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PHD THESIS SUMMARY

THE EFFECTS OF INQUIRY-BASED LEARNING ON STUDENTS' COMPETENCES AND ATTITUDES TOWARDS STEM DISCIPLINES

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List of abbreviations and acronyms

NGSS - Next Generation Science Standards Organization

OECD - Organisation for Economic Co-operation and Development

UNESCO - United Nations Educational, Scientific and Cultural Organization

NRC - National Research Council

IBL - Inquiry-Based Learning

IBSE - Inquiry-Based Science Education

IBTE - Inquiry-Based Technology Education

IBS & TL - Teacher-Guided Inquiry-Based Learning of Science and Technology

NOS - Nature of Science

NOT/I - Nature of Technology/Engineering

AEE - The Association for Experiential Learning

ISTE - International Society for Technology in Education

ITEA - International Technology Education Association

NETS•S - National Educational Technology Standards for Students

PIPP IF - Pedagogy of Primary and Preschool Education - Low Frequency Attendance

PIPP Conversion - Pedagogy of Primary and Preschool Education - Conversion Course

AigS - Teacher-guided investigative activities aimed at studying topics or phenomena

AigT - Teacher-guided investigative activities aimed at performing predominantly technological tasks

AigI - Teacher-guided investigative activities aimed at interdisciplinary study (sciences and technology)

MORE - Model - Observation - Reflection - Explanation

POE - Prediction - Observation - Explanation

STEM - Science - Technology - Engineering - Mathematics

STEAM - Science - Technology - Engineering - Art - Mathematics

INTRODUCTION

Contemporary society is characterized by an accelerated development of science and technology, which profoundly influences all areas of social, economic, and cultural life. In this context, education has the responsibility to form students capable of understanding scientific phenomena, utilizing technology critically and creatively, and developing the competences necessary to adapt to the requirements of a knowledge and innovation-based society. Recent curricular reforms, oriented towards developing key competences and promoting STEM/STEAM education, highlight the need for modern, student-centered didactic approaches that stimulate active participation, critical thinking, problem-solving, and the investigation of reality.

In the field of scientific and technological education, one of the pedagogical directions that has attracted particular interest in recent decades is Inquiry-Based Learning (IBL). This approach promotes the active involvement of students in the process of building knowledge by formulating questions, exploration, experimentation, analysis, and argumentation, bringing the learning activity closer to the authentic process of scientific and technological research. Within inquiry-based learning, the student is no longer a simple receptor of information but becomes an active participant in the process of discovering and interpreting the studied phenomena.

Numerous international research studies emphasize that inquiry-based didactic strategies contribute to the development of scientific competences, critical thinking, problem-solving capacity and motivation for learning. At the same time, they favor the development of positive attitudes toward science and technology, an essential aspect in the context of declining student interest in STEM fields. However, the effective implementation of this approach in primary education faces numerous challenges generated by insufficient training of teaching staff, a lack of adequate resources, assessment difficulties, and the cognitive development characteristics of young students.

In Romania, research on the impact of inquiry-based learning on the development of scientific and technological competences of primary school students is relatively limited, especially regarding the integration of the technological and engineering dimension into learning activities. Furthermore, there are few studies that simultaneously investigate the effects of this approach on students' knowledge, skills, and attitudes toward science and technology/engineering.

Based on these considerations, this doctoral thesis aims to investigate the impact of inquiry-based learning on the development of students' scientific and technological knowledge and skills, as well as on their attitude toward science and technology/engineering. The research encompasses both the analysis of the theoretical foundations of inquiry learning and the implementation of empirical studies regarding teachers' perceptions and the effects of applying an inquiry-based learning model in primary education.

The paper is structured into nine chapters, organized into two complementary directions: theoretical foundation and empirical investigation. The first chapters analyze the fundamental concepts regarding science, technology, scientific and technological knowledge, as well as the specificity of inquiry-based learning. Relevant theoretical models, specific didactic strategies, and the benefits of using inquiry in scientific and technological education are presented. Furthermore, the particularities of applying this approach in primary education and the foundations of the model used in the formative research are analyzed.

The applied component of the thesis includes several studies dedicated to investigating the perceptions of future teachers and teaching staff regarding inquiry-based learning, the relationship between differentiated instruction and inquiry, as well as teachers' representations of technology and engineering. The central component of the research is represented by the experimental study regarding the impact of inquiry-based activities on the development of students' knowledge and skills and on their attitude toward science and technology/engineering.

The research results aim to contribute to the development of knowledge in the field of science and technology didactics and to provide theoretical and practical reference points for optimizing the educational process in primary education. Concurrently, the paper aims to highlight the importance of promoting innovative pedagogical practices, centered on investigation and exploration, capable of forming active, reflective students who are interested in scientific and technological fields.

ARGUMENT

The choice of the topic "The effects of inquiry learning on students' competences and attitudes towards STEM disciplines" is determined by the need to identify and promote efficient methods of teaching and learning in the field of scientific and technological education, adapted to the requirements of today's society and the development needs of students.

In the context of rapid transformations generated by technological progress and digitalization, the educational system is called upon to move beyond the traditional paradigm, centered predominantly on the transmission of information, and to orient the educational process towards forming 21st-century competences. The development of critical thinking, investigation capacity, creativity, collaboration and problem-solving represents fundamental objectives of contemporary education and inquiry-based learning provides a favorable framework for achieving them.

The interest in this topic was sustained both by the professional experience and concerns of the author in the field of scientific and technological education and by observations regarding the difficulties encountered by students in understanding scientific concepts and applying knowledge practically. In many situations, didactic activities carried out in school remain predominantly reproductive, with an emphasis on memorization and information reproduction, which limits the active involvement of students and the development of investigation and exploration competences.

The analysis of specialized literature highlights the existence of positive results associated with the use of inquiry-based learning, but also the need for additional research regarding the application of this approach in primary education and the integration of scientific, technological and engineering dimensions within a coherent educational framework. In the romanian educational space, studies dedicated to the impact of this method on the development of students' competences and on attitudes toward science and technology are still insufficient, which justifies the relevance and currency of the research.

The topic of this thesis is also important through its practical implications. The results of the research can contribute to grounding effective didactic strategies for teaching sciences and technology in primary education, improving the initial and continuous training of teaching staff and promoting authentic learning experiences based on exploration and discovery. Concurrently, the research can offer useful milestones for curriculum development and for the more efficient integration of STEM/STEAM-type approaches in school activity.

By investigating the relationship between inquiry-based learning and the development of students' knowledge, skills and attitudes, the paper aims to highlight the essential role of this approach in forming an authentic scientific and technological culture right from the first years of schooling. At the same time, the research supports the idea that scientific and technological education must move beyond the transmission of theoretical content and offer students real opportunities for exploration, experimentation and understanding of the world in which they live.

GENERAL RESEARCH DESIGN

The research carried out within this doctoral thesis was conceived in a phased and integrated manner, tracking the theoretical and empirical substantiation of the formative intervention based on inquiry learning. The general research design combines exploratory and descriptive studies with experimental research, aiming to investigate the impact of inquiry-based learning on students' knowledge, scientific and technological skills and on their attitude toward science and technology/engineering.

The sequence of studies was established logically and progressively, each stage contributing to the clarification of conceptual, methodological and practical aspects necessary for designing the experimental intervention. In the first stage, the theoretical foundations of inquiry-based learning, the particularities of teaching-learning science and technology in primary education, as well as the inquiry models relevant to the research were analyzed. This stage allowed for the definition of the conceptual framework and the identification of the learning model used in the formative intervention.

The preliminary studies presented in chapters 4-6 had an exploratory role and aimed to investigate the way in which teaching staff and future teachers understand and utilize inquiry-based learning, the relationship between differentiated instruction and inquiry strategies, as well as perceptions regarding the fields of technology and engineering. The results of these researches highlighted existing difficulties and needs in educational practice, but also an openness of teachers towards utilizing investigative strategies in didactic activity.

The relationship between the preliminary studies and the experimental research is one of complementarity and methodological continuity. The conclusions obtained from the preliminary investigations contributed to the elaboration of the formative intervention, the selection of inquiry-based learning activities and the adaptation of research instruments to the particularities of primary school students. Concurrently, these studies offered reference points for formulating hypotheses and for establishing the variables investigated within the pedagogical experiment.

The experimental research, presented in chapter 7, represents the central stage of the investigative process. This was conducted on two groups of students - experimental and control - and aimed to evaluate the effects of applying inquiry-based learning strategies on the development of scientific and technological knowledge and skills. Moving forward, chapter 8 completes the analysis by investigating the attitudinal dimension, respectively the way in which inquiry-based learning experiences influence students' attitude toward science, technology and engineering.

Through its structure, the research proposes a coherent and progressive approach, in which preliminary studies ground the experimental intervention and the obtained results contribute to highlighting the pedagogical value of inquiry-based learning in primary education.

CHAPTER 1. GENERAL ASPECTS OF TEACHING AND LEARNING IN NATURAL SCIENCES AND TECHNOLOGY

1.1. Science and Technology. Conceptual delimitations

The NGSS organization integrates science, the nature of science, engineering, mathematics and scientific language into its documents (2013, 2016).

1.1.1. Science

Science represents the modern form of natural philosophy and has as its object of study nature, society and thought processes. Although experiment is an important characteristic of science, scientific knowledge is also constructed through observation, induction and mental experiments.

The literature defines science as a process, study strategy, system of knowledge, discipline or field of research (Aikenhead, 2006; Britain's Science Council, 2009; Einstein & Infeld, 1938; Grayling, 2009; Schafersman, 1997). Science investigates phenomena, processes, mechanisms and causal relationships, and includes paradigms, hypotheses, principles, laws, models and theories.

According to Ziman (1980), science represents a valid source of knowledge. Complementing this perspective, Novikov and Novikov (2013) highlight three fundamental dimensions of science: it can be understood as a social institution, as a concrete outcome embodied in scientific knowledge and as a process reflected through research activity and the production of knowledge.

Science is defined as "the systematic knowledge of nature" (Aikenhead, 2006, p. 7), extending also to the social field (Britain's Science Council, 2009; Grayling, 2009). It utilizes observation, experiment, modeling and question formulation to produce evidence and explanations about reality.

Schafersman (1997) considers science a method of discovering reliable knowledge about nature and Erduran and Dagher (2014, p. 2) emphasize that understanding science also implies understanding the way we construct this knowledge.

The primary role of science is the formulation of verifiable explanations and predictions. The result constitutes a system of knowledge about objective and subjective reality, accepted by the scientific community. Thus, science is more than a collection of facts; it is a creation of the human mind (Einstein & Infeld, 1938).

The study of science contributes to understanding its cultural value, the development of knowledge and the processes of scientific thought (Klahr, 2000). The scientist is the expert who formulates and tests hypotheses, collects evidence, and contributes to the development of knowledge within the scientific community.

1.1.2. Technology

The terms "technology" and "engineering" originate from greek and latin traditions and are linked to practical knowledge (Meijers, 2009). De Vries (2018, p. 2) defines technology as the development and use of the variety of artifacts and systems existing in society. The importance of technology in modern life led to the promotion of the concept of "technological literacy". Bunge (cited by Pârvu, 1984, p. 145) defines technology as a body of knowledge compatible with science, used for the control, transformation or creation of processes and objects with a practical purpose. Technology, however, also has an important creative component.

The distinctions between the natural sciences and technology are manifested both through their subject of study and the criteria employed to evaluate their outcomes. Thus, while the natural sciences take the universe and natural phenomena as their object of research, technology focuses on human-made artifacts and systems. Furthermore, the validity of explanations and theories constitutes the primary evaluation criterion in science, whereas technology emphasizes the utility and practical efficiency of the developed solutions (de Vries, 2018).

Regarding the conceptualization of technology, Mitcham (1994, as cited in de Vries, 2018) identifies four complementary perspectives. Technology can be viewed as an ensemble of human-made artifacts and systems, as an object of study and analysis, as a process of designing, manufacturing, and implementing technical solutions, and also as a social and human value with significant implications for societal development and quality of life.

Both science and technology utilize causal reasoning, but hypo-deductive reasoning predominates in science.

1.2. Scientific and technological knowledge

Scientific and technological knowledge is based on previous knowledge and continuously evolves (Ziman, 1980; Williams, 2011). Concepts, theories, and procedures are permanently refined and developed (Novikov & Novikov, 2013).

In the field of technology, this evolution is evident through the continuous replacement of tools and processes, such as the transition from the mechanical balance scale to the electronic scale.

1.2.1. Epistemological aspects

Enăchescu (2005, p. 47) defines science as the organized totality of knowledge data about reality.

For a discipline to be classified as a science, it must possess (Enăchescu, 2005) its own distinct object of study, a specific methodology, and a specialized lexicon; it must pursue both theoretical objectives and practical utility, foster interdisciplinary relations, and exhibit a logical organization of knowledge. Furthermore, it must be grounded in its own principles and laws, possess practical applicability, provide a theoretical model of the object under investigation and demonstrate openness to progress and continuous development.

To these characteristics, Iliescu (2013) appends five fundamental criteria that substantiate the scientific character of a field: the existence of a clear and rigorously defined terminology, the quantifiable nature of the studied phenomena, the experimental control of research conditions, the reproducibility of results and the capacity to formulate empirically testable and verifiable predictions. These criteria contribute to ensuring the rigor and validity of scientific knowledge.

Pârvu (1998) and Hirghiduș (2001) explain the transition from monodisciplinarity to interdisciplinarity through the complexity of the studied objects and the trend towards integration of disciplines. Mathematics significantly contributes to the development of epistemology by providing models of structural, statistical and interdisciplinary thinking (Pârvu, 1998).

1.2.2. Scientific knowledge

Scientific knowledge has a hierarchical structure (Ziman, 1980). The OECD identifies the following categories:

(i) *Epistemic knowledge*

Targets understanding the way scientists think and work and differentiating between observations, facts, hypotheses, models and theories.

(ii) *Disciplinary knowledge*

Comprises fundamental concepts and specific language of the discipline.

Declarative knowledge encompasses the ensemble of information and cognitive structures through which objects, phenomena and real-world processes are described and explained. This includes scientific facts, which constitute descriptions of reality derived from observations and experiments, as well as concepts, defined as abstract mental representations of objects and phenomena (Ciascai, 2001; Zlate, 1999). Prototypes and typical exemplars also fall within the category of declarative knowledge, functioning as forms of representation for a specific category and facilitating the classification and comprehension of information (Miclea, 1994; Ciascai, 2001).

Furthermore, declarative knowledge includes conceptual networks, which are composed of interconnected concepts that enable the organization and integration of knowledge into a coherent system (Astolfi and Develay, 1989, as cited in Ciascai, 2001). A significant role is also played by representations, understood as cognitively processed and reorganized perceptions that contribute to the formation and utilization of knowledge (Zlate, 2006). In addition, scientific language represents an essential tool for the acquisition, communication, and conceptualization of reality, facilitating the rigorous expression of scientific ideas and findings (Enăchescu, 2005).

Scientific statements constitute another fundamental component of scientific knowledge. These include principles, which express fundamental generalizations regarding phenomena and processes (Ciascai, 2007), as well as scientific laws, which describe the observed regularities within nature and other domains of reality (Walker, 2015). Moreover, hypotheses represent provisional explanations formulated for the interpretation of certain phenomena, which can be empirically tested through research and experimentation (Walker, 2015; Ciascai, 2001).

At a higher level of knowledge organization lie scientific theories, which unify concepts, principles, laws and hypotheses into a coherent system, thereby providing explanations and predictions regarding the studied phenomena. Through their capacity to integrate and interpret empirical data, theories contribute to the advancement and consolidation of scientific knowledge (Novikov and Novikov, 2013; Enăchescu, 2005).

Theories are constantly subject to refinement and revision (Hutten, 1970; Higgins, 2004; Williams, 2011).

(iii) *Interdisciplinary knowledge*

Results from relating concepts and contents from multiple disciplines.

(iv) *Procedural knowledge* includes: observing; classifying; measuring; communicating; formulating conclusions and predictions; formulating hypotheses; variable control; experimenting; modeling; interpreting data (Ciascai, 2007; Marzano, 2007, 2009; OECD, 2019; Walker, 2015).

Essential scientific attitudes are: curiosity, skepticism, objectivity, cooperation and accepting the limits of knowledge (Ciascai, 2001).

The resulting competences include: explaining phenomena; designing investigations; interpreting data and evidence.

OECD (2019) and UNESCO also promote transdisciplinary knowledge, organized around real problems of the contemporary world.

1.2.3. Technological knowledge

Matthew (2006) emphasizes that science aims to understand the world, whereas technology aims at the practical application of knowledge.

Pârvu (1998), citing Kupers, shows that technology does not represent just the application of science, because it utilizes its own criteria for selecting and evaluating solutions.

The technologist must possess (Grubbs, Strimel & Huffman, 2018): technological knowledge; thinking skills; professional competences; values and attitudes.

The technologist's skills include: problem identification and resolution; product design; tool and material utilization; experimentation; modeling and prototyping; project management; working in multidisciplinary teams.

Concurrently, knowledge regarding the technology-society relationship, environmental impact and ethical responsibility is essential (ITEA, 2007).

1.3. Scientific and technical thinking and knowledge processes

Knowledge processes, for instance scientific or technical ones, are grounded in critical thinking. Practicing them develops thinking skills in general and critical thinking skills in particular, for the person undergoing instruction.

Critical thinking - foundation of scientific and technical thinking

Critical thinking is considered the base of scientific thinking (Paul & Elder, 2018; Schafersman, 1997). It involves: identifying assumptions; identifying evidence; checking their validity; analyzing alternatives; decision making.

Cottrell (2005) lists skills such as: evaluating arguments; identifying erroneous assumptions; logical reflection; formulating conclusions; synthesizing information; arguing own positions.

Values promoted by critical thinking are: clarity, accuracy, relevance, consistency, depth, and fairness (Sen, 2010).

Advantages include: more sophisticated analyses; identifying information relevance; developing cognitive flexibility; formulating more rational conclusions (Osborne et al., 1996; Sen, 2010).

1.3.1. Scientific and technical thinking

Scientific thinking is closely connected to the scientific method and can be practiced by anyone trained in its application. Paul and Elder (2018) identify the fundamental intellectual standards of scientific thinking: clarity, accuracy, relevance, logic, precision, depth, significance, fairness. A proficient scientific thinker systematically formulates relevant questions, collects and interprets data, draws evidence-based conclusions, evaluates hypotheses and their implications and communicates results effectively (Paul & Elder, 2018).

1.3.2. The process of scientific knowledge

Pera, as demonstrated by Magnusson, Sullivan, Palincsar, and Templin (2004) when referencing Descartes' (1628) views on scientific knowledge, conceptualizes the process of scientific inquiry as ”a game with two players: the interested scientist who asks questions and nature providing the answers”, whereby the resulting scientific knowledge represents ”the voice of nature”.

According to Ciascai (2018), the process of scientific inquiry typically unfolds in stages, commencing with an encounter with a question or a problem identified within daily life, academic readings, or other learning contexts. This is followed by the stage of observation and data collection, which may target living or non-living entities, facts, processes, or phenomena, yielding either qualitative or quantitative data. The collected information is subsequently analyzed and processed to identify regularities and patterns, thereby enabling the development of an explanatory model of the phenomenon or process under investigation.

Based on these analyses, hypotheses, predictions and provisional explanatory models are formulated. A hypothesis represents an anticipated answer to the investigated problem, whereas a prediction indicates a possible evolution or manifestation of the analyzed phenomenon. The subsequent stage consists of testing the hypotheses and models through observations, experiments, mathematical demonstrations or other research methodologies, occasionally employing a trial-and-error strategy. Throughout this process, the control of variables is essential to ensuring the validity of the obtained results.

Depending on the outcomes of the testing phase, hypotheses may be either confirmed or rejected. The confirmation of a hypothesis requires the replication of experiments to increase the degree of certainty, whereas its rejection necessitates the reformulation of the hypothesis and the resumption of the investigation. An indispensable phase of scientific research is the communication of results to the scientific community, which facilitates the verification and replication of studies by other researchers. Ultimately, based on the formulated conclusions, the explanatory model of the phenomenon or process may be modified, expanded or invalidated, thereby contributing to the progress and consolidation of scientific knowledge.

There are several graphical models of the process of scientific inquiry, some of which are predominantly linear, while others are cyclical. In the present study, we shall refer to a linear model, namely the inductive model (Figure 1.1)

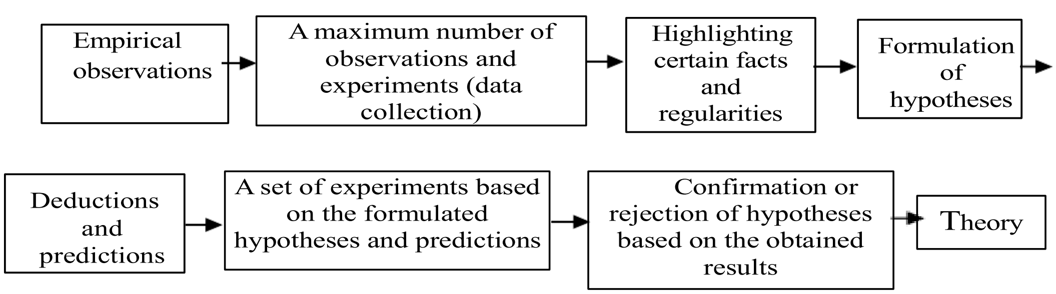

Figure 1.1. Inductivist perspective on the scientific knowledge process (Ciascai, 1999, p. 40)

Ciascai (2018) criticizes the linear inductivist model because the relationships between observations, hypotheses and theories are not strictly linear. The source cited also critiques the relationship between the facts obtained through observation or experimentation and the confirmed patterns/models of development, respectively the theory (Figure 1.2).

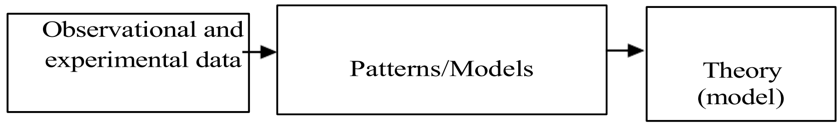

Figure 1.2. Inductivist model of the scientific knowledge process

While the model highlights the transition from observations and facts toward the formulation of theories, it fails to capture the complexity of the actual process.

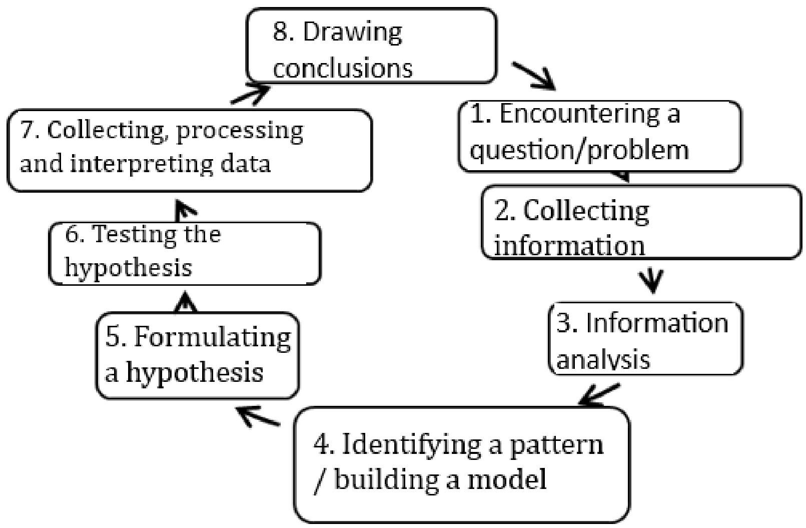

Figure 1.3. Cyclic model of the scientific knowledge process

Ciascai (2018) proposes a cyclical model in which observation, documentation, hypothesis formulation, experimentation and data interpretation mutually influence one another, allowing for the reiteration of stages when the results do not confirm the hypotheses.

1.3.3. The technological process

The technological process entails the utilization of both technical and critical thinking in order to identify and resolve practical problems. According to Kuziev (2019), technical thinking is comprised of three fundamental components: the conceptual component, which facilitates the comprehension and organization of ideas; the figurative component, which enables the mental representation and visualization of solutions; and the practical component, oriented toward the concrete application of knowledge in the creation of products or systems.

The technological process unfolds in two major stages: design, and implementation and evaluation, respectively. The design stage begins with problem identification, continuing with its investigation and the establishment of criteria that the proposed solution must meet. Subsequently, multiple alternative solutions are generated, from which the optimal solution is selected. This is materialized through the development of a model or prototype, which is then subjected to testing. The obtained results are critically evaluated and analyzed, and, when necessary, successive revisions and retestings are performed to optimize the product. The design process concludes with the presentation of the final solution.

The second stage, implementation and evaluation, aims at the actual application of the developed solution and the appraisal of the degree to which it satisfies the initially established requirements and objectives. Through this iterative process of design, implementation and evaluation, the functionality, efficiency and utility of the realized technological products or systems are ensured.

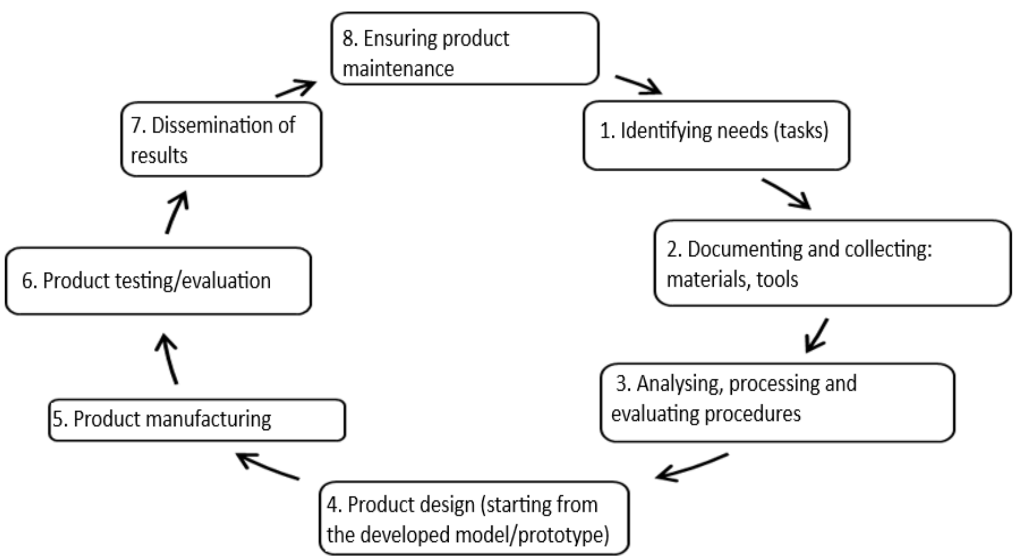

Figure 1.4. Cycle of the technological process for making a product

In the initial stage, the technologist is confronted with the task to be executed, which addresses a specific need that must be thoroughly understood and clarified. Once the problem or task is fully comprehended, the technologist must gather the necessary information. Their work is significantly facilitated if the technological product constitutes a component of an overarching assembly designed by an engineer. Conversely, it remains the technologist's responsibility to process the collected data and develop, if applicable, either a product prototype or the final product directly. Both the prototype and the final product are subsequently subjected to evaluation to assess compliance with the initial requirements, verify functional performance, and determine whether the design requires refinement or improvement.

CHAPTER 2: LEARNING SCIENCE AND TECHNOLOGY THROUGH INQUIRY

2.1. Inquiry/Survey. Conceptual clarification

The terms inquiry and enquir*y* are frequently confused in the english language. Both refer to investigative practice. In American English, inquiry is a noun denoting interrogation or questioning. In British English, inquiry specifically refers to a formal investigations conducted by government, police, scientists, etc. The term enquiry has the same meaning, but is reserved for less formal investigations (Oxford Dictionary, cited in Kidman & Casinader, 2017).

2.1.1. Conceptual delimitations

Inquiry and research are closely related concepts that share the common objective of advancing knowledge; however, they diverge in the emphasis they place on process versus outcomes. Inquiry focuses primarily on the exploration, investigation and examination of knowledge in response to questions or problematic situations, thereby stimulating curiosity, reflection and discovery. In contrast, research is oriented toward validating claims, testing hypotheses and demonstrating empirical truths through the systematic collection, analysis and processing of information. Consequently, while inquiry underscores the process of investigation and understanding, research seeks to achieve scientifically grounded conclusions and verifiable results.

Hammerman (2006, p. XXIII) defines inquiry as "a process of asking questions within a context of wonder, investigation, and the modeling of possible conclusions". Inquiry/survey is also different from discovery: inquiry is a structured, teacher-guided framework anchored in collaboration and social interaction, while discovery is less structured, open-ended and based primarily on unguided trial and error (Aulls & Shore, 2008; Hmelo-Silver et al., 2007; Mayer, 2004, as cited in Saunders-Stewart, Gyles, & Shore, 2012). Thus, inquiry-based learning is distinguished from experiment (Walker, 2015). School-based experiments typically aim to verify a predefined hypothesis and yield predictable outcomes. Within this framework, the teacher dictates the structure and procedures, thereby limiting students' decision-making autonomy. In contrast, inquiry entails the formulation and investigation of authentic questions, where the exploration process and student agency in decision-making are paramount (Walker, 2015).

The concept is compatible with the constructivist perspective and Piaget's theories, according to which knowledge is actively constructed by the student and not simply transmitted by the teacher. Inquiry facilitates the construction of concepts through direct experience and verbal interaction (Tamir, 1985).

The author believes that translating the term *inquiry* as "survey" is inappropriate in the Romanian language and proposes the use of the expression investigation based on questions, or, in its simplified form, investigation.

2.1.2. Inquiry. Historical context and evolution

Inquiry/survey is a term employed both within educational frameworks (asking questions) and in everyday life (I wonder …). The concept refers to two distinct contexts: (a) seeking information or explanations through the formulation of questions (Harlem, 2013, as cited in Gholam, 2019) and (b) possessing the capacity to engage in a question-based investigation or process. Poon and Lim (2014) attribute the concept and its application to Dewey, citing his 1909 work entitled "Science as Subject-Matter and as Method". Dewey advances the thesis that science education must mirror the authentic manner in which scientific knowledge is generated. This perspective is grounded in the paradigm shifts of the sixteenth and seventeenth centuries, when observation and experimentation replaced purely speculative explanations. As Hooke (1665, as cited in Magnusson, Sullivan, and Templin, 2004, p. 132) stated that: "The science of nature has been already too long made only a work of the brain and the fancy: it is now high time that it should return to the plainness and soundness of observations on material and obvious things".

Inquiry involves "interrogating" nature through controlled observations, explorations, experiments and investigations.

According to Hammerman (2006), teachers who effectively utilize this pedagogical approach possess profound subject-matter knowledge and well-developed pedagogical competencies, which enable them to appropriately organize and manage the learning process. Furthermore, they comprehend the difficulties and obstacles that students may encounter during learning and constantly aim to develop an authentic and sustainable understanding of the studied content. Another essential aspect is the capacity to foster environments conducive to reflection and metacognition, stimulating students to analyze their own thinking processes, monitor their learning and cultivate intellectual autonomy.

Addelin and Catarina (2018) identify further characteristics of the IBL approach (adapted): it assigns equal importance to both process and content; continuously stimulates curiosity; leverages students' questions; promotes teacher-student negotiation and collaboration; connects new knowledge with prior experiences; fosters collaboration and learning within authentic contexts; supports reflection and metacognition; utilizes formative assessment and self-assessment; and encourages the formulation of subsequent questions.

2.1.3. The culture of inquiry

Hammerman (2006) introduces the concept of inquiry-based learning science to subsequently facilitate the transition toward classrooms that use inquiry. Llevellyn (2011, p. 1) expands the scope of inquiry-based learning from the individual classroom level to the classroom culture, defining it as a ”classroom culture of inquiry”.

Alberta Learning (2004, p. 2) defines the components of an inquiry culture extended to the institutional school level: the shared vision; change agents (the involved educators); the requisite resources; teacher collaboration in developing necessary instructional materials; the development of problem-solving strategies fostered within an inquiry environment; team teaching; and the active involvement of administrators to secure the framework and resources essential for inquiry activities.

2.2. Inquiry-based learning

2.2.1. Defining the concept of inquiry-based learning (IBL)

IBL is an instructional practice in which learners are positioned at the center of the educational experience, designing their own learning trajectories and assuming responsible ownership over them (self-directed learning, according to Smith & Walker, 2010 and Bell, Smetana and Binns, 2005, as cited in Gholam, 2019). Furthermore, learners actively construct and assign meaning to knowledge (Caswell & LaBrie, 2017). Within this context, students develop a comprehensive suite of skills, ranging from formulating questions and generating answers to critical, analytical, synthesis and investigative skills, as well as problem-solving, collaboration and communication capabilities (Maxwell, Lambeth and Cox, 2015, as cited in Gholam, 2019). Saunders-Stewart, Gyles and Shore (2012) take into account the manifold iterations of IBL, noting that it fundamentally encompasses analysis, problem-solving, discovery and creative thinking.

NRC (1996), Naish et al. (1987), and van Drie and van Boxtel (2007) describe the inquiry process (Kidman & Casinader, 2017, p. 5) through nine distinct stages: (1) making observations; (2) posing questions; (3) examining books and other sources of information to see what is already known; (4) planning investigations; (5) reviewing what is already known in light of experimental evidence; (6) using tools to gather, analyze and interpret data; (7) proposing answers, explanations and predictions; (8) communicating results; and (9) personal evaluation and response. In our view, this process must be guided by a succession of formulated, revised, clarified and communicated answers (indicated in italics within the cited authors' list of activities). Furthermore, we propose reversing stages 5 and 6 and reorienting stage 9 toward process evaluation and self-assessment. From our perspective, the inquiry process consists of traversing the following stages:

1. Initiating an investigation: posing questions, making observations, recalling facts from personal experience, etc.
2. Prefiguring answers (anticipating potential answers and selecting specific ones based on pre-established criteria/requirements).
3. Documentation: (i) from textbooks, encyclopedias and volumes from other information sources to find out what is currently known regarding the formulated observations and questions; (ii) from the replication of observations; or (iii) from new observations. Documentation concludes with the collection of information considered necessary for clarifying questions and formulating explanations.
4. Analyzing, organizing and sorting information: refining and clarifying questions and answers/explanations based on pre-established criteria or requirements and designing one or more investigations (see stage 5).
5. Designing investigations: (predominantly guided observations and experiments) grounded in the knowledge and answers with which the documentation stage concludes.
6. Utilizing tools: gathering, analyzing and interpreting data.
7. Reviewing what is already known: in light of the data/evidence obtained from observations and experiments.
8. Synthesizing knowledge: developing answers, explanations and predictions.
9. Communicating results and/or applying the obtained knowledge: to new or different situations.
10. Process, product and results evaluation, along with the self-assessment of work.
11. Reflecting on learning.

The integration of the inquiry-based approach into the learning process is based on a series of principles that place the student at the center of the educational activity. In this context, teachers, resources and technology are organized in such a way as to support and facilitate the learning process of students. The proposed activities stimulate reflection, critical thinking and the use of information processing skills, encouraging students to analyze, interpret and valorize data actively. At the same time, students are directly involved in carrying out the work tasks and collaborate with colleagues to build and deepen their knowledge.

Assessment, within this approach, focuses not only on the final results, but also on the students' ability to process information and data, as well as on their level of conceptual understanding. The knowledge and skills developed often exceed the limits of a single discipline, having an interdisciplinary and transdisciplinary character. Teachers also seek to better understand how students think and process information, using this information to adapt teaching strategies. At the same time, they are concerned with their own professional development, continuously improving their skills necessary to design and implement an inquiry-based learning process.

2.2.2. Typology and hierarchy of IBL activities

Schwab (1962, cited in Walker, 2015) proposes three levels of inquiry, differentiated by who formulates the problem, establishes the method and interprets the results.

Later, Heron and Schwab (1971) develop a model with six levels: asking questions, designing, implementing the project, analyzing data, formulating explanations and conclusions, reporting, applying knowledge.

Llevellyn (2011) introduces only four levels of inquiry: the demonstrative level, the structured level, the guided level and the level of student initiation and management of inquiry-based learning.

The role of the teacher within the various types of inquiry varies depending on the degree of autonomy granted to students and the nature of the learning activities. Thus, within confirmation or demonstrative inquiry, the teacher's role is to present and explain knowledge, providing a clear model for comprehending the content. In structured inquiry activities, the teacher transitions into a coach who supports students in understanding procedures and executing learning tasks. In the case of guided inquiry activities, the teacher acts as a facilitator, guiding students through the problem-solving process and supporting the development of autonomous thinking. Ultimately, within open or student-initiated and managed inquiry activities, the teacher fulfills the role of a mentor, offering support in discovering answers and solutions to complex questions and problems (ibid.).

2.2.3. Strategies used in inquiry-based learning

The learning strategies most frequently promoted within inquiry-based learning include: questioning and heuristic conversation, problematization, problem solving, exploration, experimentation, project-based learning, outdoor learning (conducted in nature, museums, or various institutional settings), and the flipped classroom. Group work, as a learning context, facilitates students' exchange of ideas, the argumentation of perspectives and the selection of solutions.

2.2.4. Assessment in inquiry-based learning activities

Assessment is integrated throughout all stages of the investigation, targeting both the process and the final outcome. Three distinct dimensions are highlighted: assessment for learning, assessment as learning and assessment of learning.

The recommended methods include: observation, heuristic conversation, projects, portfolios, self-assessment and reflection. Assessment fulfills a formative role and contributes to the continuous regulation of the learning process.

2.3. Models of inquiry-based science and technology learning

This subchapter presents the primary pedagogical models used in inquiry-based education. The following are analyzed: the 5E model (Bybee, 2009); the 7E model (Eisenkraft, 2003); the MORE model (Tien, Rickey, & Stacy, 1999); the POE model (Champagne, Klopfer, & Anderson, 1980); the Magnusson, Palincsar, and Templin model (2006); the Walker model (2015); the Prince and Felder model (2006); the Kuhlthau, Maniotes, and Caspari model (2012).

The 5E model comprises five distinct stages: Engage, Explore, Explain, Elaborate and Evaluate. It is widely considered one of the most extensively utilized models for implementing inquiry within science education.

Kuhlthau, Maniotes and Caspari (2012) identify the following stages regarding the design process of teacher-guided inquiry:

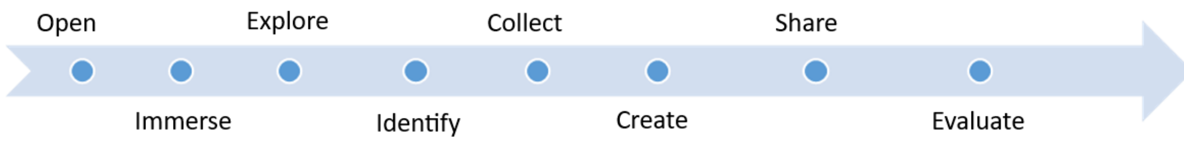

Figure 2.2. The Inquiry/guided survey design process

The model emphasizes the progressive construction of questions and the development of student autonomy.

2.4. Benefits and challenges of using inquiry

According to Pickford and collaborators (2013), inquiry-based learning stimulates the development of higher-order cognitive skills within Bloom's taxonomy, namely analysis, synthesis, evaluation and critical thinking.

Llevellyn (2011) highlights the distinct advantages and limitations associated with each type of inquiry:

Demonstrative inquiry allows for the modeling of the teacher's thinking, maintaining high structural control over the activity and ensuring increased safety. A notable disadvantage stems from the fact that the educator operates at their own pace, making these demonstrations difficult to follow for certain students.

Structured inquiry fosters the gradual development of investigative competencies and organizational efficiency. However, a significant drawback is the student dependence on the teacher, which tends to be cultivated through this particular mode of inquiry organization.

Guided inquiry enables the development of autonomy, the practice of research specific processes and the cultivation of creativity and reflection. Although the trials involved can be highly time-consuming, presenting a potential disadvantage, the targeted involvement of the teacher in guiding student activity can reduce this temporal constraint.

Student-initiated and student-led activities offer the advantage of leaving all procedural steps required by the Inquiry/survey process entirely to the students' discretion. The author concludes that the implementation of inquiry activities should be carried out progressively, starting with demonstrative and structured activities and continuing with guided and open-ended activities, as students develop the skills necessary for autonomous investigation. A distinct disadvantage, however, lies in the extensive time consumption that can arise due to the difficulty of the problem under investigation. The author concludes that the implementation of inquiry activities must be executed progressively, starting with demonstrative and structured activities, and moving toward guided and open activities as students cultivate the competencies necessary for autonomous investigation.

CHAPTER 3. TEACHER-GUIDED INQUIRY-BASED LEARNING OF SCIENCE AND TECHNOLOGY IN PRIMARY EDUCATION (IB S&T L)

The study of Science and Technology in primary education must be adapted to the students' cognitive and experiential development level. According to Kidman and Casinader (2017), drawing upon the perspectives formulated by the NRC (2000) and Roberts (2013), science and technology education addresses three fundamental objectives. Firstly, it aims to develop knowledge regarding the work of scientists, technologists and engineers, as well as to cultivate an understanding of the nature of science (NOS) and the nature of technology/engineering (NOT/E). Secondly, it targets the comprehension of inquiry as both a theoretical and practical process of knowledge construction. Thirdly, science and technology education pursues the acquisition of the scientific and technological knowledge necessary to interpret and explain the surrounding world.

These objectives highlight the importance of active learning and engaging students in authentic processes of exploration and discovery.

3.1. The study of science in primary school

In the literature, the investigative process specific to science is known as the scientific method. Staddon (2018) considers it the way scientific ideas are discovered and evaluated, while Shermer (1995) defines it as the set of rules through which humans attempt to understand the world.

In primary education, the scientific method can be grounded in three main types of reasoning, each playing a distinct role in the formation of scientific thinking. Inductive reasoning entails starting from observations and explorations, continuing with data collection and interpretation, identifying regularities, and ultimately formulating a hypothesis or an explanatory theory. Deductive reasoning involves formulating a hypothesis based on existing premises or observations, followed by the collection and analysis of data that lead to its confirmation through empirical evidence. Hypothetico-deductive reasoning, considered the most frequently utilized model in primary education and the basis of the scientific method as described by Hackett et al.

(2008) and Ciascai (2001), combines the formulation of hypotheses with their systematic testing by deducing verifiable consequences and validating them through empirical investigation.

The scientific method based on hypothetico-deductive reasoning includes the following stages: formulating observations and questions; generating hypotheses; identifying variables; designing the experimental framework; conducting the experiment; gathering data and empirical findings; drawing conclusions and formulating explanations; reformulating the hypothesis when the empirical results fail to support it.

The teacher plays an essential role in guiding this process, especially in supporting the hypothesis formulation and orchestrating experimental activities.

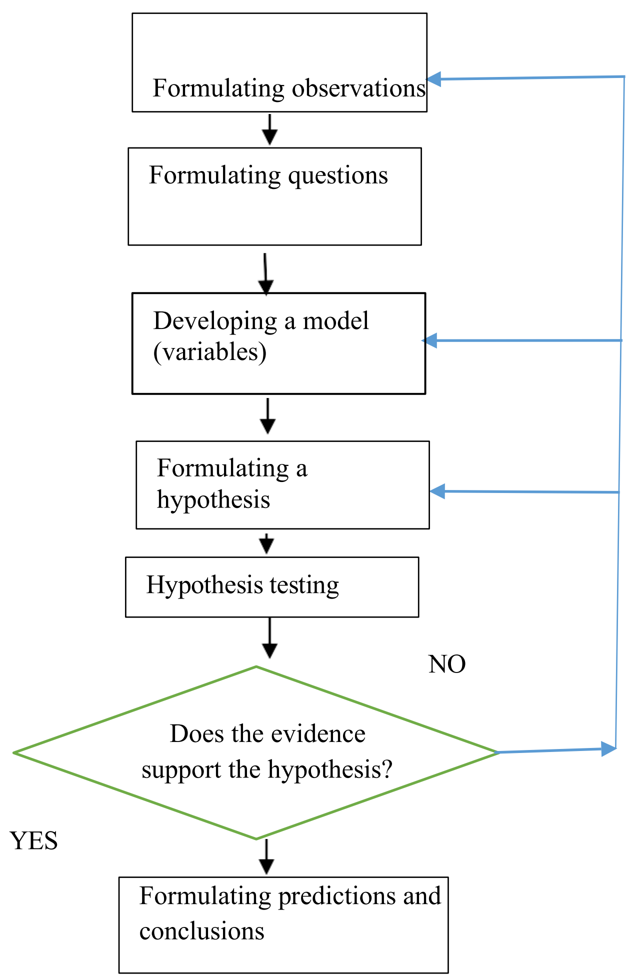

Figure 3.1. The scientific method in the primary cycle (hypothetico-deductive approach)

The figure illustrates the cyclical nature of scientific inquiry and highlights the relationship between observations, hypotheses, experiments and conclusions.

According to Johnston (2011), adapted by Ciascai (2018), the classical model of the scientific method is expanded into a multi-cyclical process, structured into five interdependent stages. The first stage, exploration, involves students observing phenomena, posing questions, classifying information and generating initial explanations and hypotheses. This is followed by the planning stage, during which the investigation's objectives are established, necessary resources are selected, variables are identified and procedures for measurement and data collection organization are defined. In the investigation stage, students implement the research plan, conducting data collection activities and managing the variables involved. The fourth stage, data interpretation, entails analyzing the obtained data and making decisions regarding the continuation, modification, or replication of the investigation, based on the drawn conclusions. Finally, the communication stage consists of presenting and defending the results before others, thereby contributing to the validation and dissemination of knowledge. This model highlights the significance of reflection and the iterative nature of the research process, in which the investigation is continuously reviewed and refined based on the newly acquired information.

Gillespie and Gillespie (2007) emphasize that authentic inquiry begins with the formulation of relevant questions by students. High-quality questions facilitate hypothesis formulation, experimental planning, prediction generation, data collection and organization, results analysis and the drawing of conclusions. Sequentially, these competencies contribute to the development of critical thinking and intellectual autonomy.

In early primary grades, formulating hypotheses can present a significant challenge. For this reason, discovery-based learning is considered more appropriate.

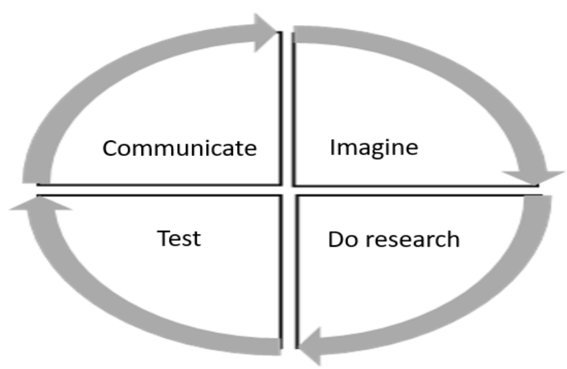

Figure 3.2. The cycle of learning through exploration

The exploratory learning cycle highlights: direct contact with the object or phenomenon; observation; the formulation of ideas; the testing of these ideas; the construction of explanations.

Johnston (2011) believes that exploration is inherently associated with experiential learning and the authentic development of comprehension.

The Association for Experiential Education (AEE) defines experiential learning as the process through which students construct knowledge and values from direct experience (Wurdinger & Marlow, 2005). Kolb's model includes four distinct stages: Concrete Experience; Reflective Observation; Abstract Conceptualization; Active Experimentation.

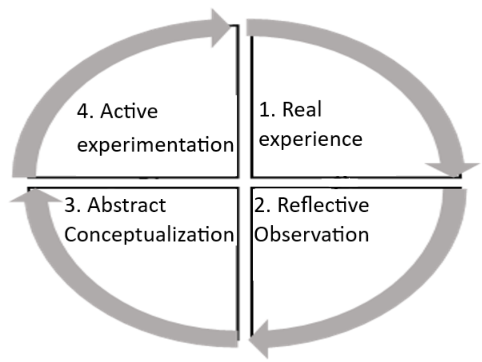

Figure 3.3. The cycle of experiential learning

The experiential learning cycle presents the relationships among these four stages and the role of reflection in knowledge construction.

Ciascai (2007) highlights the presence of alternative conceptions (”misconceptions”) that influence science learning. These originate from various sources within children's daily experiences and learning environments. They may come from simplified explanations provided by adults, the inaccurate or improper use of concepts in everyday language, the influence of movies and stories, as well as the children's own personal experiences, which contribute to the formation of intuitive representations of reality. Identifying and addressing these alternative conceptions constitutes a paramount task for the educator.

3.2. The study of technology in primary education

Technological activities involve resolving practical problems by utilizing a variety of materials, such as clay, wood, textiles, metal and plastics, among others (Makyia & Rogers, 1992). These problems can be classified as: closed-ended (with a unique solution); open-ended (with multiple solutions); technical; technological; or investigative. Such activities foster the development of critical thinking, divergent thinking, convergent thinking, creativity and evaluative capacity.

According to ISTE (2000) and ITEA (2007), technology education aims to develop competencies regarding: the nature of technology; the relationship between technology and society; the design process; technological abilities; technological subfields. Students must cultivate skills in engineering design, implementing a design process, utilizing and maintaining technological products and systems and assessing/evaluating the impact of these products and systems.

The process of technological and engineering knowledge acquisition is, much like the scientific process, inherently cyclical. For instance, Albion et al. (2018) present the following cycle of a technological activity (Figure 3.4, adapted for formal school learning):

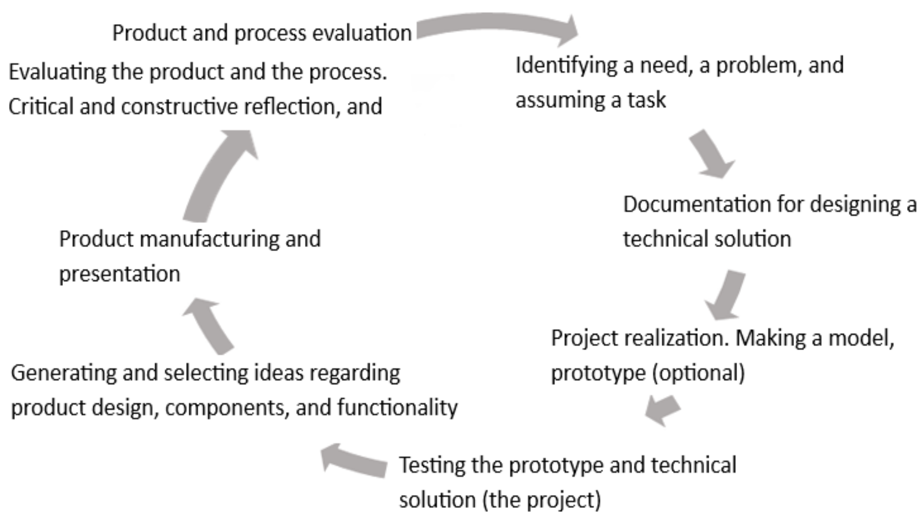

Figure 3.4. The cycle of a technological activity performed in school activities (adapted by Ciascai, 2018 from Albion et al., 2011)

3.3. Inquiry-based learning in primary education

Dewey considered learning as an active process, based on experience and interaction. Inquiry-based activities must be highly relevant to students' lives and based on their interests.

3.3.1. Identifying an Inquiry-Based Learning Model

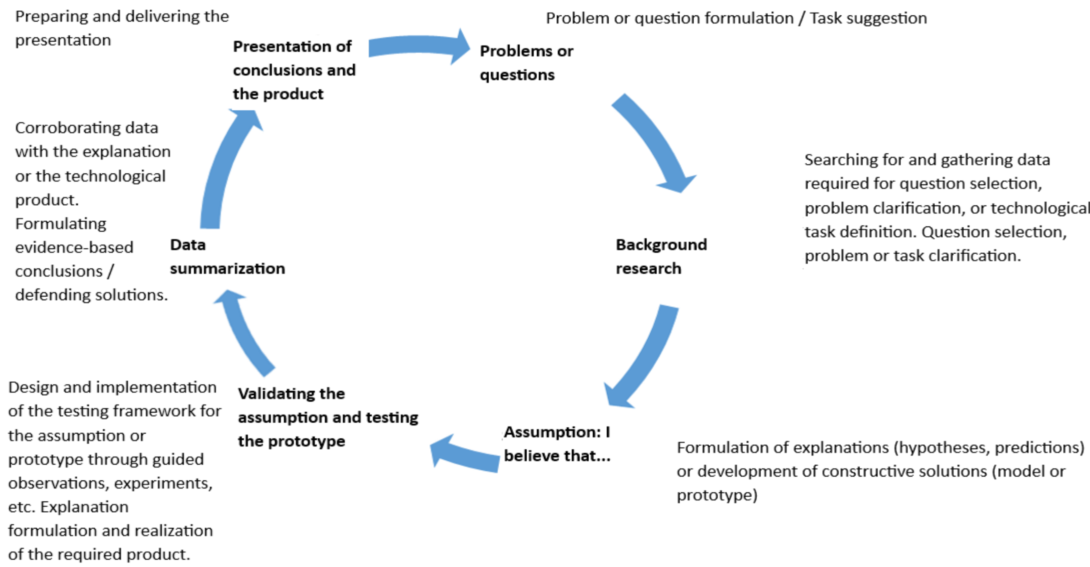

Figure 3.5. Guided inquiry-based learning model for primary education

A stage of critical reflection has been appended to this model; although not represented in the figure as it is not process-specific, it addresses any student endeavor. During this stage, students reflect both on the outcome of their work (the substantiated explanation or the technical solution) and on the investigative process itself (obstacles encountered, overcoming challenges, etc.). The review of the inquiry process is conducted to identify both strengths and weaknesses, as well as to formulate recommendations for future planning.

The research conducted is grounded in the teacher-guided inquiry approach, which is more accessible to primary school students.

Research objectives

The general objective of the present doctoral thesis is to investigate the impact of inquiry-based learning on the development of primary school students' scientific and technological knowledge and skills, as well as on their attitudes toward science, technology and engineering.

To achieve this general objective, the research aims to analyze the theoretical and methodological foundations of inquiry-based learning and to highlight the role of this approach in science and technology education. Furthermore, the thesis aims to identify the specific features of the science and technology teaching-learning process in primary education and to analyze the inquiry models utilized in instructional activities.

Another objective of the research consists of investigating the perceptions of future teachers and teachers regarding the utilization of inquiry-based learning strategies, alongside analyzing the relationship between differentiated instruction and inquiry approaches. Furthermore, the study aims to explore teachers' perceptions of the fields of technology and engineering, as well as the manner in which these are integrated into primary education.

The thesis also proposes the design and implementation of an inquiry-based formative intervention tailored to the specific developmental characteristics of primary school students, with the aim of fostering their active engagement in the learning process and developing competencies specific to science and technology education.

A central objective of the research is to evaluate the effects of inquiry-based activities on the development of students' scientific and technological knowledge and skills. At the same time, the study seeks to analyze the influence of this approach on students' attitudes toward science, technology and engineering by identifying changes in their interest, motivation and openness toward STEM fields.

The research aims to formulate pedagogical conclusions and recommendations regarding the integration of inquiry-based learning strategies into instructional practices in primary education, with a view to optimizing the educational process and cultivating the competencies required by contemporary society.

CHAPTER 4. (STUDY 1) UNDERSTANDING AND IMPLEMENTATION OF INQUIRY-BASED LEARNING BY FUTURE TEACHERS IN PRESCHOOL AND PRIMARY EDUCATION

4.1. Introduction

Inquiry-Based Learning (IBL) is a student-centered approach that fosters critical thinking, investigative competencies, and autonomy in learning. Although it is widely considered effective and is actively promoted within teacher education programs, its practical implementation often remains inconsistent.

IBL involves activities similar to scientific research, such as posing questions, investigating, formulating and testing hypotheses and communicating results. Within the framework of initial teacher training, it is crucial to analyze how future teachers understand and utilize this model when designing instructional activities.

4.2. Theoretical framework

The concept of *inquiry* is associated with investigation, discovery and problem-solving (de Jong et al., 2021). Distinct from discovery-based learning, inquiry entails the formulation and validation of explanations grounded in the obtained data (Pedaste et al., 2015).

According to the NRC (1996), inquiry represents both the modality through which scientists study the natural world and formulate evidence-based explanations and the diverse activities through which students come to understand the work processes of researchers. Justice et al. (2007) define inquiry as an ensemble of educational practices that facilitate learning.

Inquiry is conceptualized both as a process of knowledge construction and a constructivist methodology (Justice et al., 2007), as well as an educational outcome and a learning method (NRC, 2000).

According to Bybee (2002), inquiry can be understood from three complementary perspectives. Firstly, it is associated with the scientific content that students must comprehend and assimilate. Secondly, inquiry is viewed as a set of cognitive skills implicated in the process of investigation, analysis and data interpretation. Thirdly, it constitutes an instructional method through which educators facilitate the active construction of knowledge and the development of scientific thinking.

4.3. Research purpose and questions

Research purpose

The purpose of this study is to analyze how future pre-school and primary school teachers comprehend and apply the inquiry cycle when designing instructional activities.

Research Questions

1. Which stages of the inquiry cycle do future teachers implement more easily and where do they encounter difficulties?
2. To what extent do future teachers who participated in the training session on the inquiry-based model succeed in integrating the stages of this framework into a coherent investigative process?

4.4. Methodology

The type of research

This study employs a descriptive/non-experimental design, aiming to analyze students' understanding and application of the inquiry cycle without any experimental intervention.

4.4.1. Participants

A convenience sampling method was utilized, including 124 students enrolled in the distance learning program within the Pre-school and Primary School Pedagogy specialization.

4.4.2. Data collection

Data were collected within the course "Science and Science Teaching Methodology" and involves five hours of instruction (two lecture hours and three seminar hours).

4.4.3. Research instruments and procedure

Following the study of inquiry-based learning, students were assigned an assessment task that required them to explain an inquiry cycle for a scientific content area of their choice, within a one-week deadline. For the analysis of the students' assignments, an evaluation rubric developed by the researchers was employed, consisting of 11 items evaluated on a five-point scale (0 =

missing response, 1 = incorrect response, 2-4 = progressive levels of correctness). The instrument demonstrated high internal consistency ($\alpha = 0.979$). The items targeted the primary stages of the inquiry cycle: formulating research questions, documentation, hypothesis formulation, hypothesis testing and summarizing and communicating results.

4.4.4. Data analysis

The data were analyzed using descriptive and inferential statistical methods. The normality of the distribution was assessed using the Kolmogorov-Smirnov test, which revealed significant deviations from normality ($p < 0.05$). Consequently, non-parametric tests were applied. To analyze the relationships between variables, Spearman's rank correlation coefficient was employed.

4.5. Results

The analysis of the data presented in Table 4.1 highlights significant differences among the stages of the cycle inquiry regarding the students' level of performance.

Table 4.1. Results obtained for the evaluation rubric items and their processing

Item / Score	N	m	Mode	Median	SD	1	2	3	4	Missing answer
The research questions are clear	124	1.56	1	1	0.83	58.87%	29.03%	6.45%	4.84%	0.81%
The research questions are varied	124	1.56	1	1	0.84	58.87%	28.23%	7.26%	4.84%	0.81%
The research questions cover the theme	124	1.57	1	1	0.83	57.26%	30.65%	6.45%	4.84%	0.81%
Documentation is structured on important aspects	124	1.69	1	2	0.81	46.77%	37.90%	11.29%	3.23%	0.81%
Documentation is guided by the initially formulated questions	124	1.68	1	1	0.84	50%	33.87%	11.29%	4.03%	0.81%
The assumption is correctly formulated	124	1.96	1	2	0.94	37.90%	31.45%	24.19%	5.65%	0.81%

The assumption is based on knowledge acquired through documentation	124	1.92	1	2	0.93	39.52%	32.26%	21.77%	5.65%	0.81%
Testing is correlated with the assumption	124	2.38	3	3	1.15	33.06%	11.29%	37.10%	17.74%	0.81%
Summarization integrates knowledge obtained through documentation and testing	124	1.81	2	2	0.83	38.71%	44.35%	11.29%	4.84%	0.81%
Communication is structured and highlights important knowledge	124	1.64	1	1	0.79	50%	37.10%	8.87%	3.23%	0.81%
Communicated knowledge is clearly and correctly presented	124	1.63	1	1	0.78	50%	37.90%	8.06%	3.23%	0.81%

The primary findings indicate that the highest performance is recorded in the formulation of research questions, where the mean values (m ≈ 1.56–1.57, SD ≈ 0.83–0.84), point to approximately 57%–59% correct responses. Documentation is executed relatively accurately; however, it is not always rigorously guided by the formulated research questions (M approx 1.68–1.69), yielding a correctness rate of roughly 46%–50%. Conversely, hypothesis formulation presents a significant challenge for the participants (m ≈ 1.92–1.96, SD ≈ 0.93–0.94), with only 38%–40% correct responses.

The most problematic stage involves the correlation between the hypothesis and its subsequent testing, which exhibits the highest mean score (M = 2.38), (SD = 1.15); here, the cumulative percentage of partially correct and incorrect responses exceeds 50%, thereby signaling major difficulties in the coherent application of the scientific method. In contrast, summarizing and communicating results are performed better when compared to the core stages of the process (M approx 1.63–1.81), suggesting stronger performance in the final phases of the activity rather than in those dedicated to generating and testing hypotheses.

The results point to a fragmented understanding of the inquiry cycle, characterized by high performance in the initial and final stages, and conversely, low performance in the central stages.

4.6. Discussions

The results presented in Figure 5.1 highlight a differentiated pattern of student performance in relation to the stages of the inquiry cycle.

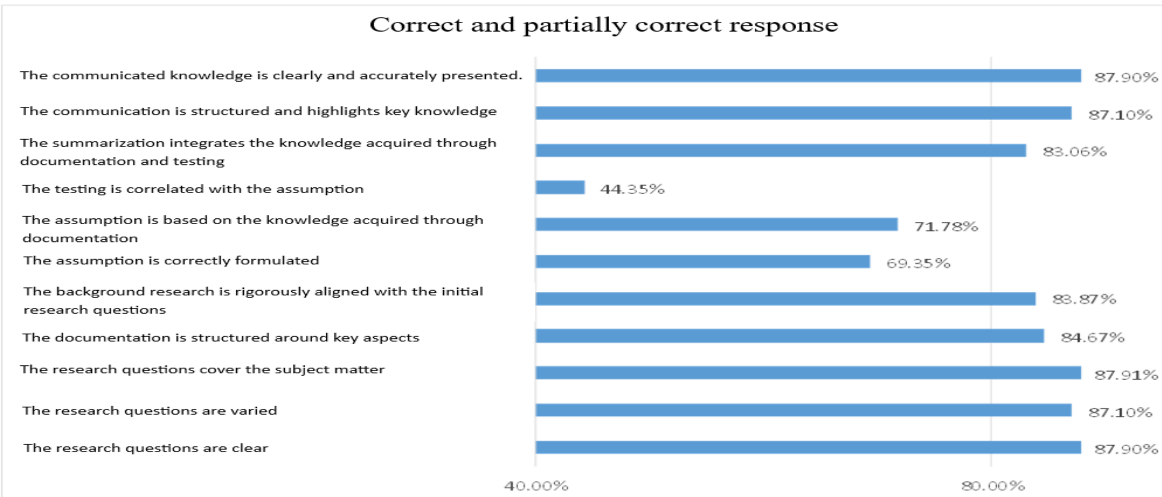

Figure 4.1. Results obtained on the evaluation grid items regarding correct and partially correct responses

The interpretation of the results highlights a high level of performance across most stages of the investigative process. Specifically, correct and partially correct responses exceed 87% in the formulation of research questions and 83% in the documentation stage, while reaching a level of 69–72% in hypothesis formulation. Conversely, the correlation between the hypothesis and its testing presents a major challenge, yielding a rate of only 44.35% for correct and partially correct responses. In the final stages, the scores return to a high level, exceeding 83–87% for summarizing and communicating result.

These data describe a U-shaped performance profile, characterized by high results at the beginning and the end of the investigative cycle, but lower performance in the intermediate stages, which involve complex reasoning and the conceptual integration of information.

This pattern confirms observations within the literature regarding the fragmented implementation of IBL and the difficulty of logically integrating its stages.

4.7. Practical implications of the research

The findings of this study highlight the necessity for a more explicit approach to inquiry-based learning within initial teacher education, with a specific focus on the relationship between hypothesis formulation and testing. It is recommended to utilize guided activities for hypothesis formulation, matching exercises to link the stages of the inquiry cycle and instructional design templates and guidelines. Additionally, adopting an interdisciplinary approach to inquiry, developing assessment tools that monitor the coherence of the investigative process and integrating reflection into training activities are highly significant.

4.8. Limitations of the study

This study presents several important limitations, such as the use of a convenience sample drawn from a single university, the exclusive analysis of students' written artifacts and the absence of interviews or direct observations. Also, the limited timeframe allocated for task completion, the lack of independent validation for the assessment instrument, and the omission of motivational and attitudinal factors limit both the generalizability of the findings and the depth of data interpretation.

4.9. Future research directions

Future research should incorporate larger and more diverse samples, qualitative methods such as interviews and focus groups and longitudinal designs. Additionally, it is necessary to analyze the impact of specific instructional interventions and to investigate the relationship between inquiry competencies and variables such as self-efficacy, motivation and attitudes toward active learning methodologies.

4.10. General conclusions of the research

The results demonstrate that future teachers possess a relatively sound understanding of formulating research questions and the documentation stage; however, they encounter difficulties in formulating hypotheses and correlating them with the testing phase. They tend to perceive the inquiry cycle as a succession of disconnected stages rather than as an integrated and interdependent process. Consequently, initial teacher education should place greater emphasis on the functional relationships between the stages of the inquiry cycle and on the development of skills for coherent instructional design.

CHAPTER 5. (STUDY 2) INVESTIGATION-BASED SCIENCE LEARNING AND DIFFERENTIATED INSTRUCTION

5.1. Introduction

The concept of inquiry is frequently used in the literature, but its meanings vary depending on the theoretical and practical context.

5.2. Theoretical framework

According to Justice et al. (2007) and the National Research Council (2000), inquiry simultaneously represents a process of seeking knowledge, a constructivist learning method, an educational objective and an instructional strategy. Harlem (2013, cited in Gholam, 2019) highlights the formulation of questions and active participation in investigation, while Hammerman (2006) emphasizes the role of curiosity in the learning process.

Bybee’s (2009) 5E Model, detailed by Northern (2019), includes the following stages: engagement, exploration, explanation, elaboration and evaluation. In the field of science, inquiry contributes to the development of scientific thinking through observation, exploration and experimentation. Bybee (2002) considers scientific investigation as learning content, a set of competencies and a teaching method.

Regarding differentiated instruction, Tomlinson and Strickland (2005) define it as a flexible approach adapted to student diversity. Differentiation is based on students' readiness levels, learning profiles and interests (Whitworth, Maeng, & Bell, 2013). The models of Schwab (1962, cited in Walker, 2015) and Llevellyn (2011) offer progressive levels of inquiry, ranging from demonstrative activities to activities conducted autonomously by students.

5.3. Research aim and objectives

The purpose of this research is to analyze how preschool and primary school teachers perceive and utilize inquiry-based learning and differentiated instruction in science teaching.

The objectives target the frequency of using these approaches, the teacher's role, student autonomy, and the gaps between theoretical principles and their practical application.

5.4. Methodology

The research was conducted between October and November 2021 using an online questionnaire adapted from Jeanpierre (2006) and Lyles & Wu (2016). The instrument demonstrated very high reliability (Cronbach's alpha = 0.957) and the items were evaluated on a 5-point Likert scale. The statistical analysis included frequencies, percentages, means, standard deviations, as well as the Kruskal-Wallis H and Mann-Whitney U tests.

5.4.1. Participants

A total of 92 teachers participated in the study, of whom 97.83% were female. Out of the total sample, 67.39% teach in primary education and 29.35% in preschool education. The majority hold the 1st didactic degree (53.26%), while 57.61% have a Bachelor's degree and 35.87% hold a Master's degree.

5.4.2. Data collection

Data were collected online via Google Drive, based on voluntary and anonymous participation.

5.4.3. Research instruments and procedure

The instrument used in the research was a structured questionnaire, adapted from validated models in the literature (Jeanpierre, 2006; Lyles & Wu, 2016). The questionnaire evaluated perceptions of inquiry and differentiated instruction across dimensions such as: the student, lesson design, content, strategies, products and evaluation.

5.4.4. Data analysis

The analysis utilized descriptive and inferential statistics. The results did not reveal statistically significant differences between respondent groups based on teaching experience or teaching level.

5.5. Results

The results of the study are based on the responses of 92 teachers, 71 of whom also completed the items regarding the frequency and timing of using differentiated instruction. The data show that differentiation is frequently used in teaching activities: 47.89% of teachers state they apply it daily, and 32.39% at every lesson. Only 2.82% claim they do not use this approach at all.

Table 5.1. Subjects' responses to the item "In which moments of a didactic activity do you resort to learning differentiation?"

Response variant	N	%
During the formulation of a problem/question to be resolved	71	67.61%
During documentation for understanding and clarifying the problem	71	54.93%
During the formulation of predictions and hypotheses	71	26.76%
During data/evidence collection and analysis	71	23.94%
During the formulation of explanations	71	54.93%
During the establishment of connections between explanations	71	35.21%
During the evaluation of learning acquisitions	71	40.85%
During the communication of results	71	25.35%
During the analysis and reflection on results and the learning process	71	42.25%

Table 5.1. highlights the specific moments when teachers implement differentiated instruction within inquiry-based activities. The highest percentages are recorded during the formulation of a problem/question to be resolved (67.61%), documentation for problem clarification (54.93%) and the formulation of explanations (54.93%). Differentiated instruction is less prevalent in stages that involve complex scientific processes, such as formulating predictions and hypotheses (26.76%), collecting and analyzing evidence (23.94%) and communicating results (25.35%). These data suggest a predominant utilization of differentiated instruction during the initial phases of the investigation.

Table 5.2. Methods/techniques for differentiating activity

Methods/techniques for activity differentiation	N	%
Flexible grouping	71	49.30%
Posing open-ended questions	71	69.01%

Providing opportunities for discovering facts, phenomena, etc	71	40.85%
Student-centered learning	71	77.47%
Self-directed learning	71	18.31%
Supplementary homework assignments	71	19.72%
Tasks assigned to students	71	23.94%
Student self-assessment	71	28.17%
Encouraging abstract/complex thinking	71	46.48%
I'm not sure what strategy to use	71	0%

According to Table 5.2, the most frequently utilized methods of differentiation are student-centered learning (77.47%) and posing open-ended questions (69.01%). Approximately half of the respondents employ flexible grouping (49.30%) and the encouragement of abstract/complex thinking (46.48%). In contrast, strategies that involves a higher degree of student autonomy are more rarely implemented, namely: self-directed learning (18.31%), supplementary homework assignments (19.72%), differentiated tasks assigned to students (23.94%) and student self-assessment (28.17%). None of the respondents reported being unsure about which strategy to utilize.

Table 5.3. Results regarding the teacher's role in learning activities

The Item	**N**	**m**	**SD**	**1+2 (%)**	**4+5 (%)**
I act as a facilitator of student learning/I make learning easier for my students.	92	4.53	0	2.17%	95.65%
I encourage students to ask questions and address them to me or to their peers.	92	4.59	0.71	3.26%	96.74%
I encourage students to seek answers to their own questions.	92	4.43	0.71	3.26%	91.30%
I encourage students to formulate scientifically oriented questions (on-topic, correctly articulated and answerable using the available materials).	92	4.33	0.71	3.26%	90.22%
I involve students in planning investigations to gather evidence in response to questions	92	4.11	1.42	6.52%	77.17%
I ask students what they would be interested in learning.	92	4.03	0	8.70%	72.83%

I am guided by students' interests when preparing my lessons.	92	4.38	0.71	5.43%	88.04%
I use discrepant, provocative events to motivate my students regarding the study of a topic.	92	4.02	0	9.78%	77.17%
I don't depend on the manual.	92	3.75	1.42	8.70%	58.70%
I focus on students' understanding of scientific concepts.	92	4.13	0	6.52%	79.35%
I support students to prioritize evidence that allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.	92	3.91	0.71	7.61%	73.91%
My students have scientific inquiry experiences focused on balancing the development of their research skills with conceptual understanding.	92	3.34	0	7.39%	45.65%

The data in Table 5.3. demonstrate that teachers primarily perceive themselves as facilitators of learning. Specifically, 95.65% believe they facilitate their students' learning process (M = 4.53), 96.74% encourage students to formulate questions (M = 4.59) and 91.30% support them in seeking answers to their own questions (M = 4.43). Furthermore, 90.22% assert that they promote the formulation of scientifically oriented questions, while 88.04% declare that they adapt their lessons based on students' interests. Moderate levels of agreement emerge regarding involving students in planning investigations (77.17%) and utilizing provocative events as a motivational strategy (77.17%). The lowest level of agreement is observed with respect to providing scientific research experiences that are balanced between investigative skills and conceptual understanding (45.65%; (M = 3.34).

Table 5.4. Activities carried out independently by students

	N	**m**	**SD**	**1+2 (%)**	**4+5 (%)**
My students formulate evidence-based conclusions and/or explanations to answer scientifically oriented questions.	92	3.27	1.42	26.09%	45.65%
My students evaluate their own conclusions and/or explanations in light of alternative conclusions/explanations (from peers, books, etc.), especially those reflecting scientific understanding.	92	3.48	0	18.48%	53.26%

My students reflect on the formulated questions, the steps taken and the results obtained.	92	3.49	0.71	18.48%	54.35%
My students analyze data on their own/through their own research.	92	3.38	0	23.91%	50%
My students interpret data based on evidence from their own research.	92	3.27	0.71	28.26%	50%
My students read documented views (of the scientific community: online articles, content from textbooks, encyclopedias) related to their own research before deciding on an answer to a question.	92	2.88	0.71	36.96%	32.61%
My students are able to argue their answers.	92	3.63	0	13.04%	63.04%
My students communicate to their peers the results of their own research undertaken on a studied topic.	92	3.53	0	19.57%	55.43%
My students communicate and justify their proposed conclusions and/or explanations.	92	3.47	0	19.57%	52.17%
My students share research results formally outside the classroom (e.g. fair/equitable scientific competition).	92	3.21	1.42	25%	44.57%

Table 5.4. presents the activities carried out independently by students within the investigative process. The highest percentages are recorded for students' capacity to argue their answers (63.04%), to communicate the results of their own research (55.43%) and to reflect on the learning process (54.35%). Additionally, over half of the teachers consider that students evaluate their own explanations in relation to existing alternatives (53.26%) and justify their conclusions (52.17%). In contrast, the use of external documentary sources is lower, with only 32.61% of respondents affirming that students consult articles, encyclopedias, or other scientific sources before formulating answers. At the same time, participation in formal dissemination activities outside the classroom remains limited (44.57%).

Overall, the findings highlight that teachers declare a frequent use of differentiated instruction and adopt a predominant role as learning facilitators. However, differentiation is applied mostly in the introductory stages of the inquiry cycle and student autonomy remains moderate, particularly in activities that require the use of evidence, critical information analysis and independent research.

5.6. Discussions

The results demonstrate a strong orientation toward student-centered learning and inquiry principles; however, their implementation remains partial. Differentiated instruction is primarily applied during the initial stages of the investigation, and the strategies utilized are predominantly general in nature. While teachers actively assume the role of facilitators, student autonomy and their engagement in authentic research remain moderate. The factors limiting full application include textbook dependency, curricular constraints and the need for supplementary professional development.

5.7. Practical implications of the research

The study recommends strengthening both pre-service and in-service teacher education training to improve the design of inquiry-based activities and develop differentiation skills. It highlights the necessity of employing more varied strategies, reducing reliance on textbooks and fostering student autonomy in formulating questions, developing hypotheses and defending conclusions.

5.8. Limitations of the study

The primary limitations of this study include the relatively small convenience sample, drawn largely from the same university institution, the predominance of female respondents and the exclusive reliance on self-reported data. The cross-sectional design not allow for the establishment of causal relationships.

5.9. Future research directions

Future research should incorporate qualitative and observational methodologies, investigate the relationship between teacher training and inquiry implementation, conduct comparative studies across diverse educational contexts and analyze the impact of these approaches on student outcomes.

5.10. General conclusions of the research

The findings indicate that teachers highly value differentiated instruction and inquiry-based learning, associating them with the paradigm of student-centered learning. Although teachers adopt a facilitator role, student autonomy and the diversity of the utilized strategies remain limited. This research underscores the existence of favorable conditions for integrating these approaches; however, their full development necessitates continuous professional development, curricular flexibility and adequate educational resources.

CHAPTER 6. (STUDY 3) TEACHERS' PERCEPTIONS ON THE CHARACTERISTICS OF TECHNOLOGY AND ENGINEERING FIELDS AND THEIR RELATIONSHIP TO THE ENGINEERING PROFESSION

6.1. Introduction

Scientific and technical education, includes both technological and engineering dimensions, currently constitutes an essential domain of the school curriculum in response to the accelerated transformations of contemporary society.

6.2. Theoretical framework

The theoretical framework emphasizes that science contributes to the development of critical thinking through exploration and experimentation, including hypothesis formulation, data analysis and evidence-based interpretation (Paul & Elder, 2019) (p. 2). Technology is ambiguously defined as both a process and a product, being interpreted either as a goal-oriented human activity or as a collection of artifacts (Albion et al., 2018; Alamäki, 1999).

Cunningham (2018) provides an integrative definition, viewing it as a system of knowledge and processes developed through engineering.

The relationship between science and technology is characterized as varied and dynamic, including dependence, autonomy, or bidirectional interaction (Gardner, 1994; Collier et al., 2011). Engineering is differentiated from technology by its emphasis on design and modeling, whereas technology targets practical application (Dietz, 2014). Engineering processes are cyclical and iterative (McCue, 2016) and the requisite competencies include logical thinking, modeling, and inquiry (Adey & Shayer, 2002; Hunt, 2018). STEM education integrates these fields, drawing support from learning theories such as distributed cognition (Schunn & Silk, 2011).

6.3. Research aim and objectives

The general purpose of this research is to identify and analyze the perceptions of teachers and future teachers for primary and preschool regarding the fields of technology and engineering, the relationship between them and the occupations of engineer and technologist.

The specific objectives aim to: analyze the characteristics of both domains, identify the skills required for the engineering and technological professions, and compare perceptions between practicing teachers and students.

Research Questions

1. How do teachers and future teachers for primary and preschool education perceive the fields of technology and engineering?
2. Is there a statistically significant difference in the selection of questionnaire items regarding the subject matter of engineering and technology and the occupations of engineer/technologist?

6.4. Methodology

The study employs a descriptive quantitative design based on a questionnaire survey. The instrument comprises items organized into two main dimensions: the perception of technology and engineering and the competencies associated with these professions. Data analysis combines descriptive statistics (frequencies, percentages, means, standard deviations) and inferential statistics (independent samples t-test, ($p < 0.05$).

6.4.1. Participants

The sample consists of 193 respondents (students and teachers), predominantly female (94.3%). The largest age is 19–24 years (28%), and 40.4% are students without teaching experience. Educational level varies: 40.9% hold a bachelor's degree, 27.5% a master's degree, and 31.1% a high school diploma (baccalaureate).

6.4.2. Data collection

Data were collected online on a voluntary basis, ensuring participant confidentiality and informed consent. The questionnaire required approximately 15 minutes to complete and data verification prior to analysis.

6.4.3. Research instruments and procedure

The questionnaire comprises 53 items, 20 of which are analyzed in this study. The first section utilizes a 5-point Likert scale and the second section employs a 4-point Likert scale. Online administration ensured standardization and facilitated access to respondents.

6.4.4. Data analysis

Data analysis was conducted using SPSS 23, including descriptive statistics and independent samples t-tests. The results demonstrate the absence of significant differences between teachers and students regarding their perceptions of technology and engineering.

6.5. Results

Respondents were asked to indicate their level of agreement with the statements included in Table 6.1., utilizing a 5-point Likert scale. In order to synthesize and clarify the findings, the "Strongly disagree" and "Disagree" categories were collapsed under the label "Disagree", while the "Agree" and "Strongly agree" categories were grouped under the label "Agree".

Table 6.1. Respondents' agreement with statements regarding the object of study of technology and engineering

Item	N	Disagree (%)	Neither agree, nor disagree (%)	Agree (%)
Technology involves the practical application of knowledge in a field	193	6.2	14	79.8
Engineering involves the application of scientific methods and the use of technological products to solve concrete problems	193	5.7	11.9	82.4
Technology is related more to the products of engineering than to its processes	193	18.1	33.7	48.2
Engineering uses the products of technology	193	12.4	20.7	66.8
The technological process also involves manual activities	193	4.6	10.9	84.4
Various tools and devices are used in technology	193	3.1	11.9	84.9
Apparatus, tools and various other technological products are used in engineering	193	5.2	11.4	83.4
Engineering design concerns the components of a product	193	9.8	18.7	71.5
Engineering design targets the entire product (device, apparatus, construction, circuits, etc.)	193	2.6	14.0	83.4
Engineering design concerns the functioning of a product/apparatus	193	8.8	10.9	80.3

The results in Table 6.1. show a high level of agreement regarding the nature of technology and engineering: 79.8% consider technology to be the practical application of knowledge, and 82.4% consider engineering to be the application of scientific methods. Also, over 80% of respondents associate technology with tools, manual activities and practical application.

However, there are conceptual ambiguities: 33.7% neutral responses and 48.2% agreement for the technology-engineering products relationship, indicating difficulties in clearly differentiating between the fields.

Table 6.2. Respondents' opinion with reference to the object of study of technology and engineering

Item	**N**	**m**	**St.Dev**	***M (101 teachers)- m (73 students)****
Technology involves the practical application of knowledge in a field	193	4.13	.946	0.17
Engineering involves the application of scientific methods and the use of technological products to solve concrete problems	193	4.23	.926	-0.07
Technology is related more to the products of engineering than to its processes	193	3.40	1.105	0.01
Engineering uses the products of technology	193	3.81	1.132	-0.04
The technological process also involves manual activities	193	4.36	.892	-0.09
Various tools and devices are used in technology	193	4.42	.857	0.09
Apparatus, tools, and various other technological products are used in engineering	193	4.28	.932	0
Engineering design concerns the components of a product	193	3.94	1.073	-0.06
Engineering design targets the entire product (device, apparatus, construction, circuits, etc.)	193	4.36	.818	0.18
Engineering design concerns the functioning of a product/apparatus	193	4.19	.982	0.02

*The data presented in Table 6.2. did not include the calculation of the mean difference for the 14 respondents who indicated "other situation" regarding their occupation (student or teacher).

Table 6.2. confirms these tendencies through high means (e.g. m = 4.42 for the use of tools in technology; m = 4.36 for designing the entire product). The differences between teachers and students are minimal (close to 0), without statistical significance.

Table 6.3. Respondents' opinion with reference to the occupations of the engineer and the technologist (%)

Item	N	1 (%)	2 (%)	3 (%)	4 (%)
A technologist/engineer must know the specifics of design in technology/engineering and carry out projects	193	0	1	9.3	89.6
A technologist/engineer must identify faults in the functioning of devices	193	0	0	16.1	83.9
A technologist/engineer must troubleshoot faults	193	.5	6.2	30.6	62.7
A technologist/engineer must optimize the functioning of a device	193	0	2.6	21.2	76.2
A technologist/engineer must create models/mock-ups or prototypes	193	.5	3.1	24.9	71.5
A technologist/engineer must use specialized language	193	1.0	2.6	37.3	59.1
A technologist/engineer must reason logically	193	.5	1.0	19.7	78.8
A technologist/engineer must reason mathematically and use calculation methods	193	.5	3.6	24.4	71.5
A technologist/engineer must implement the designed products	193	.5	1.0	21.8	76.7
A technologist/engineer must investigate/research technical problems	193	.5	1.0	21.8	76.7

Table 6.3. shows a very high valuation of engineering competencies: 89.6% consider design to be essential, 83.9% the identification of faults, and 76-77% appreciate optimization, implementation, and investigation.

6.6. Discussions

The results show a partial alignment with the literature: technology is perceived as applicative and engineering as a process of design and problem-solving. However, the relationship between them remains conceptually unclear.

The lack of differences between teachers and students suggests that teaching experience does not significantly improve conceptual understanding. At the same time, there is a high valuation of higher-order cognitive skills, compatible with STEM education.

6.7. Practical implications of the research

The study highlights the need to reform initial and continuous teacher training by explicitly integrating STEM. It is necessary to use active methods based on inquiry and projects.

Additionally, it is recommended to change the preschool and primary curriculum by integrating STEM interdisciplinarily and connecting learning with real-world contexts.

6.8. Limitations of the study

Limitations include the convenience sample, female predominance, self-reporting via questionnaire and the cross-sectional design. Furthermore, the lack of advanced statistical analyses limits the interpretation of complex relationships between variables.

6.9. Future research directions

It is recommended to expand sample sizes, conduct comparative international studies, longitudinal research and investigate STEM interventions. Qualitative methods are also needed for a deeper understanding of perceptions.

An important direction is the analysis of the relationship between perceptions and teaching practices, as well as the impact on students.

6.10. General conclusions of the research

The study shows that teachers and future teachers have a functional understanding of technology and engineering, but face difficulties with conceptual delimitation. There are no significant differences between teachers and students.

Engineering competencies are perceived as highly important and the overall image is positive. The need for conceptual clarification and the integration of STEM in teacher training is confirmed for a coherent and modern education.

CHAPTER 7. RESEARCH ON THE IMPACT OF INQUIRY-BASED LEARNING ON STUDENTS' SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE AND SKILLS

7.1. General coordinates of the research

The present research was conducted in two distinct phases. The first phase involved the implementation of the following actions:

- Investigating how teachers understand and apply the inquiry-based learning model in designing lesson plans (124 teachers of various specializations participating in the PIPP IF and PIPP Conversion programs, 2019-2021 and 2020-2022). - Study 1
- Investigating teachers' perspectives regarding the operationalized guided inquiry model.
- Revising the model based on feedback and suggestions received from the teachers (92 respondents). - Study 2
- Investigating the opinions of teachers and students regarding the role of technological and engineering education in developing inquiry skills, critical thinking and interest in science and technology (193 respondents). - Study 3
- Exemplifying the scaffolding of activities designed to help teachers in the experimental 3rd and 4th-grade classes conduct the required activities (explaining what to do and how to do it, and providing dedicated resources to perform, structure, or simplify the actions required by the classroom use of inquiry-based learning).

The second phase of the research focused on the experimental research itself, aiming to evaluate the impact of inquiry-based learning on students' knowledge, scientific, and technological skills, as well as on their attitudes toward science and technology/engineering. Within this stage, several critical procedures were executed to carry out the experimental research. Specifically, the revised model of inquiry-based learning was implemented in the third and fourth-grade experimental classes, concurrently with the organization of the experimental and control groups. Initial and final tests (pre-tests and post-tests) were administered to evaluate students' knowledge and skills, alongside instruments designed to investigate their attitudes toward science and technology/engineering. In parallel, instructional activities and the utilization of the proposed scaffolding were monitored to ensure the fidelity of the intervention implementation. Furthermore, the data obtained throughout the research were collected, processed and interpreted, subsequently followed by a comparative analysis of student outcomes between the experimental and control groups. These procedures aimed to validate the efficacy of the proposed model and to substantiate the research conclusions. The findings of the experimental research encompass multiple dimensions relevant to understanding the impact of the instructional intervention. Firstly, they aim to highlight the results obtained within the experiment, as well as to analyze the evolution of student performance throughout the learning process. Additionally, potential shifts in students' attitudes toward science and technology/engineering are tracked, reflecting changes produced at both cognitive and affective levels. Another essential aspect constitutes the validation of the revised inquiry-based learning model in relation to the collected data. Finally, the general conclusions of the research are formulated, alongside recommendations for optimizing future educational practice.

Investigating the teachers' opinions regarding the operationalized guided inquiry model was a crucial step in validating and optimizing the inquiry-based learning framework used in the formative intervention. This stage aimed to identify how teachers understand the structure and functionality of the model, as well as the extent to which they consider it useful and applicable in primary school educational activities.

The teachers assessed the operationalized inquiry-based learning model as a useful and applicable tool in teaching practice. Participants considered that the staged structure of the inquiry cycle and its associated guiding questions facilitate activity organization, student guidance and the development of a coherent pedagogical approach. Teachers highlighted the role of operationalized questions in stimulating curiosity, critical thinking and the formulation of students' own hypotheses and explanations.

The results demonstrated that the model contributes to redefining the teacher's role, shifting it toward a facilitator of the learning process and a supporter of active student participation. Furthermore, the integrated methodological scaffolding was considered valuable for reducing the difficulties encountered in organizing inquiry activities and for supporting students in solving complex tasks.

Teachers observed an increased level of student engagement in inquiry-based activities, alongside the development of skills such as observation, analysis, hypothesis formulation, data interpretation and conclusion communication. Concurrently, difficulties were reported regarding the time required to carry out the activities, the design of teaching materials and adapting to the students' varying paces of work.

The feedback received served as the foundation for revising the model, specifically by clarifying certain stages, reformulating guiding questions and developing additional exemplars of activities. The findings confirm that the operationalized guided inquiry model represents a relevant instructional tool for developing scientific and technological competencies, as well as for promoting active, student-centered learning.

The inquiry model utilized in the formative intervention

The operationalization of the model is achieved by delineating the guiding questions that must be formulated at each specific stage of the investigative cycle's progression.

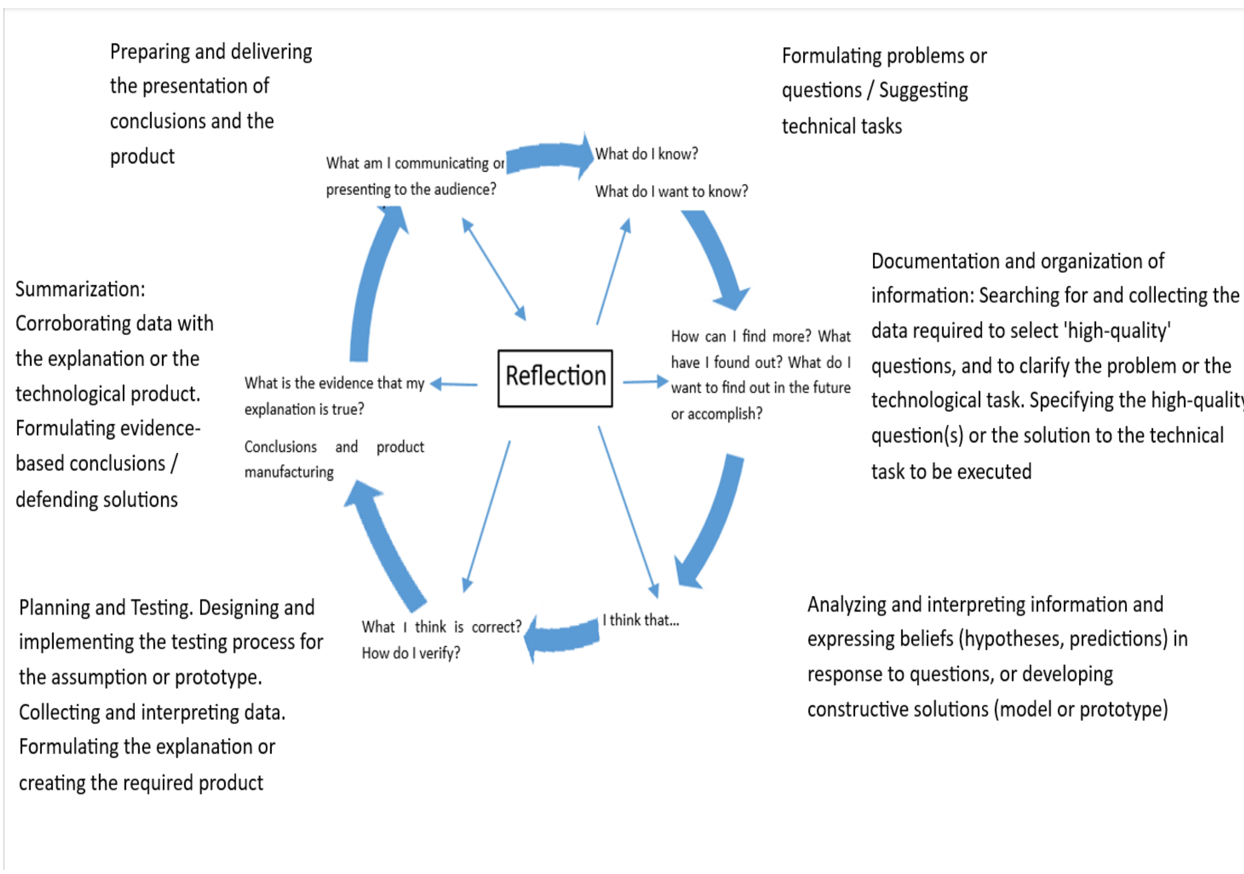

Figure 7.1. Operational model of inquiry-based learning

Guiding students in the context of the project stages is explained in Figure 7.2.

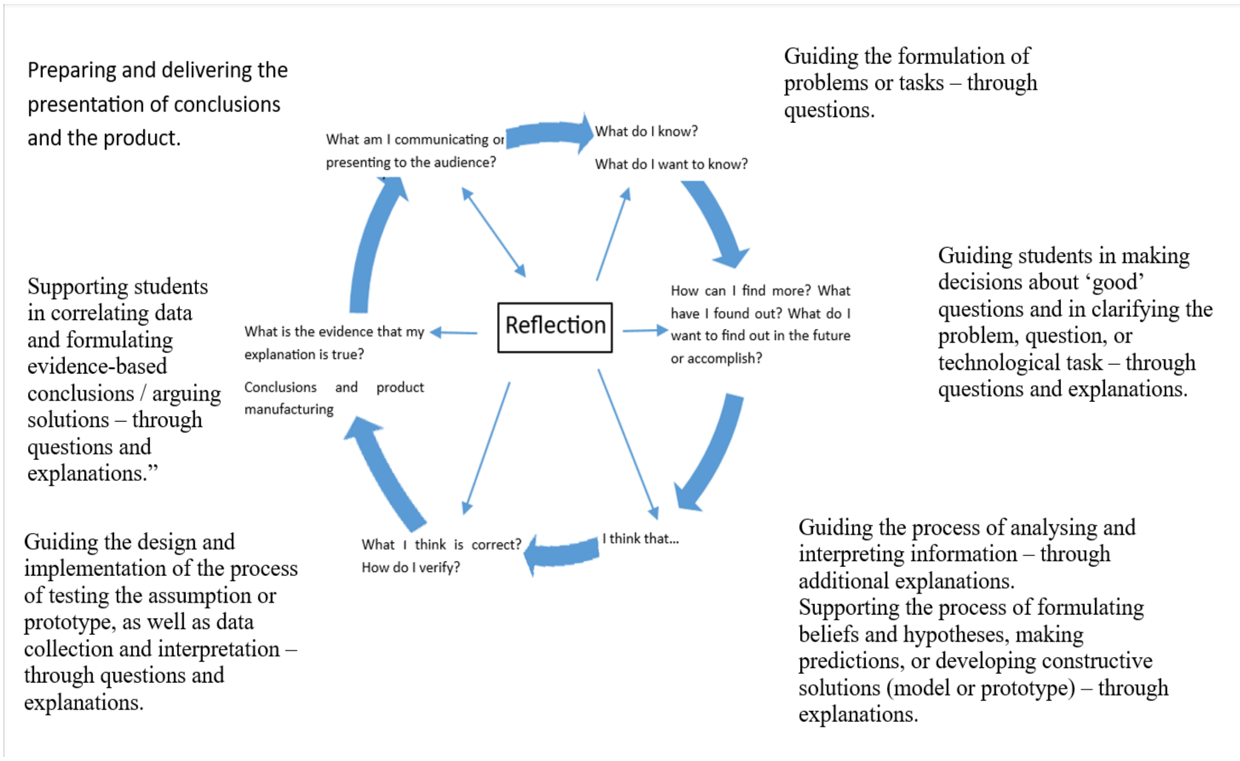

Figure 7.2. Guiding students in conducting the investigation

The Bloom's Taxonomy was utilized to design the assessment instruments. Table 7.1. illustrates how the theme of water surface and underwater transportation can be approached across the cognitive levels of remembering, understanding, applying, analyzing, evaluating and creating. Students are required to list, explain, classify, conduct experiments, formulate hypotheses and evaluate the outcomes of their own activities.

Table 7.2. exemplifies the inquiry-based learning model applied to the phenomenon of floating bodies and submarine operation. The activity aims to explain the floating of ships and the mechanism by which submarines alter their position in water using water tanks. Students formulate hypotheses, perform experiments and construct simple prototypes. The experimental worksheet for simulating ship floating utilizes aluminum foil, coins and a water container, whereas the technical worksheet for submarine operation employs straws, a container and a water vessel. The derived conclusions highlight the relationship between the forces exerted by water on bodies and the operational principles of submarines. This activity is adapted from Ciascai (2005).

Tables 7.3. and 7.4. illustrate the application of the model to the study of plant growth and the production of natural fertilizers. In the first case, students investigate the role of light, water, air and temperature on plant development using eight pots monitored over a two-week period. In the second case, the effects of natural fertilizers derived from banana peels, eggshells, coffee grounds, nettle and ash on plant growth are analyzed. The experiment utilizes ten tomato pots observed over the course of one month, concluding that fertilized plants exhibit enhanced development compared to non-fertilized ones.

The model is also applied to technological activities, such as the construction of a stethoscope, a sugar cube pyramid and a replica of the Eiffel Tower (Tables 7.5-7.7). These activities enable students to formulate questions, document solutions, build prototypes and test their functionality. Within the pyramid activity, the Pyramid of Djoser is mentioned, noting its height of 62 meters, while the Eiffel Tower section provides information regarding its height of 324 meters and its pyramidal shape.

Table 7.8. presents an instrument designed to structure student learning outcomes by analyzing the Eiffel Tower model through the lens of STEM disciplines. It integrates concepts from science, technology, engineering and mathematics, such as the equilibrium of bodies, material strength, system design and the measurement of geometric dimensions. The contributions of engineer Pănculescu to streamlining the tower's construction through the use of prefabricated components are highlighted. Concurrently, data regarding the dimensions of the Eiffel Tower (300 meters), the 1.710 steps, and the mass of approximately 100 tons are preserved. This model is inspired by the work of Makya and Rogers (2003).

Based on these considerations, the tests applied to students aimed to assess the investigation skills specific to inquiry-based learning. The skills of formulating research questions and technical tasks, documentation, formulating hypotheses and predictions, designing experiments and prototypes, carrying them out, collecting and interpreting data, formulating conclusions based on evidence, creating technological products and reporting results were analyzed. These skills represent the indicators used to evaluate the impact of the model on the development of students' scientific and technological knowledge and skills.

7.2. Purpose, objectives and questions of the experimental research

The purpose of the research was to evaluate the impact of inquiry-based activities on the scientific and technical skills of third and fourth grade students.

Research objectives:

Implementation of the instructional program based on teacher-guided inquiry activities in the subjects of Natural Sciences and, when possible, Arts and Practical Activities.
Determining the extent to which, by completing the teacher-guided inquiry program, third and fourth grade students can improve their scientific and technological knowledge and skills, while also developing specific attitudes.
Evaluating the formative intervention program and analyzing the applicability of the system of activities based on teacher-guided inquiry in schools.

The independent variable is represented by the intervention program consisting of three components:
- Teacher-guided inquiry activities aimed at studying topics or phenomena (AIgS); e.g. the study of water boiling
- Teacher-guided inquiry activities aimed at performing predominantly technological tasks (AIgT); e.g. building a paddle boat
- Teacher-guided investigative activities aimed at interdisciplinary study (science and technology) (AIgI); e.g. the study of the optical composition of colors using Newton's disc rotated by means of a spinning top

The dependent variable is school performance, operationally defined through three indicators:
D1 - the level of scientific and technological skill involved in an inquiry;
D2 - the level of technical skill;
D3 - the level of knowledge.

Table 7.9. Operationalization of the dependent variable and measurable indicators

Dimensions of the dependent variable	**Measurable indicators**	**Assessment criteria/Item types**
Level of scientific skill	Formulates research questions Formulates hypotheses and/or predictions Designs the hypothesis-testing experiment Processes/collects and interprets obtained data Formulates conclusions	Formulates/assesses (correct/incorrect) research questions Formulates (assesses true-false / correct-incorrect) hypotheses and/or predictions Designs/analyzes (correct-incorrect, complete-incomplete) a hypothesis-testing experiment

		Processes/collects and interprets obtained data (supporting or not supporting the hypothesis) Formulates conclusions (arguments regarding the validity of the hypothesis) (true-false)
Level of technical skill	Formulates technical tasks (teacher) Designs a prototype (assembly/testing device) Builds the prototype Creates the product (assembly/device)	Formulates (correctly/incorrectly) technical tasks Correctly/incorrectly designs a prototype Correctly/incorrectly builds the prototype Correctly/incorrectly creates the product
Level of knowledge	Taxonomic levels: *remembering, understanding, applying, analyzing, evaluating, creating*	Objective items, explanation items, task solving, relationship identification, value judgments, response development

7.3. Research hypotheses

Hypothesis 1. Students undergoing the formative intervention program based on learning through experiments and the use of technical sheets will achieve a higher level of scientific and technical knowledge than their peers in the control group.

Criteria for assessing the level of knowledge: taxonomic level.

Hypothesis 2. Students undergoing the formative intervention program based on learning through experiments and the use of technical sheets will possess higher-level scientific skills than their peers in the control group.

Criterion: *correctness of the procedure* (e.g., formulating research questions, formulating hypotheses/assumptions using if-then statements, designing hypothesis testing, conducting the testing, interpreting the result).

Hypothesis 3. Students undergoing the formative intervention program based on learning through experiments and the use of technical sheets will possess higher-level technical skills than their peers in the control group.

Criteria: designing a device/assembly, selecting appropriate materials, using working techniques, creating the device/assembly.

7.4. Research methodology

The research was conducted based on an experimental design, which allowed analyzing the impact of a didactic intervention program on primary school students' performance. The independent variable was represented by the intervention program based on teacher-guided inquiry activities and the dependent variable was school performance, evaluated through the level of knowledge, scientific skills and technological skills. The study included an experimental group, which benefited from the proposed intervention, and a control group, which followed traditional didactic activities. Comparing the results obtained in the initial and final evaluations highlighted the effects of the intervention program on the development of students' competences.

7.4.1. Presentation and description of the target group

The experimental research took place during the 2022-2023 and 2023-2024 school years and involved third and fourth grade students from several school units in Sălaj County. The experimental group consisted of 225 students (139 third-grade students and 86 fourth-grade students), coordinated by 10 teachers. The activities took place across five schools: "Mihai Eminescu" Secondary School Zalău, "Avram Iancu" Sports High School Zalău, The Orthodox Theological High School "Sf. Nicolae" Zalău, "Porolissum" Secondary School Zalău and "Lucian Blaga" Secondary School Jibou.

The control group included 240 students (159 third grade students and 81 fourth grade students), coordinated by 11 teachers. These students came from four school units in Sălaj County and completed didactic activities according to regular teaching practices.

7.4.2. Spatial and temporal framework of the experimental research

The experimental activity was carried out over two school years in several educational units in Sălaj County. In the schools included in the experimental group, the coordinating teachers applied the intervention program developed within the research, the implementation of activities was monitored both by the involved teachers and by the author of the research. This organization ensured a uniform deployment of the intervention and compliance with the stages planned in the program.

7.4.3. Procedure

The research procedure included three main stages: initial evaluation (pre-test), implementation of the intervention, and final evaluation (post-test). In the initial stage, knowledge tests, scientific and technological skills tests, as well as questionnaires regarding the attitude towards science and technology were administered. These instruments allowed to identify the students' readiness level before the intervention.

In the experimental group, activities were carried out through the systematic use of inquiry sheets and technical sheets. Students were actively involved in formulating research questions, developing hypotheses, conducting experiments, interpreting results, and formulating conclusions. At the same time, they designed and created practical products, developing their technological skills and creativity. In the control group, students followed a traditional didactic path, based mainly on activities provided in school textbooks and demonstrative experiments conducted by the teacher.

At the end of the intervention period, tests similar to the initial ones were administered to evaluate the students' progress and to compare the results of the two groups.

7.4.4. Data collection and processing

Data were collected through knowledge tests, scientific and technological skills tests, and attitude questionnaires. The results were evaluated based on performance descriptors that allowed an objective assessment of the level achieved by each student.

The obtained data were centralized and statistically processed using the IBM SPSS Statistics 20.0 software. The statistical analysis aimed to compare the initial and final results, as well as to identify differences between the experimental group and the control group, in order to evaluate the effectiveness of the intervention program.

7.4.5. Research instrument

The instruments used in the research were knowledge tests, scientific skills tests and technological knowledge and skills tests. These were developed in accordance with the school curriculum and were applied in both the pre-test and post-test stages. Students had 50 minutes to complete the tests.

The knowledge test included 5 items and the scientific and technological skills tests included 6 items each. The items evaluated different cognitive levels, from understanding and application to analysis and argumentation, in accordance with Bloom's Taxonomy. The evaluation of responses was based on performance descriptors organized into four levels: very good, good, sufficient, and insufficient.

7.4.6. Validation of the research instrument

To check the reliability of the instruments, Cronbach's Alpha coefficient was used. The values obtained were: $\alpha = 0.419$ for the knowledge test; $\alpha = 0.624$ for the scientific skills test; $\alpha = 0.530$ for the technological knowledge and skills test. These results indicate an acceptable internal consistency, especially for the scientific skills test.

Construct validity was verified through factor analysis. The first factor explained 38.2% of the variance for the knowledge test, 44.7% for the scientific skills test, and 41.3% for the technological test. KMO values were 0.58, 0.64, and 0.60, respectively, and Bartlett's test was statistically significant ($p < 0.05$) for all instruments. Students' responses were coded on a scale from 1 to 4, corresponding to grades from "Insufficient" to "Very good". The results confirm that the instruments used are appropriate for evaluating the research objectives and for analyzing the impact of the intervention program.

7.5. Results

Results of the first hypothesis: development of scientific and technical knowledge

The first hypothesis of the research aimed to verify the effect of the formative program based on learning through experiments and the use of the technical sheet on the level of students' scientific and technical knowledge. Statistical analysis highlighted that the two groups started from similar levels of knowledge, without statistically significant differences at the pre-test ($t(463) = -0.418$, $p = 0.676$).

Table 7.13. Descriptive statistics for the results of the experimental group's scientific knowledge tests

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness index		Kurtosis index	
Initial knowledge	225	15	5	20	14.51	2.161	-.755	.162	2.133	.323

Final knowledge	225	11	9	20	16.47	2.079	-.870	.162	.941	.323
Valid N (listwise)	225									

In the experimental group, the mean score increased from 14.51 points at the initial testing to 16.47 points at the final testing, while in the control group, the mean increased from 14.60 to 15.74 points. The difference between the groups at the post-test was statistically significant $t(463) = 3.832$, $p = .001$, indicating a superior level of knowledge in the experimental group.

Intra-group analyses revealed significant progress in both groups, but the magnitude of progress was greater in the experimental group ($t(224) = -10.944$, $p < .001$) compared to the control group ($t(239) = -6.618$, $p < .001$). The effect size was moderate-to-high in the experimental group ($d = 0.73$) and low-to-moderate in the control group ($d = 0.43$). Additionally, a significant positive correlation was identified between the pre-test and post-test ($r = .198$, $p = .003$). The results confirm the first hypothesis and demonstrate the effectiveness of the formative program in developing scientific and technical knowledge.

Results of the second hypothesis: development of scientific skills

The second hypothesis addressed the influence of the intervention program on the development of students' scientific skills. At the initial testing, the two groups recorded close results (Mexperimental = 16.18; Mcontrol = 15.53), without statistically significant differences.

Table 7.17. Descriptive statistics for the final scientific skills test results of the experimental and control groups

Group	Min	Max	Mean	Standard deviation
Experimental	9	24	18.42	2.867
Control	9	22	16.34	2.770

After the implementation of the program, the experimental group obtained a mean of 18.42 points, compared to 16.34 points in the control group . The difference between the groups proved to be statistically significant ($t(463) = 7.941$, $p < .001$), indicating a positive effect of the intervention on the development of inquiry and analysis skills.

Comparisons between the pre-test and post-test showed significant progress in both groups, but with a considerably larger effect size in the experimental group (d = 0.80 - large effect) than in the control group (d = 0.35 - small to moderate effect). Furthermore, pre-test and post-test scores were positively and significantly correlated (r = .187, p = .005). These results confirm the second hypothesis and support the role of inquiry activities in developing scientific skills.

Results of the third hypothesis: development of technological knowledge and skills

The third hypothesis monitored the impact of the program on the development of technological competences. Initial results indicated comparable levels between the two groups (Mexperimental = 15.25; Mcontrol = 14.92).

Table 7.19. Descriptive statistics for the initial and final results of technological knowledge and skills for the experimental group

	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Skewness index**		**Kurtosis index**	
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**
Initial Technology	225	14	8	22	15.25	2.850	-.043	.162	-.605	.323
Final Technology	225	13	10	23	18.51	2.155	-.682	.162	.449	.323
Valid N (listwise)	225									

At the final testing, the experimental group recorded a significant increase in performance, reaching a mean of 18.51 points, while the control group obtained a mean of 17.10 points. Statistical analysis highlighted significant progress in both groups, but it was much more pronounced in the experimental group $t(224) = -15.900$, $p < .001$ than in the control group $t(239) = -12.698$, $p < .001$.

The effect size was very high in the experimental group (d = 1.06), compared to the control group (d = 0.82), indicating a strong impact of practical and experimental activities on the development of technological competences. The correlation between pretest and posttest was positive and statistically significant ($r = .268$, $p < .001$). The results confirm the third hypothesis and highlight the efficiency of strategies based on experiment and practical application.

Results of the investigation sheets

The analysis of the 10 investigation sheets applied to the experimental group highlighted a generally positive evolution of students' performances. The means increased from 20.91 points for the first sheet to values above 22 points in the intermediate stages, remaining relatively stable until the end.

Correlations between successive sheets were all positive and statistically significant, ranging between $r = .174$ and $r = .542$, indicating the stability of students' performances over time. Paired samples t-tests showed that only the difference between sheet 1 and sheet 2 was statistically significant ($t(224) = -2.583$, $p = .010$), with the other comparisons highlighting the stabilization of progress.

Repeated measures ANOVA analysis revealed a significant effect of time on performance ($F = 4.43$, $p < .001$) and a significant interaction between time and class ($F = 25.49$, $p < .001$), showing that students in the 3rd and 4th grades had different progress trajectories (p. 2). In contrast, gender did not significantly influence the evolution of performance ($p = .286$).

Results of the Technical Sheet

The analysis of the technical sheets was carried out on a sample of 225 students, of whom 139 were from the 3rd grade and 86 from the 4th grade. The results highlighted initial differences between classes, with 4th-grade students obtaining higher scores in the first evaluation ($M = 24.66$) compared to those in the 3rd grade ($M = 22.15$).

Over the course of the three successive evaluations, a trend of convergence between the performances of the two classes was observed. Multivariate analysis confirmed the existence of a significant effect of time on results (Pillai's Trace = .040, $F = 4.541$, $p = .012$) and a significant time x class interaction (Pillai's Trace = .096, ($F = 11.661$, $p < .001$). No significant effects of gender on the evolution of performance were identified ($p = .949$). The analysis of between-subjects effects highlighted a significant effect of class ($F(1, 221) = 41.56$, $p < .001$), but not of gender ($F(1, 221) = 1.80$, $p = .182$).

7.6. Discussions

The results show that the program based on inquiry-based learning and the use of technical sheets significantly improved students' knowledge and skills, with the effects being stronger in the experimental group than in the control group. Progress was gradual and constant, and statistical analysis confirms the positive influence of the intervention. No relevant differences were identified between girls and boys, suggesting the equitable nature of the program.

7.7. Research limitations

The main limitations of the study are the use of a quasi-experimental design without random assignment of participants, the use of assessment instruments created specifically for the research and the impossibility of evaluating long-term effects. Additionally, certain external factors, such as student motivation or teacher instructional style, were not completely controlled.

7.8. Future research directions

Future research should include larger samples and randomized groups, analyze the maintenance of effects over time and investigate the role of factors such as motivation, self-efficacy and learning styles. Furthermore, the use of qualitative methods could provide a deeper perspective on students' experiences.

7.9. Practical implications

The results support the use of inquiry-based learning and technical sheets in teaching science and technology at the primary school level. These methods contribute to the development of knowledge, practical skills and applied thinking, being effective and inclusive for all students. The progressive organization of learning activities promotes the consolidation of results.

7.10. Conclusions

The study confirms that the formative program based on inquiry-based learning and the use of technical sheets has a positive impact on student performance. The experimental group recorded greater progress than the control group and the results highlight the efficiency of active teaching methods and the need to integrate them into science teaching in primary education.

CHAPTER 8. RESEARCH ON STUDENTS' ATTITUDES TOWARDS SCIENCE AND TECHNOLOGY/ENGINEERING

8.1. Research purpose

The purpose of the research was to investigate the impact of the formative intervention program based on learning through experiments and the use of technical sheets on primary school students' attitudes towards science and technology. The research aimed to identify how experimental activities influence students' interest, motivation and perceptions regarding the Science discipline and the scientific field in general.

8.2. Research objectives

The research aimed to evaluate students' attitudes towards the Science discipline and towards science in general, to compare the results obtained by students in the experimental group and the control group, to analyze the relationship between attitudes and school performance and to investigate the effects of experimental activities and the use of technical sheets on students' interest and motivation for learning science.

8.3. Research hypothesis

The research hypothesis assumes that students included in the formative intervention program, based on learning through experiments and the use of the technical sheet, will manifest a positive attitude at a higher level towards science and technology compared to students in the control group.

8.4. Research methodology

The research was quantitative, experimental in nature, conducted using an experimental group and a control group. The study took place in two stages, during the periods of March–May 2023 and February–June 2024.

8.4.1. Participants

The research sample included 465 students from the 3rd and 4th grades, of whom 53.55% were boys and 46.45% were girls. The majority of the students included in the research were 3rdgrade students (64.09%), while 35.91% were 4th-grade students. The participants came from several educational institutions: "Mihai Eminescu" Secondary School Zalău, "Porolissum" Secondary School Zalău, "Avram Iancu" Sports High School Zalău, "Sf. Nicolae" Orthodox Theological High School Zalău, "Lucian Blaga" Secondary School Jibou and "Simion Bărnuțiu" Secondary School Zalău. Most of the students involved in the research come from "Mihai Eminescu" Secondary School Zalău.

8.4.2. Procedure

The educational intervention program was implemented within the activities carried out in the Science discipline. The questionnaires were administered in the school environment under controlled conditions to ensure a correct understanding of the items and proper completion of the responses.

8.4.3. Research instrument

Two questionnaires were used: the Science Discipline Attitude Questionnaire and the Scientific Attitudes Questionnaire. In the preliminary stage, 21 teachers evaluated the utility of the instruments: 11 teachers preferred the first questionnaire and 10 teachers supported the use of the second one.

The Science Discipline Attitude Questionnaire comprises 25 items formulated as statements, was constructed using a five-point Likert scale, and recorded good reliability (Cronbach Alpha $\alpha = 0.807$). The Scientific Attitudes Questionnaire, adapted from the EpiSTEMe project, contains 25 items organized into five dimensions and achieved an acceptable internal consistency (alpha = 0.703). The Alpha coefficient values for the subscales were: perception of the science teacher ($\alpha = 0.543$), anxiety towards science ($\alpha = 0.714$), value of science in society ($\alpha = 0.649$), self-concept about science ($\alpha = 0.648$), and desire to do science ($\alpha = 0.813$).

8.5. Results

Science discipline attitude questionnaire

Students in the experimental group obtained a mean score of 89.93 points (SD = 13.075), compared to 88.17 points (SD = 11.161) in the control group. The difference of 1.76 points indicates a favorable trend for the experimental group.

Table 8.10. Independent samples t-test results regarding the attitude towards the Science discipline

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Science Discipline Attitude Questionnaire Experimental Class	Equal variance assumed	1.478	.225	1.563	463	.119	1.758	1.125	-.453	3.969
	Equal variance not assumed			1.555	441.468	.121	1.758	1.131	-.464	3.981

Statistical analysis using the independent samples t-test (Table 8.10) highlighted the homogeneity of variances (Levene F = 1.478; p = 0.225). The result of the t-test (t = 1.563; df = 463; p = 0.119) showed that the difference between groups is not statistically significant. The 95% confidence interval [-0.453; 3.969] includes the value zero, confirming that the observed differences can be explained by normal score variations.

Correlation analysis revealed a moderate and significant relationship between the two attitude questionnaires. In the experimental group, the Pearson coefficient was r = 0.435 (p = 0.000) and in the control group, r = 0.450 (p = 0.000). The Spearman coefficient values (r = 0.440–0.478; p = 0.000) confirm this relationship.

Correlations between the attitude towards the Science discipline and students' performances were low. In the experimental group, the coefficients ranged between r = -0.004 and r = 0.213 and in the control group between r = -0.059 and r = 0.068. Most p-values were greater than 0.05, indicating the absence of statistically significant relationships.

The results only partially support the research hypothesis, because the experimental group obtained higher mean scores, but the differences were not statistically significant.

Scientific attitudes questionnaire

Students in the experimental group obtained a mean score of 86.86 points (SD = 10.179), and those in the control group a mean score of 86.22 points (SD = 9.856). The difference between groups was only 0.64 points.

The results of the t-test showed that the variances are homogeneous (Levene F = 0.885; p = 0.347) and the difference between groups is not statistically significant (t = 0.690; df = 463; p = 0.491). The 95% confidence interval [-1.185; 2.467] includes the value zero.

Subscale analysis revealed similar results between groups. For the perception of the science teacher, the means were 12.59 and 12.55 (t = 0.191; p = 0.849). For anxiety towards science, the experimental group recorded a slightly lower mean (9.56 compared to 9.78), but the difference was not significant (t = -0.577; p = 0.564). For the value of science in society, the means were almost identical (20.33 and 20.32; (p = 0.978). Regarding self-concept about science, the means were 18.67 and 18.52 (p = 0.688) and for the desire to do science, 25.71 and 25.05 (p = 0.210).

Correlations between the two questionnaires were moderate and statistically significant both in the experimental group (r = 0.435; p = 0.000) (Table 8.18) and in the control group (r = 0.450; p = 0.000) (Table 8.19). In contrast, the relationships between attitudes and school performance were weak, with coefficient values ranging between (r = 0.095) and (r = 0.156) in the experimental group and close to zero in the control group. The results partially support the research hypothesis. Although the experimental group obtained slightly higher scores in most of the dimensions analyzed, the differences were not statistically significant.

General comparative interpretation

Both questionnaires revealed statistically non-significant differences between the experimental group and the control group. However, the means were consistently higher in the experimental group. The moderate correlations between the two instruments (r = 0.435–0.450; p < 0.001) confirm the coherence of the measured constructs and the relationship between the general attitude towards science and the attitude towards the school discipline.

8.6. Discussions

The results indicate the existence of a generally positive perception toward science within both groups. Although the means were consistently higher in the experimental group (86.86 vs. 86.22 and 89.93 vs. 88.17, respectively), the differences were not statistically significant (p > .05).

The moderate and significant correlations observed between the two questionnaires ($r \approx 0.43$-0.45; $p < 0{,}001$) demonstrate the consistency of students' attitudes toward science as a general domain and Science as a discipline.

8.7. Research limitations

The primary limitations of this study include the reliance on self-report instruments, the restriction of the sample to a specific educational context, the low sensitivity of the measurement tools to short-term changes and the moderate values of the Cronbach's alpha coefficients ($\alpha \approx .70$–$.80$).

8.8. Future research directions

Future research should consider extending the duration of educational interventions, combining quantitative methods with qualitative approaches, refining the measurement instruments, and analyzing the influence of confounding variables such as teaching styles, classroom climate, or family involvement. Furthermore, comparative studies evaluating different instructional methodologies are highly warranted.

8.9. Conclusions on the attitudinal dimension

Students in both groups exhibit positive attitudes toward science as a general domain and Science as an academic discipline. Although a favorable trend was observed for the experimental group, it did not reach statistical significance. The two instruments utilized demonstrate convergence, thereby validating the assessment of student attitudes. The results suggest that attitudes are relatively stable and require sustained, long-term educational interventions to undergo meaningful modification. While the intervention based on experimental activities and technical worksheets appears to positively influence student interest and motivation, its effects on the affective dimension are more subtle than those observed at the cognitive level.

CHAPTER 9. CONCLUSIONS

9.1. General conclusions and discussions

The research results highlight a predominantly favorable understanding of modern pedagogical approaches, such as inquiry-based learning and differentiated instruction, among future teachers as well as preschool and primary school teachers. However, this understanding is situated mainly at a declarative and conceptual level, whereas its translation into educational practice is often fragmented, uneven and insufficiently integrated.

The analysis of the inquiry cycle reveals a relatively constant pattern of performance, characterized by better results in the initial stages (formulating questions, literature review/desk research) and final stages (communication, reflection), while the central stages, specifically the formulation of hypotheses and their integration into testing, generate significant difficulties. This model suggests a linear understanding of the investigative process, wherein stages are perceived as independent sequences rather than as an integrated and interdependent process. Although logical relationships are implicit in the structure of the inquiry model, they require systematic practice to be coherently integrated into the investigative process. In this regard, a longer training program could facilitate the consolidation of logical connections between stages and the development of the cognitive flexibility necessary to apply them in varied contexts.

Regarding teaching practice, a discrepancy is observed between contemporary pedagogical discourse and its actual classroom implementation. Although teachers report frequent use of active strategies, differentiation and student-centered learning, their application is predominantly oriented toward tasks of low or medium complexity. Activities involving analysis, autonomous investigation and the validation of results are less utilized, including in the case of activities adapted for students with special educational needs.

In the STEM field, participants' perceptions are generally coherent, with technology being associated with the practical application of knowledge and engineering with design and problem-solving processes. Nevertheless, certain conceptual ambiguities persist in delineating between the two domains, particularly regarding the relationship between processes and products, indicating the need for more rigorous clarification in initial teacher education.

An important aspect highlighted by this research is the potential of experimental and handmade activities to support the educational inclusion of students with special educational needs. The practical, experiential and multisensory nature of inquiry-type and STEM activities facilitated their active participation, offering concrete opportunities for exploration, manipulation and personal expression. Experiments and handmade products contributed to increased motivation, engagement and self-confidence, demonstrating that inquiry-based strategies can provide accessible and effective educational contexts for students with diverse educational needs.

The results of the experimental interventions confirm the efficacy of inquiry-based learning and the use of technical sheets, showcasing significant improvements in student performance at the primary level. Learning progress is gradual and stable, but attitudinal changes toward science occur more slowly and require sustained exposure to active educational contexts. At the same time, observational results suggest that students with special educational needs displayed higher levels of participation and engagement in practical activities compared to predominantly theoretical tasks, which underscores the importance of adapting instructional strategies to individual student needs.

9.2. Original contributions of the research

The research provides relevant contributions at both theoretical and applied levels by clarifying how the inquiry cycle is understood and applied in initial teacher education. The study highlights a differentiated performance pattern across its stages, emphasizing the difficulties associated with integrating the hypothesis into the investigative process.

Furthermore, the research contributes to the understanding of the predominantly declarative and partial character of differentiated instruction in science activities, offering an integrated analysis of the relationship between inquiry-based learning, differentiation and STEM education in preschool and primary school education.

A major contribution of this study lies in integrating the perspective of educational inclusion and highlighting the potential of experimental and handmade activities to facilitate the participation of students with special educational needs. The findings suggest that practical, multisensory and concrete manipulation-based activities can function as tools to make learning accessible and to support the active participation of students with special educational needs in inquiry and STEM activities.

The study provides empirical evidence regarding the efficiency of inquiry-based instructional interventions and highlights the gap between teachers' self-reported perceptions and actual classroom practices.

9.3. Research limitations

The research presents several methodological and contextual limitations that must be taken into account when interpreting the results.

First, the use of convenience samples, which are relatively small in size, limits the generalizability of the findings.

Second, the focus on narrow educational contexts reduces the external validity of the conclusions.

Predominantly cross-sectional or quasi-experimental designs, the lack of randomization and the reliance on self-reporting constitute significant methodological limitations. The absence of direct classroom observation and methodological triangulation reduces the depth of interpretation of the results.

Regarding students with special educational needs, the research did not include a differentiated analysis by categories of disability or types of educational needs, which limits the possibility of formulating specific conclusions regarding the effectiveness of activities for different categories of students with special educational needs.

In addition, the lack of in-depth qualitative analyses and a longitudinal perspective limits the understanding of the dynamics of the educational processes investigated and the evolution of the observed effects over time.

9.4. Future research directions

Future research should aim to expand sample sizes to larger and more diverse cohorts, including international contexts, to increase the generalizability of the results. The use of mixed methodologies, combining quantitative and qualitative methods, is recommended for a deeper understanding of instructional practices and educational inclusion processes. Longitudinal studies are also required to track the evolution of inquiry competencies in both initial and continuous teacher education, alongside investigating the role of psychopedagogical factors such as motivation, self-efficacy and engagement in the implementation of active methods.

Another important direction consists of developing and testing integrated instructional models that combine inquiry-based learning and differentiation in real classroom settings.

A significant research avenue is the analysis of how experimental and handmade activities can be adapted for different categories of students with special educational needs. In this regard, research is needed on the effectiveness of multisensory strategies, visual support and concrete manipulation-based activities in developing the cognitive, social and emotional competencies of students with special educational needs.

Future studies should analyze in greater detail the influence of different educational contexts and the long-term durability of intervention effects on student performance and attitudes. Furthermore, future research should investigate the impact of inquiry and STEM activities on the social inclusion, active participation and autonomy development of students with disabilities, as well as the role of teacher training in designing accessible and inclusive educational contexts.

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