' ability to identify the essential features of objects, to formulate predictions, hypotheses, and to verify their confirmation, to conduct an experiment, to deduce cause-and-effect relationships, and to explain a process/phenomenon. Discussions with students after experimental activities played an important role in discriminating between essential and non-essential information, in systematizing information about processes and phenomena based on logical and chronological criteria, and thus in increasing the relevance of students' representations.

At the end of the study, a few conclusions emerge:

In this research, the didactic experiment was integrated into the context of Gagné's instructional model (1970; Gagné & Brigges, 1974), reorganized in the traditional structure of the lesson for the acquisition of knowledge. The design of each didactic experiment was based on the theories mentioned in study 2: the theory of cognitive development (Vygotsky, 1962, 1978), the theories of scaffolding (Wood et al, 1976), the theory of learning from multiple representations, the dual coding theory (Paivio, 1990), the cognitive theory of multimedia learning (Ainsworth, 2006; Mayer, 2014; Schnotz, 2014).

With regard to the three hypotheses tested, the results obtained by statistical analysis indicate their confirmation: the use of the experiment is a more effective teaching method for increasing the volume, the degree of completeness, and the degree of generality of students' representations, compared to observing static representations and using explanation. The differences between the two groups are very large, the effect sizes oscillating between $\eta 2p = .286$ and $\eta 2p = .771$.

The relatively small size of the sample of participants, the content sample, and the small number of learning activities based on guided experiments using worksheets included in the formative intervention could be considered as limitations of the research. Overcoming them is possible by extending the research to a larger sample of participants from rural and urban areas and by involving them in more learning activities based on didactic experiments.

The lesson plans, tests, and worksheets created in the context of this study could be useful for other teachers and other groups of students, either for regular teaching activities or for research purposes. The detailed description of the research process and the inclusion of materials in the appendices of the work allow the replication of the research in other groups.

3.4 Study 4: The Effects of Drawing-Based Learning Activities on the Formation of Scientific Representations in Students

3.4.1. Introduction

Drawing and coloring are considered important activities in children's lives (Ahi, 2017). In science learning, illustrations of different types are used to facilitate the understanding of information, and in order to understand them, readers must decode them and extract their meaning (Jewitt & Oyama, 2001). Scientific illustrations have an important role, but the ability of young readers to use and integrate information from illustrations with that from text is limited (Jian, 2018a).

Researchers have emphasized that drawing can improve conceptual learning in science, as it helps to organize knowledge and make it explicit (Ainsworth et al, 2011), to make the transition to scientific concepts (Athney, 1990; Cox, 2005), to construct meaning and share ideas with others (Brooks, 2009). Drawing encourages students to explore their representations about science (Prain & Tytler, 2012), helps to understand the development of a structure more than a finished image (Lysek & Gernot, 1981), to identify misconceptions, to understand the deeper processes that written or verbal recall cannot (Murtonen et al, 2020). Drawing can be mnemonic because people can remember drawn images better and faster than if they had imagined them or provided verbal labels (Fernandes et al, 2018). Students' drawings are evidence or indicators of students' conceptual knowledge (Chin & Teou, 2010). Through drawing, children become more able to work at a metacognitive level, talking about complex scientific concepts and reviewing them. Drawing becomes a tool for communication and problem-solving (Athney, 1990; Cox, 2005).

In comparison to drawing, providing illustrations does not guarantee the spontaneous integration of images and words (e.g., Bodemer et al, 2004; Hegarty et al, 1991), just as text-centered strategies do not necessarily generate the conversion of text into a coherent nonverbal mental representation that includes their knowledge from memory (Leopold & Leutner, 2012).

Drawing is considered a learning strategy in which students create representative illustrations to achieve a learning objective (Van Meter & Garner, 2005). Drawing is a model-based learning strategy because students generate an external nonverbal representation and create an integrated mental representation of the material to be learned or a situation model (Fiorella &

Zhang, 2018). Drawing as a model-based strategy, involves deeper cognitive processes in building a situation model (Leopold & Leutner, 2012). Model-centered strategies are closely related to generative strategies (Fiorella & Mayer, 2015, 2016) and constructive strategies (Chi & Wylie, 2014), learning strategies – activities through which students organize and integrate the learning material with their prior knowledge.

The formation of representations through the learning strategy of drawing is supported by several theories: the theory of learning from multiple representations, including the dual coding theory (Paivio, 1990), the generative learning theory (Wittrock, 1992), multimedia learning theories (Ainsworth, 2006; Mayer, 2014; Schnotz, 2014), the generative drawing construction theory (Mayer et al, 1995; Wittrock, 1990), which explains the conversion of a provided text into a drawing (Van Meter & Garner, 2005). These theories support the idea that the integration of verbal and nonverbal (visual-spatial) information supports the construction of a coherent mental representation (Fiorella & Zhang, 2018).

Purpose, variables, and hypotheses

The purpose of the study is to investigate which of the following two variants of completing didactic activities based on listening to and studying a text with photos, the one in which drawing is used based on static visual materials (photos, drawings, and schemes) or the one in which the observation of static representations (photos, drawings, and schemes) is used, is more effective for the formation of students' representations in science.

In this sense, the variables of our study are as follows: drawing, observation of static representations (independent variables), volume/completeness and complexity of representations (dependent variable), and degree of relevance of representations (dependent variables).

For the implementation of the study, the following research hypotheses were formulated:

I1 – The volume and degree of complexity/completeness of students' representations created following the use of drawing as a learning strategy are greater than in the case of verbal representations created following the use of observation of static representations as a learning strategy.

I2 – The degree of relevance of students' representations created following the use of drawing as a learning strategy is greater than in the case of representations created following the use of observation of static representations as a learning strategy.

3.4.2 Method

Participants

The study was conducted in March-April 2023 in two schools in Dâmbovița County. The selection of schools was based on the following criteria: a) school attendance by students, b) location in an urban environment, and c) the existence of parallel classes. The study involved 80 second-grade students, aged 8-9 years old, of both genders (31 female).

The students took an initial test. Based on the analysis of the results obtained on the initial test, 40 students formed experimental group 1 (GE1) and another 40 students formed experimental group 2 (GE2). The existing classes were kept, the intervention taking place in the students' classrooms.

Before the start of the experiment, I explained the objectives of the study to the students and clarified aspects related to their involvement in the study. I ensured the confidentiality of the students' personal data and respected all ethical and legal requirements imposed in the conduct of the study.

I obtained informed consent from the parents of the participating students. I concluded collaboration protocols with the supervising teachers of the classes included in the experiment. The didactic activities included in the experimental study were supported by the researcher in all classes, in the presence of the classroom teachers, at the end of the school program.

Procedure

This study is quasi-experimental, with a pre-test-post-test design and two groups of participants. The students in both groups participated in the following activities related to the deciduous forest, correlated with the topic Forest specified in the school curriculum for the subject Mathematics and the Exploration of the Environment, grade 2: Tree and Shrub, Stratification in the Deciduous Forest, and Feeding Relationships. We chose these topics because trees are part of the play environment of children in urban areas and are attractive to them (Elnesr & Said, 2023), allow rapid representation through simple schematic drawings of some components in the environment (tree, shrub), of an assembly of components (stratification of the deciduous forest), as well as simple schemes of the relationships between the components of the environment (feeding relationship/food chain). The psycho-pedagogical experiment included three stages, carried out on distinct days in two weeks: the pre-experimental stage - the application of pre-tests (20 minutes) and the analysis of the results; the stage of formative intervention; the post-experimental stage - the application of post-tests (20 minutes).

Instructional activities

In the stage of formative intervention, at each activity, in both groups, the teacher read the allocated text, and the students listened to the text and observed the images. In GE1, the text and images were visible on the screen throughout the activity (60 minutes). After the activity, as a homework assignment, the students were given access to the website where the text and images were available (Pahome, 2023a).

Students in GE1 were given three tasks: to observe the given photographs and draw a tree with a trunk and crown (without leaves) and a shrub (without leaves); to observe the given photographs and draw a schematic representation of the three plant layers in the deciduous forest; to observe a scheme of food chains in the deciduous forest, select a food chain from the scheme, and write on the line all the links (plant and animal species) in the chain, separated by arrows. In GE2, over the course of the three activities, each with a duration of 60 minutes, the texts and images were visible on the screen in the classroom. The students in GE2 were given the study materials in text format and the task to study them at home, individually. The students in GE1 and GE2 were informed that another test would be applied at the end of the second week of the formative intervention.

Instruments

Initial test. The test consisted of 20 items of varying difficulty. For each item answered correctly, we awarded 5 points. The maximum score is 100 points.

Pre-tests and post-tests. The volume, completeness, complexity, and relevance of the students' representations were measured by 2 pre-tests and 2 post-tests of our own design, which consist of 3 drawing representation items (one item for each theme) and 3 items that require written resolution. The items are correlated with the two dependent variables and with the content of the theme studied. The maximum score for each test is 10 points.

Data analysis

Preliminary analyses – at the level of the initial test

To test the equivalence of the two experimental groups, we conducted comparative statistical analyses. Since the data, at the level of the initial test, are not normally distributed ($z = 0.285$; $p = .000$), we chose to use the Mann-Whitney U test for non-parametric data.

Main analyses – testing the hypotheses

Preliminary analyses of the assumptions showed that the data collected through the two pre-tests (z = 0.451, p = .000, respectively z = 0.483, p = .000) and the two post-tests (z = 0.241, p = .000, respectively z = 0.188, p = .000) are also non-parametric, the Gaussian normal distribution being violated. Therefore, instead of time ANCOVA analyses using the pre-test results as a covariate, we conducted Quades's ANCOVA analyses for non-parametric data to test each of the three hypotheses of the study.

Analysis of visual data

The drawings created by the students were analyzed and interpreted. Image-based analysis includes the analysis of photographs and drawings (Mitchell, 2011). The drawings of the study (N=80) were analyzed in five stages: (1) observing the content of the drawings to establish some easily observable and measurable analysis criteria; (2) observing the drawings to establish categories according to each criterion; (3) analyzing each drawing to classify it into categories; (4) analyzing the categories and their weight in the evaluated drawings to identify similarities and differences; (5) interpreting the results. Based on the analysis of the drawings of trees and shrubs, we established two analysis criteria: shape and color. Based on the analysis of the drawings of the deciduous forest, we established five criteria: number of plant layers, perspective, spatial distribution of plants by category, spatial arrangement of plants according to relief, color. Based on the analysis of the drawings of food chains, we established four criteria: length of the food chain, use of the names of plants and animals, direction of energy and matter transfer, presentation and organization in space of the elements in the drawing.

3.4.3 Results

Preliminary results

The mean ranks of the two groups of students are as follows: MRdesen = 51.25 (Ndesen = 40) and MRobservare = 29.75 (Nobservare = 40). The results of the Mann-Whitney U test show that there are significant differences between the two groups of students (z = -4.467; p = .000) at the level of the initial test in favor of the group that will participate in instructional-educational activities carried out using the drawing method. We found that the groups are not equivalent. Therefore, the results of the pretests will constitute covariates in the analyses of the comparison of the two experimental groups.

Main results – testing the hypotheses

The results of the Quades's ANCOVA analysis conducted to test hypothesis 1, presented in detail in the body of the thesis, show that there are statistically significant differences between the two experimental groups. These differences are in favor of the group that studied the subject using the drawing method. The effect size is very large: Mgroup_drawing = 60.2 vs. Mgroup_observation = 20.8, η2p = .748.

Therefore, we can conclude that the statistical analyses, in the case of testing hypothesis 1, confirm the hypothesis formulated, that the use of drawing as a complementary method alongside the study of text is a more effective teaching method for the formation of volume and complexity of representation, compared to the use of observation of static representations.

The results of the Quades's ANCOVA analysis conducted to test hypothesis 2 show that there are statistically significant differences between the two experimental groups. These differences are in favor of the group that studied the subject using the drawing method. The effect size is very large: Mgroup_drawing = 58.26 vs. Mgroup_observation = 22.74, η2p = .636. Therefore, we can conclude that the statistical analyses, in the case of testing hypothesis 2, confirm the hypothesis formulated, that the use of drawing as a complementary method alongside the study of text is a more effective teaching method for the formation of relevance of representation, compared to the use of observation of static representations.

Table 3.3 presents data on the effect size of the differences between the two experimental conditions.

Table 3.3

Means (of Ranks), Standard Deviations, and Effect Size for Comparing the Two Experimental Conditions

	GE1 drawing			GE2 observation of static representations			Effect size (Partial Eta Squared)
	N	M	AS	N	M	AS	
volum și completitudine	40	60,2	11,75	40	20.80	11.11	.748
relevanță	40	58,26	15,42	40	22.74	11.08	.636

Secondary results: drawing analysis

At pretest, in both groups, the trees in the drawings are classified into the category of those with a large trunk and cloud-shaped crown, and the shrubs, into the category of those with multiple stems from the root. In 43 drawings, shrubs were not represented. At post-test, in GE1, most trees are classified into the category of those with a large trunk and crown with branches, and in GE2, into the category of those with a large trunk and cloud-shaped crown, with branches. Most shrubs drawn by both groups are classified into the category of those with multiple stems from the root.

With regard to the distribution of tree and shrub drawings by color, many drawings are monochromatic, in black (pre-test - 36 drawings).

With regard to the distribution of deciduous forest drawings by categories, at pre-test, most drawings represent the forest through a single layer of trees, while at post-test, through three layers of plants (100% weight at GE1). In terms of perspective, at pre-test, most drawings represent the forest in 2D format, while at post-test, the number of these representations decreases at GE1 and increases at GE2. Based on the distribution of plants by categories, in most drawings, plants are represented in groups, with the number of these drawings increasing at GE1 and decreasing at GE2. In terms of color, at pre-test, most drawings were represented in a single color, primarily in black pencil, while at post-test, they were represented in multiple colors (brown trunks and stems, green crowns, green herbaceous layer).

With regard to the distribution of food chain drawings by categories, at pre-test, most drawings included two links. At post-test, in 27 works, the drawn food chains included more than two links, while at GE2 the previous situation remains. With regard to the use of labels, at pre-test, most drawings did not include the names of plants and animals. At post-test, in 37 drawings, labels are included, while at GE2 labels are only present in one drawing. Regarding the representation of the direction of energy and matter transfer, arrows were not used at pre-test, but at post-test, arrows are included in 39 drawings at GE1. Regarding spatial organization, at both tests, most chains were represented in linear perspective.

3.4.4 Discussion and Conclusions

Volume, complexity and relevance of representations in "Tree and shrub" drawings

Drawings made by students are a representation of their mental models (Moseley et al, 2010), reflecting their knowledge and the perceived reality as a result of their life experiences (Moseley et al, 2010; Tunnicliffe & Reiss, 2000). At pre-test, the fact that 67 students participating in the study drew trees with a large trunk and cloud-shaped crown (Figure 3.1a) indicates a mental model of the tree that corresponds to the one identified by other researchers (Corneau et al, 2019). This drawing can be considered a prototype representation for a tree. The fact that, at pre-test, 43 students did not draw shrubs suggests that they do not have the perception, representation, and concept of a shrub.

In terms of color, 41 students drew trees with brown trunk and branches/twigs/green crown (Figure 3.1a), 39 students drew trees in one color (black pencil), 19 students drew shrubs with brown stems/branches/twigs/green crown, and 15 students drew shrubs in one color (black pencil). The drawings indicate that students have a common, simplified mental model of trees and shrubs. As a result of their previous experiences and knowledge, most students represented trees with a solid, brown trunk and a green cloud-shaped crown, while shrubs were represented similarly, but with a smaller height. The students participating in the study live in an urban environment, therefore they have a lack of experience for developing tree and shrub models.

At post-test, the drawings of 22 students from GE1 show the strong impact of drawing based on the observation of photographs of trees and shrubs and the replacement of the previous model in the drawings with other tree and shrub models, with brown branches, without a contour at the crown or bush. The drawings are similar to the trees and shrubs in the photographs (Figure 3.1b, c). The students observed in the photographs: trees and shrubs without leaves, the arrangement of the branches, crowns with different shapes and sizes. In 12 drawings, it can be observed that students integrate the branches inside the cloud-shaped crown (Figure 3.1d) into the previous model (Figure 3.1a). In the drawings of 6 students, the previous model of the tree is preserved or conserved, meaning that the observation of the photographs and the drawing did not have an effect. The shrubs with multiple stems from the root, drawn by 10 students (double compared to the pre-test), indicate that the drawing based on the observation of the photographs had an impact on their representations of shrubs (Figure 3.1b).

In the drawings of GE2 students, it is found that 23 students changed the initial model (Figure 3.1a) by integrating the branches inside the tree crowns (Figure 3.1d), while 17 students preserved the initial model (Figure 3.1a), therefore the observation of the photographs did not have an impact on them.

Figure 3.1

Trees and Shrubs Drawn by Students at Pre-test and Post-test

(a) Pre-test GE1 (b) Post-test GE1 (c) Post-test GE1 (d) Post-test GE1

Regarding the color, the drawings of students from both groups at the pre-test indicate a canonical realistic perception, based on thought, of colors, as they used brown to color the tree trunks and green to color the crowns (Figure 3.1a), confirming an aspect also revealed in other studies (Ahi, 2017). Villarroel (2016) emphasizes that the canonical use of colors can show that the student has correct knowledge about the object represented. In the case of trees, their representation with a brown trunk and a green crown is relevant for spring, after leafing out, and for summer. Through the photographs proposed for observation and the drawing of trees and shrubs, the students' representations were supplemented with relevant aspects, specific to the woody plants in the deciduous forest in winter.

A general characteristic of all students' drawings, at both tests, is the representation of trees and shrubs with few details, which confirms findings from other psychological research suggesting that, at the age of 8-10 years, children exaggerate less in their drawings and add fewer details if not asked to do so (Cherney et al, 2006). Another characteristic of all drawings of trees and shrubs is their representation without roots, which indicates an incomplete representation of their component parts. This gap can be explained, first and foremost, by a transfer deficiency since students studied the components of herbaceous plants in kindergarten and the role of these parts in first grade, but they were not able to transfer them to woody plants.

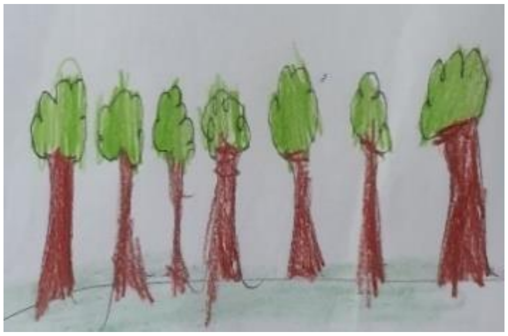
This incomplete representation can also be explained by the fact that students, who live in an urban environment, have not had relevant real-world experiences in which to observe the roots of trees and shrubs and to construct a correct and complete mental model of the component parts of trees. A third explanation may be that the roots, leaves, flowers, and fruits of the trees and shrubs were not visible in the photographs provided, and there was no reference to these components in the provided text.

Volume, complexity, and relevance of representations in deciduous forest drawings

In this study, we analyzed and interpreted the volume, complexity, and relevance of students' representations in deciduous forest drawings based on five criteria mentioned earlier. The most important aspect we followed in the representation of the forest is stratification. *According to the criterion of the number of layers*, the fact that, at the pretest, 53 students represented the deciduous forest through a layer of trees arranged on a line (Figure 3.2) suggests a prototype representation for the forest, but, from a scientific perspective, the representation is incomplete. This way of representing the trees at the bottom of the sheet, on a "base line", corresponds to the period of schematism, specific to the evolution of drawings in children aged 7-9 years (Lowenfeld, 1947) or the phase of intellectual realism (Luquet, 1927).

Figure 3.2

Deciduous Forest Drawn by a GE2 Student at Pre-Test



At the post-test, all students in GE1 represented all three layers of the deciduous forest, which indicates a significant effect of drawing these layers after observing the photographs in the formative intervention stage. Of the students in GE2, only 11 represented all three layers, while 29 represented a single layer of trees and the herbaceous layer, which indicates a deficient perception of the shrub layer in the photographs, an aspect also observed in the first item of the test.

According to the criterion of perspective, the fact that, at the pre-test, 53 students represented the deciduous forest in a 2D format (Figure 3.2), with all the trees drawn on a single line at the bottom of the page, indicates the period of schematism (Lowenfield, 1947) or the phase of intellectual realism (Luquet, 1927), when children draw what they remember from what they have seen, what they have understood, and how they have understood. The fact that at the post-test 27 students represented the deciduous forest with the trees and shrubs arranged on two or more planes (Figure 3.3) may be explained by their placement in the phase of visual realism (9 – 11 years – 14 years).

At the post-test, the number of 2D representations of the forest decreased in GE1 from 32 to 21, but increased in GE2 from 21 to 27. The number of representations that depict multiple planes of the forest increased in GE1 from 8 to 19 and decreased in GE2 from 19 to 13.

Figure 3.3

Deciduous Forest Drawing by a GE1 Student at Post-Test

These representations of the forest in GE1 were influenced by the observation of the forest layers in photographs and by the fact that they drew, through transfer, what they saw in the photographs, thus in accordance with reality.

Drawing the forest after observing photographs resulted in the construction of representations that depict multiple planes similar to those found in art. In the representation of the planes inside the forest, in many drawings it can be observed that the trees are arranged along parallel lines (Figure 3.3), which indicates a similarity with the arrangement of trees in orchards.

The fact that the number of 2D representations of the forest increased in GE2 can be explained by the fact that the students paid little attention to the photographs and activated the previous model of object placement, especially compared to the pre-test, where they represented trees and shrubs on a line (Figure 3.4). In deciduous forests, shrubs are often found in the marginal, more illuminated areas, while herbaceous plants form a layer arranged among the woody plants, at the base, elements visible in the provided photographs.

Figure 3.4

Deciduous Forest Drawings by Two Students from GE2 at Post-Test

According to the criterion of spatial distribution of plants in relation to their category, in the drawings, two ways of representation are highlighted: grouping of plants by category (trees, shrubs) (Figure 3.5a); random distribution (alternation of plants from different categories) (Figure 3.5b).

Figure 3.5

Spatial Distribution of Trees in the Deciduous Forest in the Drawings of Students from GE1 and G2, at Post-Test

(a) GE1 (b) GE2

According to the chromatic criterion, the fact that at the pre-test, 25 students in GE1 had monochrome/black drawings, similar to the drawings of the trees from the first item, can be explained by the convenience of drawing in pencil. 10 students from GE1 kept this option at the post-test, even though the requirement of using colors was specified. Overall, it is observed that students tend to use the color green for the anatomical parts of plants and brown for the trunks of trees, specifically matching this color scheme in their drawings with some aspects of plant life (Villarroel, 2016). It is assumed that they deliberately choose colors, assigning them a specific meaning (Villarroel, 2016) and a key role for object recognition (Kimura et al, 2010) and for their semantic processing (Hayakawa et al, 2011).

Volume, Complexity, and Relevance of Trophic Chain Representations

The fact that at pre-test, most students in both groups represented the feeding relationship between a producer and a consumer (2 links), in a horizontal or vertical linear scheme, without labels and without arrows between links, indicates the absence of representations of the complexity of feeding relationships. Although students in GE2 had the opportunity to analyze trophic chains in the drawings provided by the teacher and to recite the written text, their drawings at post-test are similar to those at pre-test, confirming what has also been reported in other studies: on the one hand, they paid little attention to the illustrations and, on the other hand, they did not process the information visible in the illustrations in depth (Jian, 2016; Jian & Ko 2017; Hannus & Hyönä, 1999), but neither the information in the text.

The results of the students in GE1 at post-test (Figure 3.6a) are much superior to those of the students in GE2 (Figure 3.6b), as a result of the drawing activity in the formative intervention, when they were asked to construct multiple trophic chains based on the observation of the drawings provided by the teacher and following the instructions regarding the procedure.

Figure 3.6

Representation of Trophic Chains in the Drawings of Students from GE1 and GE2 at Post-Test

GE1 (a) GE2 (b)

At the end of the study, a few conclusions emerge:

Regarding the two tested hypotheses, the results obtained through statistical analyses indicate their confirmation: the use of drawing as a complementary method alongside text study is a more efficient teaching method for enhancing the volume and complexity of representation compared to using the observation of static representations, with a very large effect size: M_draw_group = 60.2 vs. M_observation_group = 20.8, $\eta 2p = .748$ (hypothesis 1). The use of drawing as a complementary method alongside text study is also a more efficient teaching method for enhancing the relevance of representation compared to using the observation of static representations, with a very large effect size: M_draw_group = 58.26 vs. M_observation_group = 22.74, η2p = .636 (hypothesis 2).

Learning by drawing was effective in the formation of representations, namely the two model-based learning strategies (Fiorella & Zhang, 2018): an original strategy of manual conversion of photographs into drawings (drawing a tree, a shrub, and the stratification of a deciduous forest) and a drawing strategy based on a drawing generated by the teacher, described in the literature (van Meter, 2001; van Meter & Garner, 2005; van Meter et al, 2006) (drawing trophic chains). The learning strategy by drawing has beneficial effects on the internal representations of students participating in the study, effects reflected in the students' drawings and presented in the literature: (1) they build more detailed representations (Long et al, 2018); (2) they change the similarity structure of visual object concepts (Goldstone, Lippa & Shiffrin, 2001); (3) they differentially change the visual features that are prioritized in their internal representations (Long et al, 2018); (4) they include in their drawings distinctive visual features that are sufficient to identify the category (e.g., tree, shrub) that they intended to draw (Long et al, 2019); (5) they draw the plant world differently (Villarroel, 2016); (6) they tend to use colors realistically and deliberately choose colors, attributing specific meanings to them (Villarroel, 2016).

The limitations of the study are represented by the relatively small size of the sample of participants, the content sample, and the small number of drawing-based learning activities included in the formative intervention. These limitations can be overcome by extending the study to a larger sample of participants, both from rural and urban areas, and involving them in more drawing-based learning activities.

The study can be extended by using drawing-based learning strategies in other educational disciplines. The materials created, tests, and projects of self-designed learning activities are also useful for other teachers and other groups of students. The description of the research procedure and the materials included in the study allow the replication of the research to other groups.

CHAPTER IV

CONCLUSIONS

4.1 Conclusions on the Relationship between Theoretical Premises and the Applied Part

At the theoretical level, first, we note that, in psychology, the term "representation" is assigned several meanings, being analyzed as process, product, and capacity, and that there is still no consensus on what mental representations could be (APA, p. 641). Also, we note that, in the literature, mental representations and external representations are distinguished, which are used to represent reality in material and digital forms. In educational sciences, both internal or mental representations and external representations are used, which is why a profound knowledge of both categories is necessary.

Therefore, in the thesis, we have made a synthesis of the concept of representation and represented this concept in a diagram.

Second, at the theoretical level, various processes or mechanisms are explained that take place in the human mind and through which representations are formed. The way these processes are presented, the diversity and complexity of the theories make it difficult for practitioners in the field of educational sciences to understand and transfer, respectively apply the information, which probably explains the low interest in research on the formation of representations in primary education, in science.

Thirdly, we have observed that in science learning, according to our thesis, it is supported by several theories upon which we have based experimental activities. Given that the formation of representations begins with perception, often multimodal, teaching and learning in science should take into account the cognitive theory of multimedia learning based on multiple cognitive theories: "working memory theory," "dual coding theory," "cognitive load theory." These theories help us understand the mechanisms of transmission, perception, and processing of information through auditory and visual channels and the fact that each subsystem of working memory has limited capacity.

From the perspective of these theories, we conclude that in teaching and learning science, optimal or better-adapted conditions should be provided based on the cognitive development level of primary education students. This refers to the volume and level of difficulty of the information provided, the format in which information is presented, and the channel(s) through which information is conveyed. We also argue that for science learning in the classroom, given the complexity of scientific knowledge, it is essential to organize teaching activities while considering the theory of cognitive development (Vygotsky, 1962, 1978). It is important to design and organize learning activities within the students' Zone of Proximal Development (ZPD), and the processes of knowledge mediation supported by the teacher, which impact internalization and the formation of students' representations, are crucial. An essential role in achieving systematic and in-depth science learning lies in adhering to theories regarding learning and teaching through scaffolding. Scaffolds should be understood as processes or tools through which a child can solve a problem, complete a task, or achieve a goal that surpasses their capacity or competence (Wood et al., 1976). In this way, scaffolding acts as a mediator in the child's Zone of Proximal Development.

Fourthly, we have found that in science education, there are instructional models aimed at teaching and learning in general, but there are no instructional models that primarily focus on the formation of representations. Drawing from various learning theories, we recognize that shaping representations in science can be creatively and optimally integrated into original instructional models, structured in stages, which specify the actions performed by both teachers and students, their roles, the teaching methods and strategies used in each stage and their application, the organization of activities, evaluation methods, the cognitive processes performed by students, and other details that facilitate the implementation of the model in practice.

4.2 Conclusions Regarding the Achievement of Research Objectives and Confirmation of Hypotheses

This thesis had two main objectives: exploring the conceptions of primary education methodologist teachers (PMÎP) about representations and their teaching practices used in shaping representations in science at the primary level; exploring the effects of certain teaching methods and strategies on the formation of representations in science at the primary level.

The first objective was achieved through Study 1, in which we collected data from PMÎP through interview-based surveys. The analysis of PMÎP's conceptions provided us with consistent guidelines for selecting the teaching methods and strategies to be tested in experimental activities, revealing preferences for using specific teaching methods and tools in science learning and identifying some theoretical gaps.

The second objective was accomplished through Studies 2, 3, and 4.

Study 2 aimed to analyze the effects of learning activities based on observation. Statistical analyses confirm the three tested hypotheses: direct observation is a more effective instructional method compared to observation through photographs and/or drawings, with very large effect sizes. The guided observation through worksheets learning strategy contributed more to increasing the volume, complexity, and generality of representations in the three themes in activities based on direct observation of objects compared to those based on observation through drawings and photographs.

Study 3 focused on assessing the impact of learning activities based on experiments on students' representation formation in science. Statistical analyses confirm the tested hypotheses, demonstrating that the use of experiments is a more effective teaching method for increasing the volume and complexity of students' representations and the generality of their representations compared to observing experiments in photographs and drawings and listening to the teacher's explanation.

Study 4 aimed to investigate the effectiveness of drawing based on observing static visual materials (photographs, drawings, and diagrams) compared to observing static visual representations (photographs, drawings, and diagrams). These activities were organized through association and in conjunction with instructional activities based on listening to and studying texts illustrated with photographs, drawings, and diagrams.

Statistical analyses confirm the tested hypotheses, showing that the use of drawing as a complementary method alongside text study is a more effective teaching method for increasing the volume, complexity, and relevance of representations compared to using observation of static representations, with a very large effect size.

4.3 Implications of the Thesis

Theoretical implications

Our phenomenological survey in study 1 was the first to explore the conceptions of primary school methodological teachers (PMÎPs) about representations. Our study was the first to analyze the practices used in the classroom, in teaching and learning science, with the purpose of contributing to the formation of representations, while existing studies have analyzed other aspects. The novelty is represented by the fact that we explored, from multiple perspectives, the conceptions of teachers with expertise in classroom practice and in the evaluation of other teachers.

Studies 2, 3, and 4 have several theoretical implications in the field of educational sciences. The most important and original theoretical contribution is the design and implementation of three instructional models: the observation-based instructional model using observation sheets; the experiment-based instructional model using experimental activity sheets; and the learning-by-drawing strategy instructional model. Each instructional model focuses on a teaching method that we selected to test its effectiveness in forming representations in science students, by comparison with other teaching methods or strategies. For each instructional model, there is a description of the steps in text and a visual representation. These instructional models were designed based on the theories mentioned above.

Methodological Implications

Several procedures were refined in the studies conducted. Study 1 offers a way to interview participants, adapted to the context of the COVID-19 pandemic, by collecting written responses. Study 1 provides an original way of presenting the selection of responses from the interviewees, which are associated with the categories in which they were included by the researcher. This way of presenting the responses and the categories allows for a deep understanding of the formation of categories of conceptions.

Studies 2, 3, and 4, which are similar in terms of research organization, have several methodological implications. First, we mention the selection of study participants. Being studies in the field of educational sciences, which explore the learning of primary school students, to ensure the authenticity and correctness of the research, classes of students were selected based on criteria, the experiments were carried out in each selected class, thus opting for a quasi-experimental research, from a naturalistic perspective. Each group included in the experiment was composed of two classes and included between 40 and 51 participants. Statistical data processing was carried out according to the equivalence of the classes.

Second, we refer to the extension of each formative intervention in terms of the number of activities, duration, and contents studied. In each of studies 2, 3, and 4, in order to test the established hypotheses, we carried out three distinct teaching activities, each with a different content, without an obvious connection between the contents.

Third, we monitored the organization of each activity in the formative intervention, in all groups. To avoid differences in the implementation of the activities, they were carried out by the researcher, in the presence of the classroom teachers, with the exception of activities in which the teacher had only the role of transmitting information or precise tasks, without having a cognitive impact on the students.

Fourth, we rigorously followed the planned steps for each activity. To ensure a correct test, at each study, the activity was structured on the basis of the same instructional model, for each group.

Practical Implications

This research has, primarily, practical implications. First, the entire conception of the thesis is filtered through the author's professional competence (in the field of science, psychology, pedagogy, and didactics), the author's qualities as a primary school teacher, and the in-depth study of the literature on the research topic. These professional filters ensure a careful focus on the holistic approach to the learning process carried out by students, starting with the pre-figured objectives and ending with their realization by students. The formation of specific science competencies, mentioned in the school curricula, was constantly pursued, and the choice of content, in terms of diversity, difficulty level, and level of depth, aimed at cognitive stimulation of students. The satisfaction of the students involved in the research and the statistical results demonstrate that students can achieve very good results when classroom teachers show passion, involve them in interesting and challenging activities, and are partners with students in the didactic activity, an aspect specified in the TIMSS study.

Second, the materials (pre-tests, post-tests, observation sheets, experimental activity sheets and other work sheets, lesson plans, texts, photographs, drawings, schemes) designed, developed, and applied in the context of this research can be benchmarks for primary school teachers and for researchers who would like to carry out identical or similar studies.

Third, the systematic and detailed description of the activities carried out and the instructional models, as well as the visual representations of them, provide interested parties with the information they need to understand the didactic process deeply, facilitates the explanation of the results obtained by students, and the application of these instructional models in other contexts. The dissemination of the research results through the publication of the thesis in print and electronic format facilitates access to the knowledge of teaching and learning methods that can be successfully applied to science, but with careful adaptation to the characteristics of the students in the class.

4.4 Limitations and Future Research Directions

Although our research has reached relevant conclusions and has important practical, methodological, and theoretical implications, the thesis has some general limitations that should be considered. In study 1, the written collection of responses could be a limitation of the research by the fact that no additional questions were used to deepen the investigated aspects and by the possible influence of the PMÎP discourses on the existence of theoretical aspects described in the literature. The relevance of the formulated responses depended on their openness to provide details, their personal vision, and their central or marginal positioning on the problematic of the study. As with any phenomenological study, the interpretation of the results is influenced by the subjectivity of the researcher. The research could be extended: by using this interview guide in other studies; by requesting more extensive responses; by cutting out some parts of the investigated problematic and deepening them.

Studies 2, 3, and 4 had several limitations. An important limitation is the small number of participants and the gender variable. Although the literature mentions that these dimensions of the groups involved in the experiment do not affect the validity of the independent variables, however, the statistical results have little power of generalization. For a generalization of the conclusions, future research could have been conducted on representative samples, in which the selection of participants was carried out by randomization. Another limitation is the fact that the results can be strongly influenced by the characteristics of the students in the classes involved in the experiment. The way in which activities are organized and the materials used by the teacher should be adapted to the specific group of students with whom they work. A limitation is the relatively small size of the content sample and the small number of learning activities included in the formative interventions. To overcome this limitation, future research should be extended to more activities and content elements. In carrying out this extended research, the most problematic and constraining limitation is the resource of time.

4.5 General Conclusions

The systematic formation of students' scientific representations is important for knowledge in general and for scientific knowledge in particular, for optimal adaptation and valorization in a knowledge-based and sustainable society, and teachers have an essential role in this formal process of representation formation.

We also consider that teachers need a deeper and broader understanding of the concept of representation and the ways of forming internal representations in students, of theories about learning for the realization of scientific knowledge and the development of scientific skills through teaching and learning in science.

Teachers' conception of teaching, their psycho-pedagogical, didactic, and scientific competence, their passion for science and for teaching, their motivation and responsibility influence the choice and use of teaching and learning methods and strategies, as well as educational resources and content, all of which have a strong impact on student outcomes.

In the end, students' desire to learn and know is decisive in the formation of their own representations, influenced by their needs, goals, interests, and motivation, by their willingness to be involved in learning and to put in effort to achieve their goals.

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