Extended summary of the doctoral thesis

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INQUIRY-BASED LEARNING (IBL) IN TEACHING NATURAL SCIENCES IN PRIMARY EDUCATION

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Statement

I, the undersigned, Turșan Vasile-Grigore, having the quality of doctoral student of the "Babeș – Bolyai" University, declare the following:

- The doctoral thesis entitled "INQUIRY-BASED LEARNING (IBL) IN THE TEACHING OF NATURAL SCIENCES IN PRIMARY EDUCATION" was carried out by strictly observing the four values of academic integrity – honesty, responsibility, replicability and validity of knowledge.
- The similarity analysis of the doctoral thesis was carried out at the Doctoral School "Didactica. Tradition, Development, Innovation", using the Turnitin Report.
- The thesis complies with the writing standards specified in the APA Publication Manual (7th edition).

- The published studies address the issue of this research and are cited in the thesis.

.... 2025 Signature

Thanks

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LIST OF PERSONAL PUBLICATIONS

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Abstract

Thesis entitled *INQUIRY-BASED LEARNING (IBL) IN TEACHING NATURAL SCIENCES IN PRIMARY EDUCATION. APPROACHES AND DEVELOPMENTS*, particularizes the strategy of investigation in the study of natural sciences in primary education.

The thesis is structured in two parts: a theoretical part and a preliminary research and formative interventions. It provides conceptual clarifications on the differences between inquiry and exploration, experiment and laboratory work. The main difference is found in the very name of the concept of inquiry, i.e. a research approach that does not necessarily involve experimental or laboratory activity.

The study of natural sciences in primary education aims to understand the concepts considered accessible to students, coming from various fields: physics, chemistry, biology, ecology, astronomy. To make it easier for students to understand them, exploration, experimental observation and experiment are used, depending on their age. A special place is occupied by online simulations.

Preliminary research aimed to investigate teachers' and students' perceptions of natural science learning and inquiry-based learning. Based on the results of these researches, an investigation guide applicable to teaching activities in primary education was developed.

The use of the inquiry learning guide to the third and fourth grades in natural sciences classes has demonstrated that inquiry learning can significantly increase students' motivation and engagement in science activities and, as a result, students' performance in science.

Keywords: investigation, IBSE, primary education, natural sciences, school performance.

Thesys Content

Part I. Theoretical foundations

Chapter 1. Study of Natural Sciences in Primary Education in Romania and Abroad

1.1 Scientific knowledge as a process, construct and meaning

Sarukkai (2012) reviews a variety of perspectives on science. Of these, the best known concern science as a concept, a system of knowledge, a method (the scientific method), an investigation (inquiry), a process of searching for truths, a specific way of reasoning (scientific thinking). The cited source (2012, p.10) and Ciascai (2018, p. 41) consider science as an approach/process of accumulating knowledge about the universe and organizing it into facts, concepts, laws, principles and theories. The Ohio Academy of Science, mentioned by Sarukkai (2012, p.12), defines science from a methodological perspective: "science is a systematic method of continuous investigation, based on the testing of scientific hypotheses, measurement, experimentation and the construction of theories, which leads to explanations of natural phenomena, processes or facts that may subsequently be subject to testing, revision or falsification, if they are not considered to represent truths or accepted or rejected on the basis of scientific evidence".

1.1.1. Construction of scientific knowledge

Scientific method and thinking

The knowledge that is obtained in the process of knowledge is organized and reorganized according to the contexts in which it is used. This approach involves observational actions, logical deductions, the connection of knowledge and the interpretation of connections, which gives scientific knowledge a functional and personalized character (Bocoş, 2013, p. 472).

In the process of deepening a scientific field through study, scientific thinking evolves. It goes from the pre-scientific stage, characterized by confronting a problem, delimiting it and anticipating a solution, to the scientific stage, of understanding and the ability to explain facts and phenomena in the real world, to internalize them. The last stage is that of creative scientific thinking, capable of developing and expanding the body of knowledge in order to respond to personal needs and aspirations (Enăchescu, 2005; Bunge, 1978).

Scientific thinking includes scientific reasoning, which differs from other modes of reasoning/reasoning (Zimring, 2019). The sources cited above explain five modes of reasoning in science: inductive, deductive, dialectical, divergent reasoning and analogy that they identify as specific to the approach of scientific knowledge (Ciascai, 2001, p. 17-18). It should be noted that causal reasoning is frequently used in the explanation of scientific knowledge, starting from the idea that, in the context of a phenomenon, a cause (or several) generates an effect. Its practice involves logical thinking (inductive, deductive, analogical or abductive reasoning) as well as the use of facts to formulate conclusions regarding the cause-effect relationship. However, the cause-and-effect relationship is most often complex and therefore attributing effects to a cause, without a solid basis of facts, can lead to errors.

Science elaborates its explanations using, in the context of modes of reasoning, a series of scientific processes: making observations, comparisons and classifications, measuring, making inferences, formulating hypotheses and predictions, controlling variables, collecting and interpreting the data obtained, formulating findings and conclusions. Hypotheses, Ciascai (2021) shows, are not built on anything but on observational or experimental facts. By particularization, predictions derive from hypotheses whose confirmation is attributed to the hypothesis (ibid).

The process of scientific knowledge

The process of scientific knowledge involves: (i) a structured (staged) and systematic approach; (ii) a goal consisting in obtaining objective and verifiable knowledge regarding natural phenomena and processes; (iii) a set of scientific procedures (observation, comparison, discrimination, etc.); (iv) methods and strategies (problematization, modeling, demonstration, observation, experiment, exploration, etc.); (v) a set of scientific capacities and skills (formulation of problems, predictions, hypotheses and conclusions); (vi) a set of values and attitudes (doubt, perseverance, curiosity, etc.)

The stages involved in the scientific approach are the following (Ciascai, 2001):

- Observation: the observation of a phenomenon or process, i.e. the reading of the text of a question or problem. Observations can be either direct (seen, heard, measured directly or with the help of instruments) or indirect (collected from secondary sources: descriptions, summaries, reports, etc.). They can also be empirical, oriented towards one aspect or systematic, targeting several aspects. Observations may or may not involve manipulating variables.

- Formulating a research question that guides the research approach: the question is based on the observations initially collected and has the role of guiding the investigation. It is particularized in specific, clear and concrete questions, able to guide the research process.
- Preliminary, in-depth research: documenting and reviewing existing literature in order to collect additional information and thus clarify research questions, to understand in depth the data and facts previously learned, to exist the existing knowledge and to identify any gaps in knowledge that can be overcome in the context of the research carried out or to determine whether the proposed research has not already been carried out. Based on the information collected, a preliminary explanatory model is developed that integrates facts and knowledge.
- Making hypotheses and/or predictions: A hypothesis is a possible explanation for the questions, facts, or phenomenon being observed. It must be clear, specific, testable and falsifiable. The prediction is a consequence of the hypothesis and must meet the same requirements as the hypothesis. The experiment tests the predictions derived from the hypothesis and their confirmation validates the hypothesis from which they were derived (Ciascai, 2001) Therefore, the prediction distances itself from guessing (Pânișoară, 2024, p. 302). This is also true for the supposition, whose source is the attempt to explain the facts/phenomena studied.
- Research design: making a detailed plan to test the hypothesis, including independent variables (what changes), dependent variables (what is measured), and controlled variables (kept constant or under control). Also, the results of the experiment are more credible if working with experimental and control groups/batches.
- Conducting the experiment and collecting data: the experiment is carried out according to the project and frequently involves experimental equipment. In the context of the experiment, data is collected through measurements, observations, or the use of other data collection techniques and tools.
- Data analysis: The data collected is organized and analyzed using statistical methods to determine whether the initial hypothesis holds up. Data analysis can reveal relationships or patterns that may or may not be anticipated. The experimental approach ends with a set of findings that describe the evidence to support or not the hypothesis.

- Drawing conclusions: By analyzing the data, researchers draw conclusions about the validity of the hypothesis. The conclusions are based on the findings previously formulated and the knowledge acquired from the literature. If the hypothesis is not supported by the data (evidence) then it must either be revised or rejected. If the hypothesis is confirmed, it can contribute to the development of scientific theory.
- Distribution/publication of results: the results and conclusions of the research are made available to the scientific community through publication in journals, or through scientific communications. This peer review process ensures the validity and reliability of the research.
- Replication of research/experiment and verification of experimental results: Other researchers can proceed to replicate the experiment to verify the results or expand them. Reproduction is important to give confidence to research findings.
- Theory development: If a hypothesis is repeatedly confirmed by various experiments and observations, it can help to develop or modify another scientific theory.

This approach, in a simplified form, is applied at the level of pre-university education.

1.1.2. Scientific skills – terrorist-applicative considerations

Ability is defined as a person's ability to do certain things or perform tasks, with ease or skill (DEX).

Scientific Process Skills

Scientific process skills can be divided into two categories (Karamustafaoglu, 2011 cited by Maranan, 2017, p.14), namely basic scientific process skills and integrated scientific process skills, the former conditioning the development of those in the second category.

Basic scientific process skills include observing, classifying, measuring and using numbers, making inferences, predicting, communicating, formulating questions, and using the relationships between space and time. Skills in the second category include data interpretation, operational definition and control of variables, formulation of hypotheses and experimentation, formulation of inferences and generalizations (Center for Curriculum Development, 1993 cited by Turiman, Omar & Mohd Daud et al., 2012, p. 113; Karamustafaoglu, 2011 quoted by Maranan, 2017, p.14).

Scientific Research Skills

The construction of scientific knowledge implies the possession of the skills of scientific process, but there is also the opposite option, in which, through the approach of knowledge, scientific skills are formed and developed (Faheem et. al., 2015, Karamustafaoglu, 2011, in Maranan, 2017, p.14). Analyzing scientific investigation as a method, Ciascai (2006, pp. 33, 34) presents in a version adapted from Carin (1993), the list of processes and capacities necessary in a scientific investigation: classification, inference, generalization, formulation of predictions and hypotheses, measurement, data collection and data interpretation, argumentation and decision. A set of methods used as aids is added to the list: modeling, observation, experiment, problematization and evaluation.

Ngoh (2008) and Akben (2014) affirm the importance of scientific skills by showing that there is a connection between practice and learning science through investigation.

1.1.3 Typology of scientific knowledge – theoretical-applied considerations

Scientific knowledge must also be seen as the results of the process of building scientific knowledge. They can be classified from several perspectives.

Ciascai (2018) lists several categories of knowledge: (i) phenomena, states and properties, (ii) systems; (iii) laws, conclusions, hypotheses and statements; (iv) concepts; (v) instruments and appliances; (vi) technical, practical, life applications; (vii) algorithms, methods and techniques of action, etc.

The taxonomy of knowledge, proposed by Anderson (1995), includes three main categories of knowledge:

- *Procedural knowledge* incorporates concepts, rules, and algorithms and is gained through hands-on experience and repetition. Procedural knowledge concerns the way of carrying out specific problems, tasks or processes (context dependence), through a series of stages or actions that are logically and sequentially organized.

- *Conditional knowledge* includes propositions, principles, laws, axioms, theories, and postulates. The syntax of these statements is of the if-then or condition-action type.

- *Declarative knowledge* refers to the scientific knowledge we have, of which we are aware and which we can explain. Declarative knowledge is based on facts, is organized and structured. Declarative knowledge learning involves connecting new knowledge to existing knowledge, reorganizing acquired knowledge, and developing new knowledge that is meaningful to learners. Declarative knowledge is the foundation on which procedural and implicit knowledge is built.

To this knowledge are added:

- *Strategic knowledge* that refers to the mental processes involved in a learning situation. Strategic knowledge is used for the purpose of self-regulation of actions in the learning situation.

The construction of knowledge, regardless of the nature/typology of knowledge (Rus, 2015), involves the use of a set of search and discovery processes.

1.2 Teaching-learning of natural sciences in Romania

1.2.1 Science curriculum in Romania

The new school curricula, which came into force in 2013 (for P-I-II) and 2014 (for grades III-IV) include as a structure: the presentation note, which presents the set of scientific and didactic values of the discipline and argues its compositional structure; general competences, which aim at the student's knowledge and attitudinal acquisitions; specific competences, derived from the general ones and to which there are many examples of learning activities; learning contents: these target three main areas, according to the curricula of the Preparatory, I, II, III and IV classes: *life sciences, earth sciences and physical sciences*; methodological suggestions: they are support tools for teachers in order to facilitate the choice of the most appropriate teaching and evaluation strategies in teaching approaches;

Ciascai (2006), analyzing the school science curricula, shows that they denote a major interest in the implementation of a student-centered educational process, in a real way and not just declaratively.

1.2.2 Scientific literacy and the specifics of science learning activities

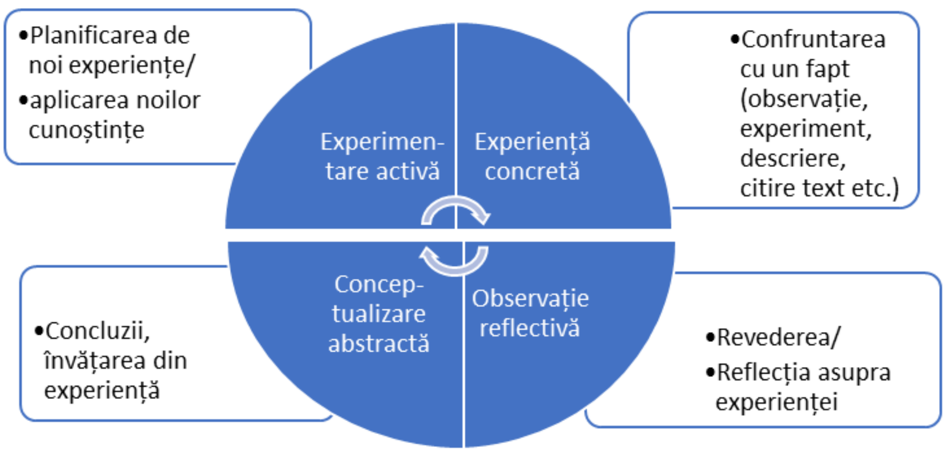
Ciascai (2018) is of the opinion that the transmission of scientific knowledge on the didactic track implies its remodeling, the emphasis being shifted from its scientific character to the didactic one for its adaptation to the student's particularities and to the learning context.

Scientific literacy, along with mathematical, technical or technological literacy is a necessity in the digital age. It involves knowledge and understanding of scientific concepts and processes necessary for decision-making, doubting ideas and statements considered scientific, coming from different sources, initiating an approach to testing hypotheses (including in everyday life), collecting evidence, arguing with reference to evidence, etc. and interest in participating in events, civic and cultural science and supporting economic productivity (Turiman, Omar & Mohd Daud et al., 2012).

In Romanian practice, the most used model of science learning at primary level is the experiential cycle. Experiential education considers the relationship between the individual and the environment a source and a tool of knowledge. The experiential learning model, based on the theories of Dewey (1938) and Kolb (2015) promotes the stimulation of students' curiosity, learning by doing and the connection of new knowledge with previous knowledge. The model requires students to ask questions, think critically, test assumptions, and formulate conclusions. Its use contributes to the development of independent and group learning skills and values and attitudes such as preference for hands-on learning, perseverance, confidence and positive attitudes towards learning (Levy & Moore Mensah, 2021).

Figure 1.

The experiential cycle after Kolb (2015)



The practical application of the experiential learning model involves:

(i) Preparation of the learning activity: announcing the objective to be achieved through the learning activity, in a formulation adapted to the students' understanding and awareness by the students of it. At this stage, the teacher encourages the students to specify what they know or want to know about the topic of the lesson, possibly by using the KWL graphic organizer or a concept map. Also, the students are informed about the form of organization and the available materials.

(ii) Concrete experience: confronting facts, observation, questions and problems, preferably with the source in everyday experience, stimulating interest and motivation for the study of the topic.

(iii) Reflective observation: reflection on observational facts, guided by the teacher through questions and additional observation and study tasks. To provoke reflection, the questions must be varied, such as: What...?, Who...? Why..., Why ..., When....?, Where...?, How...?, Under what conditions...?. It is also at this stage that the information obtained through observation is processed.

(i) Conceptualization of learning: learners develop their knowledge or finalize it based on the reflections made in the previous stage. They draw conclusions by summarising the findings and additional knowledge gained from the exchange of information.

(ii) Planning new experiences and applying new knowledge. Reflection on the learning process and product is accompanied by evaluation and self-evaluation of progress by the teacher and students. The enrichment of knowledge is achieved by applying new knowledge in concrete situations (Ciascai, 2022).

It should be noted that the assimilation of new knowledge is done throughout the cycle in conditions of monitoring by the teacher the progress of the students, of practicing the formative and formative assessment.

The didactic strategies used at the level of primary education are based on methods such as observation, learning through discovery, investigation, experiment, modeling (Dulamă, 2012). As a result, learning forms (and develops, as far as possible) the skills of observation, independent research, experimentation, modeling, problem solving, logical deduction and prediction, use of new scientific knowledge in contexts of life, communication and collaboration. The preferred forms of organization are frontal, group/team and less often individual. Of course, the choice of the appropriate form of organization is also influenced by the availability offered by the learning environment (classroom, laboratory, natural environment, etc.), the age level, the stage of perception and understanding of the students, the index of previous acquisitions, the pre-established objectives and the learning methods that the teacher masters or prefers.

Observation, used in science learning and beyond, has a "heuristic and participatory" value (Cucoş, 2014, p.347), contributing to the formation of clear and precise representations of the facts and objects subject to observation and facilitating the construction and understanding of concepts, processes, patterns and models.

Investigation, at the level of primary classes, most often takes the form of exploration. Thus, systematic or oriented experimental observations are also carried out of experiments, the latter representing a simplified version of the experiment. Ciascai (2022) shows that exploration is carried out outside of assumptions, and there is no factual support necessary for their elaboration. In fact, through exploration, the student tries to identify some attributes by trying to perform various operations: to smell, to taste, to break, to bend, etc. As a result, exploration is often marked by trial and error. Oriented observation is a very close approach. Systematic observation and experience both involve the existence of variables (independent, dependent or controlled) and manipulation. All the methods listed above involve formulating questions, prefiguring an answer in the form of a prediction, operating with the independent variable and observing the results (of the change undergone by the dependent variable), processing the data and interpreting them (Ciascai, 2022). Ciascai (2007) is of the opinion that the didactic experiment, like the scientific one, encompasses several methods and procedures, relying heavily on systematic observation. As for applicability to the science discipline in primary education, experimental activities, in the presence or absence of a laboratory, can take different forms, depending on the theme of the lesson. For example, practical applications can be carried out by observing phenomena such as evaporation, melting, condensation, solidification, water circuit, both in the classroom and in nature. Very important, as a working tool in carrying out experimental activities, would be the experimental activity sheet, which greatly supports the actions of assimilation, classification and understanding of the observed elements and phenomena. Modeling under the two hypostases: building models and using models (Ciascai, 2007) is often used in primary classes: arranging a herbarium, building a virtual insectarium, designing, building and caring for an aquarium. As action-based methodologies, which aim at the practical character of learning and which value individual or group forms of activities, the above-mentioned methods are joined by experiment, problem solving, algorithmization, project method, practical works stimulate the functions of thinking, train logical-mathematical intelligence by establishing connections, associations, cause-effect relationships between concepts, laws and phenomena.

1.2.3 Analysis of science textbooks in Romania

The school textbook has undergone an evolution at a conceptual, structural and functional level. Today, there is a variety of textbooks for each subject, and in addition to these, the market offers a diversified range of auxiliaries. We will refer in the following to the Natural Sciences textbooks for the third and fourth grades.

.- The textbooks for the first and second grades promote interdisciplinarity, proposing for learning contents from mathematics and environmental exploration.

- The textbooks for the third and fourth grades approach the natural sciences in an integrated way, the scientific investigation being increasingly used in the approach to the learning process.

The analysis of the Natural Sciences textbooks for the third and fourth grades allows the following considerations:

- *Scientific contents*. The scientific content of the third grade textbook covers several branches of science: physics and chemistry (gravitational, electrostatic, magnetic interactions, properties of bodies, states of aggregation, water circuit in nature), biology and interdisciplinary themes (Earth and living environments, man, plants, animals, pollution). In the fourth grade textbook, the knowledge is related to the life cycles, the relationships between living things, the Earth as a planet in the solar system, the living things in the past – the evolution or extinction of species, the characteristics and properties of bodies and the natural and artificial sources of light and heat.
- *Didactic processing of scientific content*. The didactic approach to scientific content is poor in interdisciplinary connections in these textbooks. Knowledge is presented progressively, from simple to complex. The reasoning behind the approaches is inductive. The proposed activities are varied: transmission of knowledge, development of scientific skills, activities of consolidation and fixation of knowledge as well as evaluation activities and even self-evaluation. The concepts and notions used are made explicit. Tasks are short, operationally formulated and varied Work tasks are built as varied items, covering a wide variety of objectives so that solving them supports deep learning.
- *Writing textbooks*. The language used is scientifically correct and adapted to the students' understanding. The terminology is defined and only then used. There is a table of contents so that the student can easily orient himself in reading the manual.
- *The quality of the illustrations*. The contents presented are accompanied by illustrations, respectively fonts and colored backgrounds to facilitate the students' understanding and easy identification. The images are representative and sized, depending on the complexity of the content to which it is associated.

1.3. **Teaching-learning of natural sciences at international level**

1.3.1 Science curriculum in countries with international test results

The field of science occupies an important place in international education. The European Commission and the education departments of universities value *basic competences in science and technology as* an essential condition for quality education in the list of key competences (Schnepf et al., 2015). The importance of science is also revealed by its integration into PISA testing (OECD, 2023.

The PISA tests follow the levels of competence formation in three areas, reading, mathematics and science and emphasize the practical aspect of education. At the level of the science field, acquisitions that refer to life sciences are evaluated. There are six levels of competence in science (OECD, 2018, pp. 115-118).

Following the 2018 PISA science tests, the ranking of the countries with the best results is as follows: China, Singapore, Macau, Estonia, Japan, Finland, South Korea, Canada, Hong Kong and Taiwan.

It is important to know the science curriculum implemented by countries with important results in international tests. We will refer to Singapore below. Singapore's Ministry of Education (MOE) centers the science syllabus on a core: "Science for Life and Society," from which the goals of science education derive. It also promotes the vision: "Inspire, Investigate, Innovate". Thus, students inspired by science are fascinated by its relevance in everyday and global life, considering it a way to solve challenges and transform the world. With solid foundations and investigative spirit, they critically analyze scientific ideas, being open to careers in the scientific field for the good of society. At the same time, students innovate by applying scientific knowledge to create creative solutions to real problems, making a significant contribution to STEM fields.

According to the EOM (2022), science education is based on three fundamental pillars:

(i) *Basic ideas of science*. These ideas represent essential concepts that connect the subdisciplines of science (biology, chemistry, physics), providing conceptual coherence and a framework for students' progress at different educational levels.

(ii) *Practices of science*. The practices involve three components:

o *Ways of Thinking and Doing in Science (WOTD):* Students learn to investigate (formulate questions, design experiments, analyze data), evaluate and reason (support evidence-based ideas, make informed decisions), as well as develop and evaluate solutions (use models, develop explanations and solutions).

- *Understanding the Nature of Scientific Knowledge (NOS*): Science is evidence-based and focuses on explaining the real world through models. It is a critical, sustainable process, but open to change in light of new evidence, reflecting the consistency and order of natural systems.

- *Science-Technology-Society-Environment (STSE) Relationship:* Students understand the risks and benefits of science applications, the ethical, social, and environmental implications, as well as how scientific discoveries drive technological progress and technology supports advanced research.

These pillars develop investigative skills, critical thinking and social responsibility.

(iii) *Values, ethics and attitudes in science*. Science, as a human enterprise, includes ethical and social considerations. Students are encouraged to analyze ethical dilemmas associated with the application of science and to express their informed ethical positions in debates on complex socio-scientific issues.

These three dimensions (Basic Ideas in Science; Science Practices and Values, Ethics, and Attitudes in Science) integrate knowledge, practice, and responsibility into science learning (MOE, 2022, pp. 1-8).

In conclusion, in most European countries, the fields of science are taught in an integrated way, even if some start this integration earlier and others later (Mullis et al., 2016).

The aims pursued and the methods of approach are differentiated. Some countries aim at performance through the curriculum proposed to students and others aim at professional training. The common aspects of the science curriculum are represented by the contents, the difference being made by their structuring in terms of the chronology of learning, the modes of application and the goals that will be achieved.

1.3.2. Didactic approaches used in international practice

In international practice, training strategies are presented that have not found their current use in our country: inquiry-based learning, gamification, STEM education.

Science teaching both domestically and internationally promotes the idea of integrating scientific fields based on the fact that explaining the facts of life is impossible without perspectives from various fields. Kreijkes & Greatorex (2024) describe models of curricular integration. They range from three to ten models.

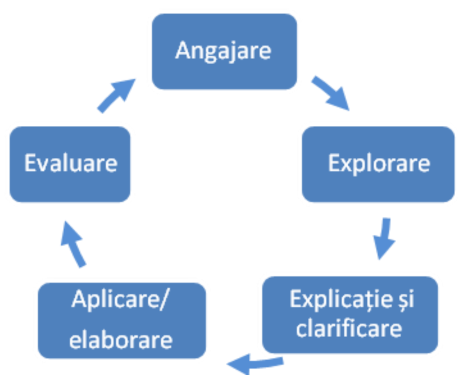
A study by TIMMS, presented by Roth and Garnier (2007) on the teaching of science in different countries, demonstrated that, in the case of countries with high results in international tests, the existence of connections between scientific learning activities and in-depth learning of concepts is highlighted. The Czech Republic, for example, favors learning through content designed to stimulate/challenge learning, Japan favors evidence-based learning, Australia makes connections between the content studied and real life, the Netherlands emphasizes independence in the assimilation of scientific content, the USA integrates a complex of methods and procedures, partially encompassing the features valued by other countries.

In terms of learning models, the most commonly mentioned as current use are the 5E and 7E models. The successor models of the 5E model (called the BSCS model, 1980) are the Herbart model (circa 1900), the Dewey model (circa 1930), the Heiss, Obourn and Hoffman model (circa 1950s), the Atkin and Karplus model (1960).

The 5E model proposed by Bybee and Landes (1980) is considered the best-known model of this type (Settlage & Southerland, 2012). It involves the following stages: engagement, exploration, explanation, application/elaboration and finally evaluation.

Figure 2

The 5E model proposed in 1980 by Bybee and Landes (Bybee et al., 2006)



In the Employment stage, students come into contact with objects and phenomena or are reminded of certain life experiences. The teacher emphasizes the connection between previous knowledge and that to be studied. It also stimulates students' curiosity by highlighting aspects that challenge students' interest. In the Exploration stage, students come into direct contact with objects or phenomena, study them (exploration), document themselves from various sources (encyclopedias, textbooks, films, etc.), make various observations or experiences and hands-on activities, as the case may be. The teacher responds to requests and guides the students' steps. In the Explanation stage, students show how they understand facts, phenomena and concepts, specifying what meaning they attribute to them. The teacher pursues the clarity and coherence of the explanations regarding the new knowledge (concepts) and skills developed by the students. Elaboration is the stage in which students use/apply new knowledge to deepen/expand their understanding and achieve the development of skills. The teacher guides the application of concepts and collects feedback. In the evaluation stage, the students, with the support of the teacher, carry out the evaluation of knowledge (declarative, procedural, conditional) and skills. It also reflects on the learning process and the value of new knowledge. The teacher can appreciate the development of the students and the efficiency of the activity.

Ballone Duran and Duran (2004) modify the BSCS cycle by placing the Evaluation stage at its center, based on the consideration that students practice, at the teacher's suggestion, constantly, the evaluation of their actions at each stage. Manoli et al. (2015), citing Bybee et al. points out that The training models described above served as a basis for building newer models. One such model is the 7E cycle (Eisenkraft, 2003) which differs from the 5E cycle in that the employment stage of the 5E cycle is divided between the presentation of prior knowledge and employment. The motivation for this division is the necessary importance to be given to tacit knowledge on whose understanding the success of the new learning depends. Another change made by Eisenkraft to the 5E cycle is the addition of the extension stage. "The addition of the extension phase to the elaboration phase is intended to explicitly remind teachers of the importance for students of achieving knowledge transfer" (Eisenkraft, 2003, p.59, quoted by Balta & Sarac, 2016, p. 62). All the aforementioned models are characterized by an orderly succession of stages, which, although they may mislead the reader by suggesting the idea of uniformity, nevertheless allow variations at the level of connections between stages (Manoli et al., 2015). The construct of models can suggest a double approach – inductive or deductive, respectively a space of hypothesis or a space of experiment and applications (Klahr & Dunbar, 1988). Engaging and exploring denotes an approach "inductive, empirical, data-driven", and question and prediction encourage a "deductive, hypothesis-based approach". The difference between the models is also given by the weight of the form of learning organization: individual or group investigation.

1.3.3. Analysis of science textbooks from abroad

The analysis of science textbooks from abroad allows highlighting some themes, less addressed in Romanian textbooks, such as "balance between theoretical and practical knowledge", "portrayal of minorities", "equality of women and gender", "dealing with socio-scientific problems", "knowledge of indigenous communities", "cultural and religious sensitivity" etc. To these are added topics regarding the description of graphic information, vocabulary, intelligibility and readability of the content, its accuracy and coherence, the role of textbook questions, addressing misconceptions and the diversity of specific methods of knowledge construction and evaluation (Liu & Khine, 2016).

A general descriptive framework of science textbooks abroad reveals that their subject matter values the understanding of the connections between the theories and laws of science and scientific phenomena and processes (Ahtineva, 2005).

Chapter 2. Inquiry-based learning

2.1 Inquiry learning. Specification of the concept

2.1.1. Conceptual boundaries

The term "inquiry" or "enquiry" translates as investigation, investigation or research, that is, the discovery and meticulous study, carried out systematically, with the aim of discovering something. (Dex. 2009). For example, Sutman et al. (2008) talks about the "discovery or inquiry instructional framework" referring to the implementation of a learning model by investigation or discovery. We also come across terms such as "inquiry-based learning" (IBL), inquiry-based science learning (IBSL), "discovery learning", "inductive teaching and learning", "guided inquiry" (Spronken-Smith et. al. 2007). Another didactic strategy that fits science learning, derived from IBL, is presented by Alvarado and Herr (2003) as "objects-based-inquiry". The term inquiry is integrated by other authors in the expression "inquiry-based teaching" as a teaching strategy adapted to student-centered learning (Warner and Myers, 2011). Rugg (1931) uses the term "experimental inquiry" as a method of learning science. Inquiry, as a method, was introduced in education during the 60s (ACER for education).

Inquiry-investigation

The term inquiry used in English-speaking literature is a legal term (DEX) in Romanian. As a result, we will assimilate this concept to that of investigation (research). An investigative/research activity, Carin et al. (2005) shows, can take on three forms of investigation to which Ciascai and Turșan (2022) add another one:

- interrogative investigations – to identify and formulate problems and questions to be investigated, to clarify other problems, as a basis for reflection, etc.

- descriptive investigations – collecting data and information based on observations and measurements made, in order to obtain answers to certain questions and problems;

- classification investigations: organization, sorting and grouping of the obtained data according to their specificity and usefulness;

- experimental investigations: the use of controlled experiments to test hypotheses.

As it results from the typology of Carin et al. (2005) and Ciascai and Turșan (2022), by investigation we also designate learning through interrogation, documentation/documentary research and not necessarily through experimental activity. In addition, most often in the structure of the lesson IL represents a stage. The educational value of this learning activity lies in its cognitive, formative and attitudinal functions.

The following are the opinions of other researchers regarding the investigation. Some consider the investigation a phased approach (Linn et. al., 2004), objectified in a system of methods (Hammerman, 2006; Lee et. al., 2004), respectively a process (Justice et al., 2007), an inquiry-centered approach to learning (Student Achievement Division, 2013), a context of learning built on questions and problems (Prince & Felder, 2006, p.9). Finally, Budd Rowe (1976) differentiates between investigation and interrogation, the latter being considered a strict attribute of the teacher. Kuklthau et. Al. (2007), referring to guided inquiry, describes, from a more complex perspective, the concept of inquiry, showing that it "is a way of thinking, learning and teaching that changes the culture of a school into a collaborative community of inquiry" (p. XIII). He emphasizes that this does not only involve finding correct answers to questions but also involves study, exploration, research, reflection and evaluation. Staver and Bay, cited by Price and Felder (2006, p. 9) distinguish between three stages of different complexity of investigation: structured investigation, guided investigation and open investigation. In the first type of investigation, students receive a problem, a sketch on how to solve it and benefit from the teacher's support. In the guided investigation, the students receive the problem and must also discover the method of solution, asking for the teacher's support if necessary. In the open investigation, the students formulate the problem and solve it without the teacher's involvement.

It should be noted that, in the use of investigation, it is very important to correlate the results obtained with previous acquisitions as well as to capitalize on them in an optimal learning environment.

2.1.2. Inquiry-based learning (IBL)

Turşan and Ciascai (2020) define inquiry-based learning as a learning approach through which students, alone or under the teacher's guidance, build their knowledge, skills and acquire attitudes and values. IBL, in the sense of the above-mentioned researchers, shapes the lesson by superimposing the IBL stages with the stages/moments of the lesson. In other words, the lesson is placed in an IBL framework. In this way, knowledge is acquired, skills and abilities are formed, respectively competences and attitudes towards the process of knowledge and learning are developed.

The advantages of inquiry-centered learning are multiple. From these we select: IBL can be adapted on a large scale in education, building an entire curriculum based on this concept. Also, in a didactic context, it can be used as a learning method (Cleverly, 2003); in inquiry-based learning, students follow the steps of cyclic learning, with deep, summary or non-teacher involvement (Alvarado & Herr, 2003); according to Gholam (2019, p.113) inquiry-based learning is defined as a "student-centered strategy", in which students are asked to formulate and research a problem of interest to them or to formulate their own questions and seek answers to these questions (Caswell & LaBrie, 2017, cited by Gholam, 2019, p.113; Alvarado & Herr, 2003);

Inquiry-based learning, both as a basis for implementing the curriculum and as a methodology, can be an essential factor in streamlining the fulfillment of educational goals. It should be noted that there are a multitude of internal or external factors that can become facilitators or real challenges in order to obtain the pre-established investigative performances.

2.1.3. Inquiry-Based Science Education (IBSE)

Since the beginning of the twenty-first century, inquiry has been associated with the natural sciences. Subsequently, after the introduction of the concept of inquiry/investigation, the *Inquiry-Based Science Education (IBSE) paradigm was* introduced.IBSE is defined by Crawford (2014) as a process that involves students in the activities of asking questions, designing and conducting experimental investigations, collecting and interpreting data to obtain evidence, creating arguments, building explanatory models, applying them and communicating findings in order to deepen their understanding of the natural world. IBSE contributes to the development of experimental, critical thinking and creativity skills and can improve students' learning performance (Crawford, 2014 cited by Strat et al., 2023, p. 191; Rodrighez et al. 2019, cited by Rahayu et al., 2024).

Researchers' opinions regarding IBSE are listed below:

- Farren et al. (2012) and Calalb (2018), citing multiple sources, argue that the implementation of inquiry in many countries, in order to improve approaches in science learning, has been done as a type of pedagogy; Calalb (2017) believes that Inquiry based Science Education (IBSE) emphasizes understanding phenomena and events and developing skills that will ensure lifelong learning. At the same time, IBSE values the child's natural curiosity; bin Ahmad et al. (2023) consider that skills related to inquiry, problem-solving, observation, and creative thinking as well as motivation for science learning are enhanced in the student through the implementation of inquiry-based science learning.

The countries in the European community that started to adopt the IBSE curriculum at national level, according to the ESTABLISH report (2011) were: Cyprus, Estonia, Malta, Poland, and those that integrated this concept into the curriculum were: Czech Republic, Germany, Ireland, Italy, Netherlands, Slovakia, Sweden. The most highlighted aspects at the level of the new curriculum in these states are the planning of investigations, the analysis of experiments, the search for information (CEAE, 2020). For example, three components are mentioned in the structure of the Australian curriculum: understanding science, science as human effort and scientific inquiry" (*Australian CURRICULUM).* In contrast, in 2013 Singapore's science curriculum stated that it was IBSE-centric. In the methodological component of the science curriculum in the first years of schooling in the UK, the "scientific enquiry" is found as a working method (National Curriculum in England, 2013).

In Romania, at the level of science curricula in grades III-IV, investigation is partially integrated as a competence to train students: "Investigation of the environment using specific tools and procedures". In order to form this competence, certain inquiry-based learning practices are recommended as learning activities: formulating questions, choosing working methods and resources, predictions, conclusions, reflections. (Curriculum for the discipline of Natural Sciences, grades III-IV, 2014).

2.2. Typology of investigative activities and their relationship with the lesson

2.2.1. Modeling of investigative activities. Synthesis

According to the National Research Council/NRC (1996), Bybee (2002) which refer to science lessons, IBL involves the phased completion of the lesson. Being among the *founders* of cyclic models of investigation, Deway is very often cited in the literature. Morgan (2014) shows that Dewey introduces and describes inquiry (inquiry/investigation) as a process of conscious decision-making, out of the need to distinguish between habits and conscious action. Remarkable is the fact, the quoted source shows, that in the approach of Dewey's investigation, the research is not delimited by life or by the everyday. As a result, Dewey's systematic approach to investigation involves five steps:

1. Recognizing a situation as problematic.

2. Defining the problem, starting from the problem-situation and concretizing it into a problem.

3. Developing a strategy to solve the problem.

4. Assessing potential actions in terms of consequences.

5. The selection and implementation of actions that are considered to be likely to address/solve the problematic situation (Morgan, 2014, p. 1047).

2.2.2. Models of non-experimental investigative activities

The literature also mentions other models adapted by practitioners after the models mentioned above and according to the specifics of their classes. An example is the model called by Elkins-Tanton (2024) "the Beagle model". According to this model, the teacher sets the objective of the activity, according to which the learning activity is divided into two parts:

- Learning stage: the teacher or students formulate a set of questions or problems. These are submitted to class discussion, a process in which some questions are clarified and others are answered. The remaining questions are analysed and the investigation collects the data necessary to formulate the answers
- The deepening of knowledge stage: students reflect on the understanding of new knowledge by attributing meaning to it and share their knowledge, an approach from which they can extract/give new meanings to their knowledge. In the case of this model, the students are the ones who organize and start the entire investigation process, the teacher being a simple supervisor who ensures the correct orientation of learning.

Pedaste et. al. (2015), based on the study of several investigation cycles, generated an investigation-based learning framework, which contains general stages that can be customized by their personalized interpretation or reinterpretation. New phases or sub-phases can also be added to minimize learning activities. The phases of the presented framework are 4: Orientation, Conceptualization, Investigation, Conclusion.

A final model mentioned in the present study is the Kuhlthau et. al. (2012). This model includes 8 stages:

(i) Challenge – to stimulate curiosity and open mind. Students are faced with a learning task.

(ii) Immersion: studying new content, useful for clarifying the task and identifying assumptions or ideas that can be explored.

(iii) Exploration: ideas, assumptions and content are explored using information and data from various sources or are the result of personal observations. Exploration is guided by reflection and involves making evidence-based decisions.

(iv) Identification: selecting, based on arguments, the question/problem that will be the object of the investigation and establishing the way to build the solution (documentation, debate, investigation, experiment, etc.

(v) Data collection: data collection for the development and refinement of the solution.

(vi) Creation: reflection on learning, creating meaning and deepening understanding.

(vii) Communication: sharing of acquisitions and learning experience.

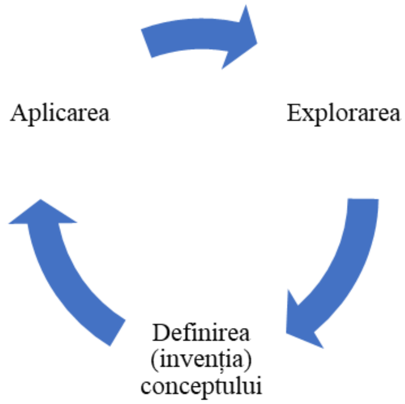
(viii) Evaluation: evaluation of the achievement of objectives, reflection on the content and the learning process.

The description of these models does not suggest experimental interventions, which allowed them to be classified in the category of non-experimental investigations, which do not involve manipulation of the independent variable under controlled conditions. In non-experimental research the variables are measured as they appear, without any further manipulation and the purpose of the research is not to identify causal relationships.

The POGIL project provides a description of the process-oriented guided inquiry learning activity, considered a reference for the scientific and practitioner community.

Figure 3

POGIL Cycle



The POGIL cycle (Figure 3) involves the exploration of the object (through direct querying) to identify the patterns and relationships of the object studied (phenomenon, process, concrete object, etc.). Based on these characteristics, a concept is defined that is then applied to deepen its learning.

POGIL process skills are: oral and written communication, information processing, problem-solving, critical thinking and metacognition, self-assessment and peer evaluation, management, teamwork (Moog & Spencer, 2008).

The criticism of non-experimental investigation models concerns the typology of the documentary sources used, most often reduced to written materials, family collaboration or watching films. Visits to cultural institutions or the involvement of experts are omitted.

2.2.3. Models of experimental investigative activities

John Dewey (1859-1952) is credited with two models of inquiry-based learning. The first model includes three stages: defining a problem, formulating a hypothesis and performing tests (Pedaste et. al., 2015) and the second five stages: question, research/investigation, creation, discussion and reflection (Von Taden, 2004, p.14)

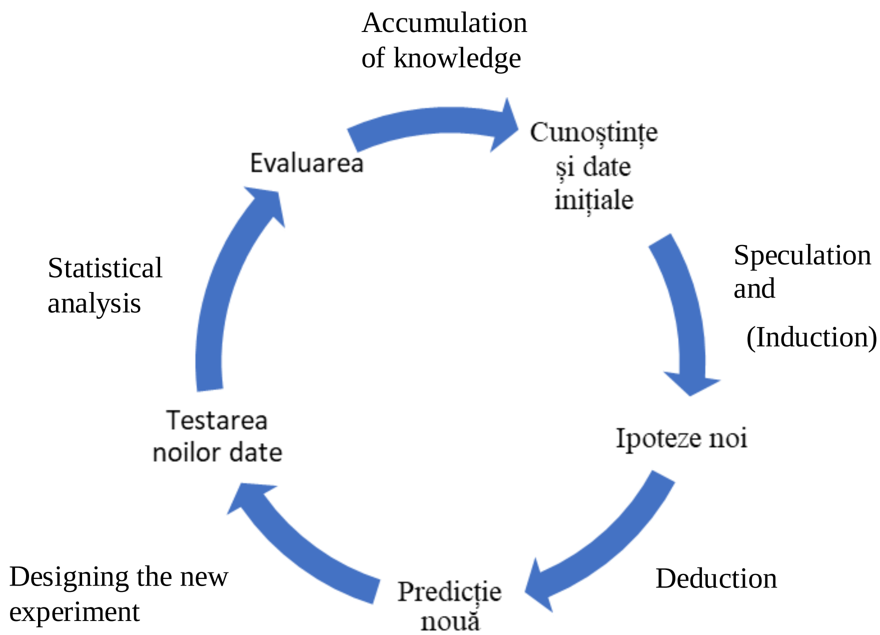
This second model starts from a problem or question that, when investigated, leads to data based on which new knowledge is developed. These are related to individual knowledge and are the subject of debate. The exchange of knowledge and the reflection carried out on it allow the verification of the understanding of knowledge and lead to the revision of knowledge or to its extension (completion of a new cycle).

A cycle worth mentioning was developed by Groot & Spiekerman (1969). Known as the De Groot cycle, it consists of an empirical model and was later taken up and developed by other researchers. Hoijtink et al. (2023, p.2) consider that the De Groot cycle represents "a model of cumulative knowledge generation through scientific research. The empirical cycle described is a pragmatic guide for researchers that includes and links open science practices." The cycle has five stages. It has as its starting point a question or a set of questions. The answer formulated to these questions (assumptions, predictions or hypotheses) is tested through an experiment, and the result of this test will represent an explanatory model subject to discussion and evaluation.

Given the reliability of this cycle, Wagenmakers et al. (2018) reviewed De Grrot's empirical cycle (1969). The revised cycle has 5 stages: Observation, Induction, Deduction, Testing and Evaluation (Figure 4).

Figure 4

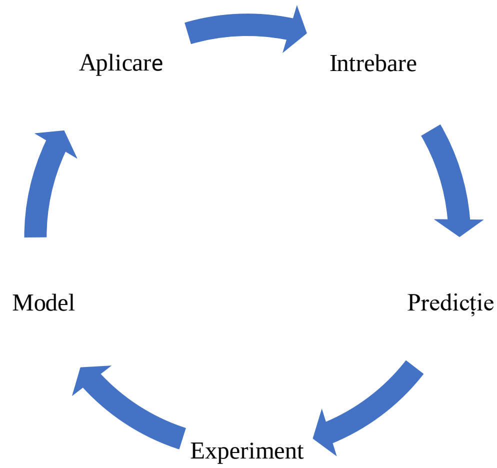
De Groot's empirical cycle (1969) after Wagenmakers et al. (2018)



The investigation model (Figure 5) proposed by White and Frederiksen (1998), has as its starting point a question or a set of questions, collected from a set of knowledge and initial data, based on which hypotheses are formulated from which a prediction is derived, which is tested through an experiment, and the result of this test will represent an explanatory model subject to application in specific situations to evaluate its effectiveness.

Figure 5

The Cycle of Investigation after White and Frederiksen (1998)



The second model of the investigation cycle proposed, a year later, by the two researchers joined by T. A. Shimoda is built to be as detailed and easy to implement as possible (White et. al., 1999).

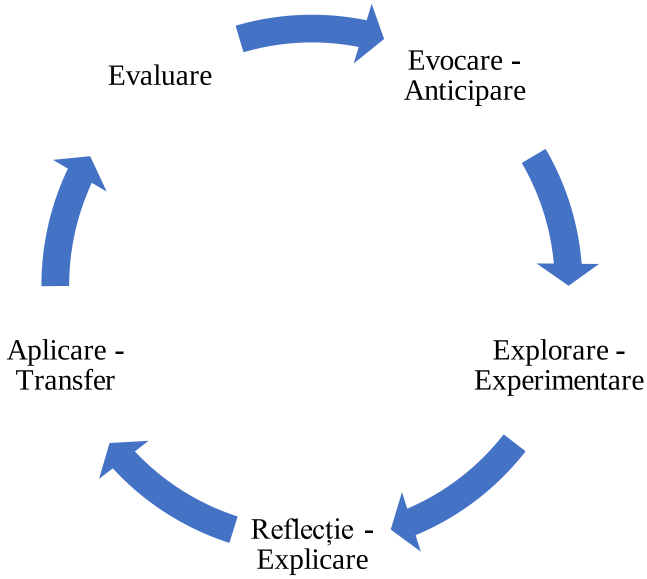
The presented cycle consists of six stages grouped into three categories of activities: (i) asking questions; (ii) research that includes hypothesis formulation, investigation, data analysis, and explanatory model building, and (iii) evaluation. White et al. (1999) observe that: (i) the analysis, model and evaluation present a complement brought by the new model to the previous ones; (ii) the stages of the cycle correspond to a succession of objectives to be achieved by the students. In the first phase of the investigation, the students will have to ask a research question with reference to the proposed theme. In the second stage, the students will establish hypotheses/predictions with reference to the question asked. The third stage is represented by the students' experiments through which they test the hypotheses. Data analysis allows the model to be developed. This is followed by the presentation of the findings and thus the assessment of the cyclical process and results, including the understanding of new purchases.

The models proposed by Bybee et. al. (1989, 1990) are frequently used in practice and as a result were presented in the previous chapter.

The following are the IBSE cycles. A first cycle illustrates the learning framework described by Temple et. al. (2003) called the ERR framework (Evocation-Realization of Meaning-Reflection). The cycle includes five stages and has been extended to integrate the experimental activities (Figure 6):

Figure 6

Cadrul ERR Temple et al. (2003) extins, descris de Sarivan et al., (2003, pp. 41-46)



In the first stage, the students remember and reflect (or present, and discuss, if the activities are carried out in groups or classes) on the initial knowledge related to the topic to be studied, anticipate the solution/solutions or how to obtain them, design an exploration or experimentation approach. In the second stage, the students put the projects into practice, collect and interpret the data. In the Reflection-Explanation stage, elaborate the solution(s) by providing an evidence-based explanation. It then uses the solutions in various contexts to validate them, and in the last stage it evaluates their correctness, based on the results of the respective testing, those obtained through application and transfer.

All 15 models exposed in the two chapters of the paper have the merit of presenting a phased approach that facilitates its application in practice by students. The difference between the models is given: a) by the type of investigation promoted by the model (non-experimental or experimental) and b) by the way in which the investigation relates to the lesson, respectively to a system of lessons; the number of stages; by the weight of documentation or experiment in inquiry-based learning.

It should also be noted, with reference to documentary research, that the debate and consultation of specialists, as a source of information or for evaluation purposes, are activities little or not mentioned at all in the models presented. Evaluation is also given the same importance as reflection. The construction of meaning and the deepening of knowledge are neglected in most models. The explanation of the roles of the teacher and students in the context of inquiry-based learning (including in guided learning models) is incompletely specified.

2.3. IBSE Learning Framework. Deepening

2.3.1. Activities of students and teachers in inquiry-based learning

The literature mentions the existence of three and four types of scenarios, respectively. To exemplify the three-scenario model, we refer to the 5-stage cyclical model proposed by Bybee (1989): engagement, exploration, explanation, elaboration, evaluation. Ciascai (2022) proposes to extend the Exploration stage to Experimental Activities, showing that, depending on the age of the students, the activities carried out in this stage can be exploration, observation (systematic or oriented) and experimental. As a result, the roles of the teacher and students in the experimental activities will be presented in Table 1.

Table 1

Student and teacher activities in the three types of scenarios presented (Bybee model, 1989, adapted by Ciascai, 2022)

IBL scenario type	Student activity	Teacher's activity
Open-ended IBL scenario	The student builds his knowledge	The teacher responds only to the student's requests
	The student carries out the investigations independently	The teacher observes and intervenes only when necessary or to respond to students' requests
Guided IBL scenario	The student builds knowledge	The teacher supervises the development of the activities in each phase
	The student carries out the investigations under the supervision of the teacher	The teacher is a facilitator (supervisor and guide)
Structured IBL scenario	The student builds his new knowledge in collaboration with the teacher	The teacher accompanies the student in the process of building new knowledge
	The student carries out the investigations led by the teacher	The professor leads the investigation activity

It is very important that, regardless of the type of scenario that exists, during each stage of the investigation cycle, the teacher holds the function of motivator.

Lleweiiyn (2011) proposes a framework with four investigation scenarios (Table 2) and describes the roles of students and the teacher during learning in each scenario.

Table 2

Scenarios of the investigative framework after Lleweiiyn (2011, p. 15-17) - adaptation

Investigation scenario	Teacher's activity	Student activity
Demonstration investigation	The teacher asks, explains and demonstrates and integrates knowledge	The student asks, collects data, relates knowledge and elaborates explanations
Structured investigation	The teacher trains the student in carrying out investigative steps and processes	The student solves the tasks received and deepens or expands them
Guided investigation	The teacher plans and initiates investigations.	The student implements the plans and carries out the investigations
Student-led investigation	The teacher is an organizer and mentor	The student investigates, interprets data and formulates explanations

ACER for education proposes four scenarios of the investigation framework: the confirmatory scenario, the guided investigation scenario, the structured investigation scenario and the open investigation scenario. The four stages involve the following steps:

- confirmation scenario: students receive a question, a method or a known result and must remember the process of obtaining the result, thus confirming and deepening knowledge by practicing skills and applying knowledge;

- the structured investigation scenario: students are given a question or task and a method that lead to a single result;

- the guided investigation scenario: students are given a question or task and must identify or design and carry out an investigation approach. The solutions can be multiple;

- The open investigation scenario: the students choose the question, design the investigation approach to obtain the solution.

Table 3

Stages and strategies of the IBSE model according to who holds the predominant role: the teacher or the student (Walker, 2013, p.19), adapted from Ciascai (2022)

Investigation stage	Stages of the investigation framework							
	Asking questions	Document	Planning the investigation	Conducting the investigation	Data analysis	Formulation of conclusions	Reporting	Application
Confirmation period	Is	Is	E/P	Is	Is	Is	Is	E/P
Structured learning internship	P	E/P	P	E/P	E/P	E/P	Is	E/P
Guided Learning Internship	E/P	E/P	E/P	Is	Is	Is	Is	Is
Open learning internship	Is	Is	Is	Is	Is	Is	Is	Is

As it results from the synthesis presented in Table 4, the involvement of the teacher and students in IBL activities may differ from one stage to another, depending on the complexity of the activities required, which allows the construction of a greater variety of guided learning approaches, better adapted to the concrete context of learning (Ciascai, 2018).

2.3.2. Integrated teaching methods and means in the IBL learning framework

The completion of the stages of inquiry-based learning requires the integration into the instructional-educational process of learning methods and means for the fulfillment of work tasks or the achievement of pre-established operational objectives and certain skills can be formed and developed.

Next, a selective description of the methods integrated in the IBL learning framework will be made.

Dialogic methods

Communication involves the presentation of information. Conversation is an approach through which information/knowledge, ideas, thoughts or emotions are transmitted and received between two or more parties. Discussion involves an exchange of ideas or opinions between two or more people, usually in an informal way. Debate is a formal and structured process in which participants express their views argued through evidence in order to support or reject an idea.

All of these methods involve operating with questions, exposing ideas and arguments, and referring to evidence. In relation to inquiry-based learning, asking questions triggers learning situations. The way in which the questions should be used is very important, taking into account several criteria: the typology of the questions, the circumstances of use, the connection of the questions as well as the thematic content to be explored through the questions. It is recommended to rank the types of questions used in the conversation.

Table 4

Variety of questions possible to be used in a simple investigation

Stage	Types of questions that can be used
Asking questions	What?, Who?, When?, How?
Data collection, information	What?, How?, Why?, Why?, Which?
Formulation of hypotheses/predictions	What will happen if...? How is it explained..?, Why?, Which variable is manipulated?, Which variable changes its value? Etc.
Data processing and interpretation	What?, How?, When?, Why?, Why?
Explanation	How is it explained?, Why?, How do you think that? , How can we?
Reflection/evaluation of the outcome and process	What happened? How did it happen? Do you agree with/that...?, Do you think you used the correct procedure?, What is your opinion?, Why is it happening...?

The questions are not predetermined, the selection of the question depends on the situation. In addition, the questions can be reformulated during the investigative process, depending on the situations that arise, the complexity of the knowledge, the answers formulated by the students, etc. Conversation is ubiquitous throughout IBL, and most of the questions used are heuristic.

Problem solving and problematization

The difference between problem and problematization is obvious. The problem is a construction created or not by the teacher and aims to engage the student in identifying the necessary solutions to find out the result by using the acquisitions already accumulated. Problematization involves solving a problem-situation. It is characterized by the conflict between the student's knowledge or beliefs and the new fact/new knowledge. This conflict will be solved through a research activity, discovery on the part of the student, under the guidance of the teacher.

Problematization is one of the methods most frequently invoked by teachers when referring to the active engagement and involvement of students in the teaching-learning process (Ciascai, 2011). In reality, however, students are not confronted with problem situations, but with problems. There is a terminological confusion here, pointed out by Ciascai (1999).

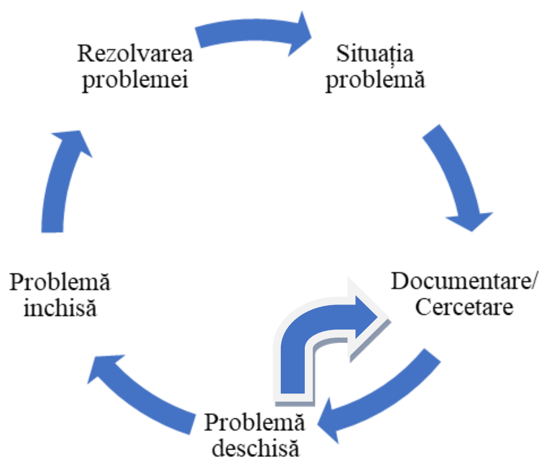
The problem situation differs from the open problem in that it generates a socio-cognitive conflict (Ciascai, 2001). In fact, most often, the problem-situation contradicts the student's knowledge, knowledge to which the student adheres/believes to be correct and sufficient to provide explanations. This knowledge has its source in life experience but can also be acquired in the learning process.

The stages of solving the problem are: studying the problem in order to identify the input and output data; prefiguring the solution and choosing the solution method; solving the problem, which involves applying the method and obtaining the results; verification of solutions and method, application of solutions and extension of method.

The steps involved in solving a problem situation are shown in Figure 7.
Once formulated as a closed problem, it is solved by following the steps specified above.

Figure 7

Stages of problematization



If we look at problematization from the perspective of its theoretical complexity as a method and associate it in practice with IBL, we understand that it represents the productive core of IBL.

Experimental activities

Exploration is an active method of learning that involves contact with the object, the fact, the phenomenon to be studied for its research. Exploration involves more than a simple visualization, it involves trial and error and ends with the collection of information on which it operates. Thus, exploration involves the interpretation, organization, classification as well as the presentation in different forms of the new information identified as a result of the exploratory activity. The difference between systematic observation, experiment and exploration is that the latter does not presuppose the existence of pre-established explanatory models. In current practice, exploration is close to empirical observation, with the difference that in an exploration the emphasis falls on the direct or instrument-mediated contact with the object of exploration.

Experiment and systematic/oriented observation, Ciascai (2022) shows, involve research directed by assumptions, hypotheses or predictions as well as the manipulation of variables.

As regards the relationship between IBSE and experimental activities, it should be noted that they are integrated with great frequency in the stages of the approach.

Learning through discovery

Introduced by John Dewey, learning by discovery has been taken up as a way of acquiring new knowledge in everyday life. Discovery can easily be confused with exploration or experiment. Viewed in terms of a product, the discovery is the result of observation or experiment. Seen as a process, discovery is an organized approach in the sense that it involves confronting curiosities, questions, unsolved or apparently unsolved problems in relation to certain topics and whose solution is sought. Discovery, however, has characteristics of spontaneous learning, generated by the direct observation of objects, phenomena, etc., as a result of which new things are found, or previous and new knowledge are related.

Didactic discovery or learning by discovery supports inquiry learning (IBL) by practicing the inductive and deductive reasoning, necessary in IBL in the stages of building the explanatory model and validating it in practical applications.

Didactic modeling

Modeling also falls into the category of methods that stimulate scientific investigation. The model is more than a simplified reproduction of objects, phenomena or processes of reality (Tiron & Stanciu, 2019) but rather a reproduction of those aspects of reality to which direct observation or experiment has limited access. Therefore, the model represents a substitute for a more complex system (object or process), used for the purpose of studying it (Ciascai, 2006; Cucoş, 2014). Cucoș (2014, p. 349) identifies two functions of the model used in the didactic activity: illustrative (presentation of knowledge) and cognitive (construction of knowledge).

Within IBL, the model can be integrated as a means/resource used in exploration/discovery and as an object of study. Based on its observation and analysis, students can obtain valuable information that meets their cognitive needs; Made by students, it can be used in an experiment.

Case study

The case study, or case method, has its roots in England at the end of the nineteenth century and in France at the beginning of the twentieth century. It is defined two-dimensionally, as a method of instruction and active learning and respectively as a research method having as object of study a case (a particular situation of a person, a student, institutions, etc.) and using as procedures the analysis and debate of a proposed case (Dictionary of Pedagogy, 1979). As Cucoş (2014, p. 347) argues, the method can be used inductive as well as deductive, in the start of the case, going through certain stages: "the notification or discovery of the case, its examination from several perspectives, the selection of the most appropriate methods for analysis, the processing of the respective case from a pedagogical point of view, the establishment of conclusions". Trif (2024, p. 363) suggests the following steps: identifying the context of the case; debate/discussion of the case; the resolution of the case.

When it comes to the use of the case study in the IBL cycle, we can talk about the existence of a similarity between the case study and the non-experimental IBL.

Group/team work

Teaching activities that promote interaction, collaboration, partnership between students, are based on interactive, group/team learning methods. Lorge et al., (1958) are of the opinion that the performances of groups are superior to individual ones, especially in solving problems, whose solutions are identified more quickly by stimulating creative thinking, thus shortening the duration of investigations.

Inquiry-based learning clearly involves group/team activity. The efficiency of practical research and solution actions increases in the case of using groups as a form of learning organization (Neacșu, 2015, p. 106). Alvarado and Herr (2003) consider it important to organize the classroom in small groups through which students aim to obtainbeneficial results for themselves and their peers (Smith, 2000).

IBL and especially IBSE involve solving problems/problem situations that are often complex. The existence of the group facilitates the faster identification of solutions.

In the context of the group investigation, the activities of exploration, debate, analysis and exposition of explanations are carried out. The students formulate hypotheses/predictions together, prepare and apply necessary experiments, each member having a well-defined role. The evaluation of the activities undertaken, the reflections on one's own decisions can be made within the group, inter-groups as well as teacher-students. The roles held by the students can be reversed, depending on the students' skills in relation to the given topic and the actions to be followed, on the qualities and skills of the students developed along the way and, of course, on the needs of the group regarding the efficiency of the research. Although each student has a well-defined role, the decisions that are made as a result of a common goal for which each student works together

The role of the teacher remains an important one in actively observing the relationships between the members of the groups in order to permanently orient the students' activity towards correct and deep learning. In order for the team/group activity to be effective, a series of conditions must be met: (i) small number of people; (ii) diverse and complementary skills; (iii) engagement in the light of a common purpose; (iv) the purpose being described by performance objectives; (v) group members develop an approach for which they hold themselves mutually accountable (Katzenbach & Smith, 2015).

Critical thinking. Critical reflection

Critical thinking can be defined in terms of skill or process. In the first case, we are talking about the ability to analyze, interpret and evaluate information logically and objectively, in order to reach clear and well-founded conclusions. In terms of process, critical thinking involves examining problems, hypotheses, evidence, and arguments. At the same time, critical thinking allows the identification of biases, reasoning errors and the implications of knowledge and ideas. From a didactic point of view, critical thinking can be described from a double perspective: learning method and competence to be developed. The ERR framework and methods such as: *the cluster method, the method, the cube method, I know/want to know/I learned, brainstorming, thinking hats, R.A.I.* they serve the development and practice of reflection and critical thinking.

Critical reflection is the process of analyzing and evaluating personal ideas, actions, experiences, or beliefs in order to better understand and improve them. It is an essential component of critical thinking, as it involves self-analysis and the desire to learn: from mistakes, from observed behaviors, from someone else's actions, etc., or to understand one's own choices and points of view more deeply (Pânişoare, & Manolescu, 2019).

Inquiry-based learning is, through its construction, integrative of critical thinking and reflection processes.

In conclusion, the totality of the above-mentioned methods, integrated in the investigation approaches, creates a complex, logical, relational learning framework, oriented towards the formation and development of a varied set of instrumental, interpersonal and systemic skills.

All these methods used in the IBL learning framework have in common the placement of the student at the center of learning. They intertwine in their application at the IBL level, stimulating each other and working together to go through the stages of the investigation cycle and implicitly to the concretization of learning.

The teaching materials

The teaching materials of education represent another component of the didactic strategies, along with the forms of organization, techniques, methods and procedures, which support the educational process in order to achieve the educational goals.

Ionescu and Bocoş (2001) argue that the didactic materials, due to their importance in learning, have essential functions: they stimulate and maintain motivation, they have a formative role, they create visions of their own interests, they support the experimental investigation activity.

Cucoş (2014, p.352) classifies the teaching materials into two main categories: "materials that include a didactic message" (natural, substitutive, functional, actional objects, figurative and graphic, symbolic, technical supports, etc.) and "materials that facilitate the transmission of didactic messages" (equipment in laboratories and workshops, equipment and apparatus for facilitating sports activities, musical instruments, computers, instruments with a reality simulation effect, etc.)

The choice of teaching materials is made depending on the other components of the teaching strategies.

In the case of IBL, for the use of teaching materials, a set of requirements must be taken into account: the preparation of the necessary teaching materials,their accessibility and use at the appropriate time, the complete capitalization of each material, the correspondence of the teaching material with the complexity of the object of study and the methods used, the relationship of the teaching material with the purpose, type and purpose of the activities within IBL/IBSE.

The use of materials in different forms and hypostases for carrying out IBL procedures trains students skills such as systematic observation, analysis, synthesis, experimentation, selfdiscovery. The effects of the educational means are lasting and can be contextualized in each situation that arises throughout the learning process.

2.3.3. Evaluation of IBL activities

Evaluation of the IBL process

From the point of view of evaluation, the entire process of inquiry-based learning is followed throughout its development. In other words, the informational content is evaluated and then the process of assimilation of knowledge. Evaluation activities are integrated to support IBL activities, not just to examine them. Thus, assessment, as an integrated part of the IBL process, is very important in helping students to deepen and consolidate their understanding and at the same time encourages them to get more involved in the learning and assessment process (Laboratory School at the Dr. Erick Jackman Institute for Child Studies, 2011).

In the work *Growing success. Assessment, evaluation, and reporting in Ontario Schools"*, by the Ontario Ministry of Education (2010) present some conditions that should be taken into account in the evaluation of the IBL process:

- integrating the assessment into the IBL cycle by organizing and planning it together with the establishment of the stages to be followed in the training/self-training activity;
- establishing evaluation criteria together with the students, so that they know what to relate to quantitatively and qualitatively in the activities completed;
- to emphasize the continuity of evaluation; for the entire IBL process, the evaluation should always have a formative purpose.

Forms in which the IBL process can be evaluated are the following: identifying and following the evaluation indications, managing the way of advancing in order to achieve the goals, obtaining the feedback in the key moments of the lesson. These evaluative actions can be carried out with the help of the teacher or can fall exclusively within the scope of the students' self-evaluation activity.

The tools for systematically measuring learning during the investigation, used by both the teacher and the students, can be (Hammerman, 2006): observation sheet, continuous dialogue, questionnaires and satisfaction scales.

In conclusion, the assessment carried out in the context of IBL is integrated into learning, as a means of improving it. Also, students are mainly those who plan and apply their evaluation criteria as well as those who obtain the results of the evaluation process.

The role of feedback in IBL activities

Effective feedback is clear, constructive, personalized and stimulates active participation through open-ended questions. It is applied at all stages of the process, from formulating questions to presenting conclusions, facilitating the development of critical thinking and investigative skills. Feedback can be formulated in different forms and in various contexts. Lebrun and Berthelot (1994) present several hypostases of the feedback: a "general" framework in which explanations are brought with extensive indications on some actions undertaken; a "specific" framework, in which the feedback contains clear explanations of the answers obtained;

Feedback can be provided by the teacher, in response to the student's request to find out the teacher's opinion on an aspect of his work, it can be provided by the student who recalls an action or presents a concrete result obtained.

IBL approaches, in which students are the main protagonists of learning and which bring the teacher in the role of assistant, observer, guide, require continuous feedback. The role of feedback in this learning framework is structured as encouragement where moral pressure is greater, as a recommendation where there are uncertainties, as guidance where the quality of 0solutions is low and as a complement in situations of insufficient solutions. Chen et al. (2016), consider that the complex structure of the content to be investigated directly influences the need for feedback.

In conclusion, IBL activities cannot achieve their maximum effectiveness without continuous feedback.

Summative and formative assessment

Summative assessment is used to assess students' knowledge and skills at the end of a chapter, module, semester or project. Formative assessment supports the learning process through continuous feedback. The evaluation can also be criteria. Brazdil et. al. (2003) mentions that the definition of the evaluation criteria must be done in a simple and clear way" and that they should "produce values that can be interpreted by the user".

The (summative) evaluation of the results can take place at the end of a lesson, a learning unit, but the more often it is done, the more effective it is for learning.

There are a variety of tools for evaluating results and acquisitions of a volitional, attitudinal nature, etc. We highlight the following: the interview, the dialogue, the learning diary, the tests, the project and the portfolio, the observation sheets, questionnaires to verify the achievement of the objectives, satisfaction scales, scales of attitude towards learning. Well used, both categories of assessments contribute to the reinforcement of learning.

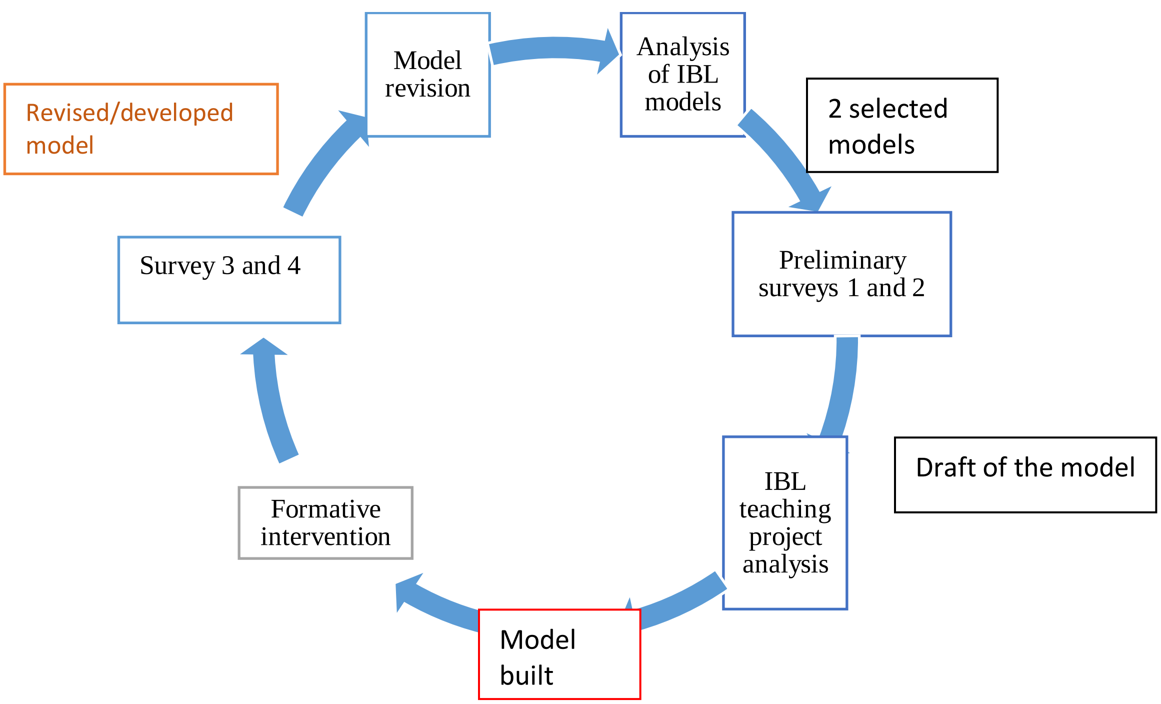
Chapter 3. Exploratory research

The organization of the research is an important element of originality. Thus, the research is organized in two chapters, chapter 3 and chapter 4 and completed by chapter 6 of conclusions. Chapter 3 is dedicated to exploratory research meant to gradually lead to the configuration of the model that founded formative research.

The program of exploratory research is presented in Figure 8.

Figure 8

The approach of experimental research



The program of exploratory research is explained in Table 5 by specifying the stages, the period of conducting the research in each stage, the participants or units used, the tools and the results obtained.

Table 5

Exploratory research program

Research	Period	Participants/ material	Instrument	Results
Documentation and analysis: IBSE models that can be adapted in formative intervention	November 2019 - January 2020	20 models	Analysis grid - models	6 selected models of which 2 meet the highest score
1st Survey: Teachers' knowledge and opinions on IBL	February-2020	102 teachers with various specializations – students of the PIPP specialization – Professional Conversion	The dimensions covered by the survey: D1. Teachers' attitudes and beliefs regarding the use of IBL D2. The relationship between IBL and school subjects D3. IBL applicability at various education levels	Contribution to the completion of the IBL model
2nd Survey: Teachers' knowledge and opinions of IBL	February-2020	81 teachers with various specializations – students of the PIPP specialization – Professional Conversion	The dimensions covered by the survey: D4. Respondents' knowledge of how students learn D5. Difficulties encountered by teachers in using IBL D6. Distribution of IBL-specific tasks between teacher and students D7. IBL's contribution to the development of students' skills	Contribution to the completion of the IBL model
Document analysis	May – June 2020	97 IBL activity projects	Analysis grid	Contribution to the completition of the IBL model
3th Survey: Teachers' knowledge and opinions on IBL	March-May 2023	76 teachers	The dimensions covered by the survey: D1. Teachers' attitudes and beliefs regarding the use of IBL D2. The relationship between IBL and school subjects D3. Applicability of IBL by education levels	Model review/development
4th Survey: Teachers'	March-May 2023	76 teachers	The dimensions covered by the survey:	Model review/development

knowledge and opinions on IBL			D4. Respondents' knowledge of how students learn D5. Difficulties encountered by teachers in using IBL D6. Distribution of IBL-specific tasks between teacher and students D7. IBL's contribution to the development of students' skills	

As shown above, the research carried out at this stage included an analysis of the 20 models specified in the theoretical part of the thesis. The analysis was carried out from the perspective of the applicability of the models in the didactic practice, respectively in the teaching-learning of the Natural Sciences discipline in the third and fourth grades. Based on the analysis, 2 models were identified: the Bybee model (2009) and the Dek Ngurah Laba Laksana model (2017) which obtained the highest score.

The research also included two surveys applied to teachers (102 and 81 respondents respectively) through which the doctoral student investigated their opinion on inquiry-based learning. The dimensions submitted to the investigation were six, three being taken from the literature and three elaborated by the doctoral student (Al Naqbi, 2015; Edelson et al., 1999; Eric, 2020; Lou et al. 2015; Nicolás-Castellano, 2023; Ramnarain & Hlatshwayo, 2018). These dimensions are presented in Table 5 and the questionnaires used in the survey are included as Annex 5a and Annex 5b. For the items taken (adapted) from the literature of the field, the procedure of ensuring the fidelity of the translation made by the experts was applied (Tsang et. al., 2017). The merit of the thesis lies in the enrichment, through the newly introduced dimensions of the doctoral student, of the knowledge on IBL, mainly of the estimated IBL benefits, with reference to students. The results obtained through the surveys show the following (selective presentation): teachers' attitudes and beliefs regarding the usefulness of IBL are, for the most part, favorable to it, teachers consider that the field of Science lends itself best to the implementation of IBL (81.40%); the distribution of averages for beliefs and attitudes about the usefulness of IBL does not appear to differ by age; there are some significant differences in teachers' attitudes and beliefs about the usefulness of IBL only in the case of teachers who teach in schools from different environments, urban (M=3.861, SD=.412) and rural (M=3.558, SD=.658), with $t(54.554) = 2.552$, $p=0.014$. Among the main difficulties encountered by teachers in implementing IBL in Natural Sciences classes are the lack of support provided by the curriculum (49.30%), insufficient time resources for preparing IBL lessons (49.70%), insufficient teaching materials (48.10%), not including the IBL approach in school textbooks (43.20%).

In order to refine the results, additional statistical processing was carried out (9selective presentation):

- differences in attitudes and beliefs regarding the usefulness of IBL according to demographic factors (age, experience, level of teaching and teaching environment)
- correlations between teachers' knowledge of how students learn, about the skills developed by IBL and about the difficulties of implementing IBL (depending on the level of teaching);
- comparisons in teachers' knowledge according to their demographics.

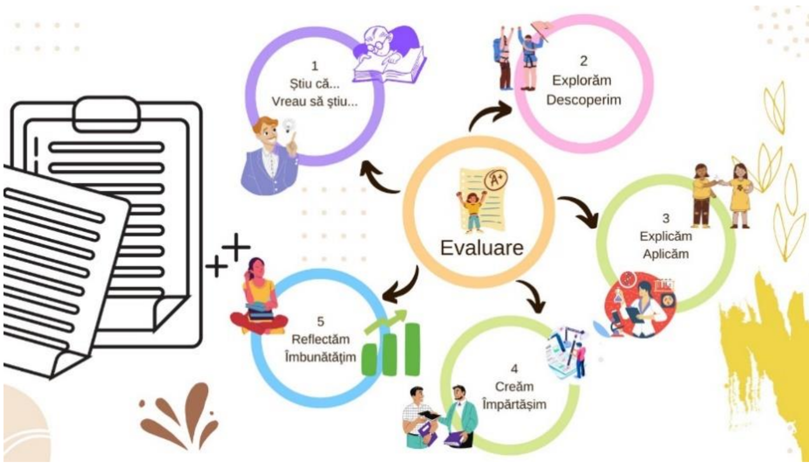
Significant correlations arise in the case of teachers' knowledge of how students learn and knowledge about the skills developed in students by the IBL approach. The correlations are also maintained in the case of analyses on separate groups: preschool teachers and primary school teachers. The difficulties of implementing IBL do not correlate with either of the two types of IBL knowledge

Except for the age categories 40-44 years and 50-54 years, statistical analyses indicate that there are no age differences in teachers' knowledge of how students learn and knowledge of what skills IBL develops in students.

In addition to the surveys carried out, the student also carried out the analysis of 97 projects of investigation-based teaching activity, drawn up by a sample of teachers.

The purpose of this research was to structure the model used in the formative intervention. The results obtained reveal that only one stage of the IBL approach is less valued by the authors of the projects: documentation.

Based on the results of the research, the following IBL model was developed:



The model that was the basis of the formative intervention, developed by the doctoral student, was presented to the teachers from the experimental classes considering that, in order to successfully conduct IBL activities, teachers must be well acquainted with the model. 12 teachers participated in the intervention, of which 6 in the experimental classes and 6 in the control classes.

The total number of students involved amounts to 280, of which 86 from the third grade and 194 from the fourth grade.

The main research hypothesis was that: Students who learn science based on IBL have higher school performance compared to those who learn natural sciences traditionally. The secondary hypotheses formulated concerned gender differences and differences in performance between students in third and fourth grades: There are gender differences in science scores in students (tested in general and then separately on control and experimental groups and then on the time they were tested – gender differences in pre-testing, gender differences in post-testing and gender differences in retesting); There are differences in the performance of students in the natural sciences depending on the level at which they study (third grade and fourth grade).

The analysis of the data obtained in the formative intervention allowed us to find that there are significant differences in the school performance in the natural sciences between the students who participated in the IBL training program and those who did not participate in this training program. On the other hand, there were no significant differences in the school performance in the natural sciences between the female and male students, nor in the performance of the students in the natural sciences according to the level at which they study (third grade and fourth grade). However, the IBL formative intervention thus seems to be more effective in the case of fourth grade students than in third grade. As for the average scores obtained by the students participating in the formative intervention, they increased from the initial testing stage to the final testing stage, the difference remaining statistically significant at the time of retesting.

The limitations of the research carried out concern the lack of interest of teachers in experiential learning, determined by the lack of the necessary equipment, but also by the time constraints imposed by the need to comply with school curricula. This lack of interest is manifested by the students' inability to carry out experimental activities and influences the interest in and success of IBL activities

The discipline of Natural Sciences cannot be the only context for the implementation of the IBL. The results obtained encourage us to believe that IBL can be used in most disciplines: mathematics, history, geography, technology, etc. We believe that IBL contributes not only to the deepening of knowledge in the field in which it is applied but also to the development of specific thinking and this issue deserves to be researched.

At the same time, in addition to the scientific/specific way of thinking, inquiry-based learning develops students a set of skills, attitudes and values that can be used in life and not only in the school laboratory. The study of acquisitions that can be achieved through the use of inquiry-based learning outside of school is a possible research topic. The effect of IBL activities on students' motivation for learning can be a topic of study. Another research direction can be to determine the effectiveness of IBL in the formation and development of students' metacognitive skills.

We deduce from the results obtained through exploratory research and formative intervention that inquiry-based learning can represent, for theoretical knowledge and its implementation in practice, a key element that opens the door to new fields of knowledge.