BABEȘ-BOLYAI UNIVERSITY, CLUJ-NAPOCA
FACULTY OF PSYCHOLOGY AND EDUCATIONAL SCIENCES
DOCTORAL SCHOOL "EDUCATION, REFLECTION, DEVELOPMENT"

SUMMARY - DOCTORAL THESIS

Developing the competence to explore biological systems, processes, and phenomena with scientific tools and methods through practical activities and digital technologies. Applications in the 7th grade

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Contents

Keywords: scientific competence, scientific exploration, practical activities, inquiry-based learning, project-based learning, experiential learning, cooperative learning, digital technologies, *e-learning, blended learning, m-learning*

Introduction

Doctoral thesis entitled: *"Developing the competence to explore biological systems, processes, and phenomena with scientific tools and methods through practical activities and digital technologies. Applications in the 7th grade"* examines the impact of practical activities and digital technologies on the development of students' competence to explore biological systems, processes, and phenomena using scientific tools and methods, in the context of Biology education in the 7th grade. Within the current educational paradigm, which emphasizes competence development – defined as a functional integration of knowledge, skills, and attitudes (European Council, 2018) – the discipline of Biology contributes essentially in fostering scientific competences, offering educational experiences that integrate both experimental, applied activities (Leite & Dourado, 2013) and digital technologies (Oakes, 2009; Jaipal, 2009). The active engagement of students in exploring the living world, based on practical activities that include observation, investigation, experimentation, cooperation, and the use of digital tools facilitates the development of scientific knowledge, skills and attitudes (Suyanto et al., 2022; Kapici et al., 2019; Nwohocha, 2024).

The motivation for choosing this research topic stems from the need to adapt the teaching and learning of Biology to a more interactive and practice-oriented approach, aimed at fostering the competence of scientific exploration through learning experiences grounded in the application of scientific methods. Moreover, this study reflects the imperative of aligning traditional, lecture-based teaching methods with the current pace of technological advancement by integrating digital tools into the educational process. We consider that practical activities, combined with the use of digital technologies, offer students the opportunity to directly explore biological concepts, thereby facilitating the development of conceptual and procedural knowledge, systematization and practical skills, as well as collaborative attitudes and critical interpretation of information, all of which are formed during the seventh grade.

The aim of the thesis is to investigate the impact of the systematic use of practical activities and digital technologies on the development of general competence 1: *"exploring biological systems, processes and phenomena with scientific tools and methods"* (Biology Curriculum, 2017), among seventh-grade students through the study of Biology. The research aims to demonstrate the effectiveness of this instructional approach by implementing an intervention program grounded in the scientific content related to the seventh-grade curriculum and based on learning sequences that integrate practical activities and digital technologies.

The thesis is structured into two main parts: *Part I – Theoretical foundation*, and *Part II – Experimental research*. Both parts are divided into several chapters, each addressing key aspects of competence development through the study of Biology. *Part I - Theoretical foundation* - establishes the conceptual and theoretical framework of the research. It includes an analysis of how Biology is approached in lower secondary education, as well as a review of teaching strategies focused on the development of scientific competences through practical activities and the integration of digital technologies. This section includes three chapters.

Chapter I. The study of Biology in lower secondary school. Conceptual and curricular design considerations analyzes the status and role of Biology in the Romanian educational system, from a curricular and conceptual perspective, taking into account both historical developments and current educational trends. It addresses aspects such as the integration of Biology into the national curriculum, the targeted general and specific competences, the proposed content, and the interdisciplinary nature of the school syllabus.

The first section of this chapter explores the integration of Biology as a compulsory subject in the lower secondary school curriculum in Romania, within the field of "Mathematics and Natural Sciences". It emphasizes its formative and informative role, highlighting Biology's contribution to developing students' ability to analyze the living world through inquiry and exploration, enhancing observation skills, logical and critical thinking, and fostering responsible attitudes toward personal health and the environment (Biology Curriculum, 2017; Marinescu, 2018).

Next, the chapter examines, from both diachronic and synchronic perspectives, the main stages of curriculum reform in Romania and their impact on the curricular and instructional design of the national curriculum, including Biology. Curriculum, understood as a dynamic and interpretable concept (Lunenburg, 2011), has been shaped by differing interpretations and prevailing political ideologies over time, factors that have generated significant difficulties in implementing a coherent framework for educational policies (Potolea et al., 2012; Mândruț et al., 2013).

According to Potolea et al. (2012), the stages of educational reforms in Romania have exhibited both discontinuities and continuities, with positive and negative consequences for the education system. Over time, there has been a clear trend of transition from a traditional educational model, centered on the transmission of content, toward a more modern one, focused on objectives and subsequently on competence development (Ministry of National Education, 2019) (Figure I.1.). However, the paradigm of content-based instruction continues to exert influence in curricular documents and educational practice (Ardelean & Mândruț, 2012, p. 11).

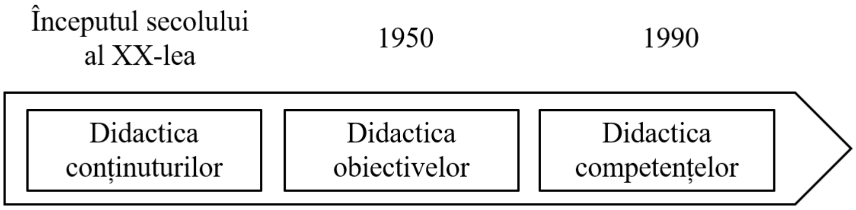

Figure I.1. Evolution of didactic approaches in Romania

The official introduction of the term "curriculum" in Romania, in 1998, marked the beginning of a new educational vision, centered on clearly defined outcomes – currently expressed in terms of competences – and on the coherent articulation of content, teaching strategies, and assessment methods (Georgescu et. al, 1998; Cristea, 1998; Cucoș, 2006; Bocoș, 2017). According to the National Education Law of 2011, updated in 2023, competences – defined as a "multifunctional and transferable set of knowledge, skills and aptitudes" (Art. 4) – have become essential educational outcomes, shaping the reconfiguration of both the national curriculum framework and subject-specific syllabi.

The following section of Chapter I analyzes the structure of the lower secondary school Biology curriculum. The revision of the curriculum document, in 2017, marked the transition from an educational system based on objectives to one focused on competences, in alignment with European educational trends. Structurally, the 2017 Biology curriculum includes the following components: *introductory note, general and specific competences, examples of learning activities* associated with these competences*, contents, lists of practical works,* and *methodological suggestions (including assessment guidelines)*.

The analysis of this document was conducted from a reflective and interrogative perspective, following the model proposed by Bocoș (2017) and Pop-Păcurar & Kenyeres (2023), and structured around the guiding questions: *why?*, *what?*, *how?*, *who?*, and *under what conditions? The introductory note* answers the question *why?* (is Biology taught and learned) and highlights that the 2017 Biology curriculum ensures an educational process focused on competence development, aligned with both the TIMSS Science Framework (2011) and the European Parliament and Council Recommendation on Key Competences for Lifelong Learning (2006/962/EC). The subject also contributes to the development of behavioral and axiological benchmarks (values and attitudes), such as "cooperation between individuals;

observation skills and receptiveness; investigative spirit; critical interpretation of observed facts", among others (Biology Curriculum, 2017).

The general competences together with the *specific competences* also answer the question *why?*. *General competences* represent the knowledge, skills, and attitudes acquired by students at the end of a learning cycle (four years). These include: *"1. Exploring biological systems, processes and phenomena with scientific tools and methods*; *2. Communicating appropriately in various scientific and social contexts; 3. Solving real-life problems in the living world based on logical thinking and creativity*; *4. Promoting of a healthy lifestyle in a natural environment conducive to life"* (Biology Curriculum, 2017). These general competences are developed progressively and cumulatively through the achievement of specific competences over each academic year (Pop-Păcurar, 2013). Derived from the general ones, *specific competences* are intended to be acquired over the course of a single school year and are characterized by gradual progression and increasing complexity at each grade level.

The categories of *learning activities* and *methodological suggestions* answer the question *how?* They guide the educational process toward applicability and competence development by creating appropriate learning contexts. The 2017 Biology curriculum concludes with a set of teaching strategies and assessment benchmarks applicable to each grade level, highlighting both positive aspects and areas for improvement.

The question *what should be taught and learned?* is addressed through an analysis of the content and practical work set out in the syllabus. *The contents* are reorganized according to biological functions (nutrition, relationship, reproduction) and systems (digestive, respiratory, circulatory, excretory, nervous, endocrine, reproductive), serving as reference points for competence development, not as goals in themselves (Ministry of Education and Research, 2019). However, there is a noted persistence of curriculum overload and a lack of authentic implementation of the competence-based paradigm.

Practical work, characteristic of disciplines in the area of sciences, contributes to the development of procedural knowledge and practical skills (Leite & Dourado, 2013). They can be carried out in various contexts – laboratories, nature, museums or industrial units – but their effectiveness depends on the school infrastructure (learning spaces – laboratories and laboratory tools) and the applicability of methodological suggestions. Analyzing the question *under what conditions? (spatio-temporal and material)* correlated with practical work, indicates the presence of material and logistical limitations that hinder the effective implementation of these activities (Ministry of National Education, 2018; Kenyeres et al., 2022).

The question *who?* pertains to the age-specific characteristics of students aged 11–14, who are in the process of cognitive development and identity formation (Piaget, 1983; Spellings, 2005). Being considered digital natives (Prensky, 2001), they require interactive learning environments and the integration of technology in the instructional process.

Finally, the comparison between the Biology curricula from 2008 and 2017 highlights significant conceptual progress – the transition from objectives to competences –, while also revealing the persistence of elements that still require revision. Curriculum reform remains an ongoing process, open to continuous improvement.

The following section of Chapter I provides an applied analysis of the conceptual and operational dimensions of the general and specific competences developed through the study of Biology. Based on the definition of competences provided by the European Council (2018), this section focuses on the development of scientific knowledge, practical skills, and attitudes relevant to the scientific domain.

Scientific knowledge includes both *declarative/conceptual knowledge* – information about biological processes and concepts (De Jong & Ferguson-Hessler, 1996), such as respiration, reproduction or photosynthesis, and *procedural knowledge*, defined as understanding of action sequences and implicit or explicit rules (Star & Newton, 2009), such as the steps of scientific investigation. **Scientific skills** refer to the practical application of this knowledge in learning contexts, through the use of instruments, conducting experiments, communicating results and collaborating in teams. **Scientific attitudes** encompass the value system and beliefs fostered through the study of Biology – curiosity, spirit of observation and investigation, critical interpretation of data and others (Biology Curriculum, 2017).

The Biology curriculum promotes four general competences, with the present research focusing on the first: *"exploring biological systems, processes and phenomena with scientific tools and methods"*, by developing the specific competences intended for seventh grade. These competences encourage students' active involvement in observation, experimentation, and investigation. The specific competences for seventh grade derived from general competence 1 are: *"1.1. systematizing information from texts, videos, tables, drawings, diagrams, used as sources for exploring biological systems, processes and phenomena; 1.2. independently carrying out investigative activities based on worksheets developed by the student; 1.3. assuming roles within the team to solve assigned tasks"* (Biology Curriculum, 2017).

These competences support the integrated development of scientific knowledge, skills and attitudes in grade VII as follows (Figure I.4):

1. *Declarative/conceptual knowledge*: acquisition of information about the function of relating and reproducing.
2. *Procedural knowledge:* knowledge of investigative algorithms involving hypothesis formulation; choice of methods and instruments; carrying out observations; data collection; data interpretation and drawing conclusions; knowledge of instruments and steps for making microscopic preparations and for carrying out demonstration experiments.
3. *Scientific skills*: conducting investigations, performing relevant experiments (e.g., germination, reflex responses or sensory acuity experiments), as well as classification skills and teamwork.
4. *Scientific attitudes:* developing the spirit of observation and inquiry, collaborative teamwork for task completion, and critical interpretation of collected data.

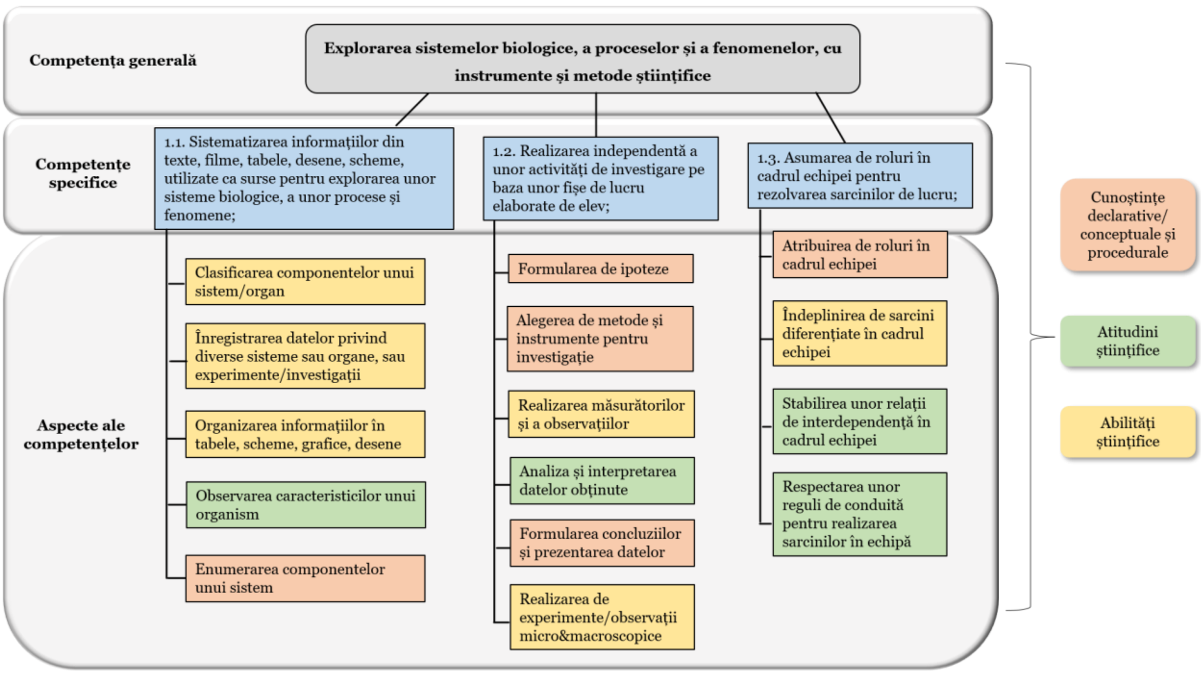

Figure I.4. Components and characteristics of general competence 1, in seventh grade, for the subject Biology (adapted after Arnold et al., 2023)

Continuing the analysis of competences developed through the study of Biology, it is essential to address their practical dimension – namely, the process of curricular operationalization, which involves the transition from the written curriculum to the implemented and, ultimately, the achieved curriculum. According to the model proposed by Voiculescu (2011) and expanded by Ardelean & Mândruț (2012), this process includes four essential stages: (1) *definition of competences*: through curricular documents anchored in an international reference framework; (2) *structuring learning activities and content*: enabling the application and consolidation of competences, through learning contexts involving activities of investigation, observation and experimentation of biological phenomena, both in the classroom and in other environments (laboratory, nature); (3) *selection of teaching strategies* oriented towards the integrated formation of knowledge, skills and attitudes, through active and learner-centered methods – working with text or graphical representations, inquiry, experiment, demonstration, modeling, debate, case study, role play (Bîrnaz, 2019); (4) *assessment of competences*: establishing assessment standards and performance descriptors at both micro and macro levels, ensuring consistent evaluation – considering the dimensions of *knowledge, application, or reasoning* (Ministry of Education and Research, 2019), as well as the cognitive objectives: *knowledge, comprehension, application, analysis, synthesis, and evaluation* (Potolea et al., 2011).

Finally, Chapter I examines the interdisciplinary nature of the Biology Curriculum. Biology supports an integrated approach to knowledge through the presence of concepts and terms shared with other sciences in the "Mathematics and Natural Sciences" curricular area, as well as through the potential to transfer and adapt Physics and Chemistry concepts in explaining biological phenomena. Experimental activities – such as pigment extraction, starch detection, or photosynthesis demonstration – make use of interdisciplinary methods, thereby enhancing scientific learning through applicability and contextualization. Although the stated educational outcomes emphasize the integrative potential of Biology, the curriculum document offers limited methodological guidance for implementing interdisciplinary approaches. Both the structure of the curriculum and the organization of content in textbooks maintain a predominantly monodisciplinary perspective, which restricts the implementation of authentic, collaborative, and integrated learning.

In ***Chapter II. Developing the competence to explore biological systems, processes, and phenomena with scientific tools and methods through practical activities***, the concept of practical activity is theoretically grounded and categorized based on the context in which these activities occur – either in the laboratory or in nature. The chapter also analyzes the main forms of learning facilitated through such activities: inquiry-based learning, experiential learning, project-based learning, and cooperative learning, as well as the methods of implementing practical activities within educational practices. It highlights the role of practical activities in developing students' scientific competences, alongside the challenges associated with integrating them into classroom instruction.

The first section of the chapter focuses on clarifying the conceptual meanings associated with practical activities that can be conducted in the laboratory (Leite & Dourado, 2013) or in nature (Bokor et al., 2014). *Practical activities carried out in the laboratory* are characterized by strict control of variables, the use of scientific equipment, and systematic organization according to the scientific method (Hofstein & Lunetta, 2004; Abrahams & Reiss, 2012). According to Leite and Dourado (2013), these tasks facilitate the acquisition of procedural knowledge and the reinforcement of conceptual knowledge by integrating theoretical aspects with practical skills. In the context of the development of general competence 1, in seventh grade, through the study of the subject Biology, relevant practical activities may include micro- and macroscopic observations, preparation of microscope slides, dissections, identification of physiological processes, investigation of environmental factors affecting plant germination and growth, and demonstrative experiments (Biology Curriculum, 2017). *Practical activities carried out in nature* provide students with authentic contexts for observing phenomena in their real dynamics, fostering the development of a responsible attitude towards nature (Funderburk, 2016; Dourado & Leite, 2013). The Biology Curriculum (2017) recommends for seventh grade students activities such as observing how environmental factors influence plant and animal growth and development, as well as investigating reproductive behaviors and defense mechanisms in various species.

Subsequently, Chapter II discusses the main types of learning that are engaged through practical activities: *inquiry-based learning, experiential learning, project-based learning,* and *cooperative learning*, each of which specifically contributes to the formation of scientific literacy and facilitates exploration of the living world.

Inquiry-based learning (IBL) is a learner-centered process that involves formulating questions, planning and carrying out experiments, collecting and interpreting data, and presenting findings (National Research Council, 1996, p. 23). IBL encompasses both "*mind-on*" (research-based) and "*hands-on*" (practical experimentation) activities (Llewellyn, 2013) and fosters the development of cooperation (Constantinou et al., 2018), procedural knowledge (Arnold et al., 2023) and scientific skills (Taramopoulos & Psillos, 2021; Șahintepe et al., 2020). Thus, IBL provides an optimal framework for the development of all the specific skills derived from general competence 1, especially the last two, among seventh graders through the study of Biology.

Experiential learning (*EL)* is a process in which knowledge is constructed through direct experience (Kolb, 1984). In science education, EL facilitates the development of competences through conceptualization and transfer of experience from theory to practice (García-Sánchez & Luján-García, 2016). According to Kolb's (1984) cycle, practical activities provide authentic contexts for active engagement, reflection and structuring knowledge. Therefore, EL supports the formation of general competence 1, in seventh grade, through direct interaction with the object of study, a key aspect also recommended by the Biology Curriculum.

Project-based learning (PjBL) is a structured teaching-learning-assessment method, similar to inquiry-based learning, that engages students in inquiry-driven research guided by concrete questions and tasks, resulting in concrete products produced by the students (Krajcik & Blumenfeld, 2006). In the field of science education, the specific form of *project-based science learning* (PBS) has been introduced, which involves students in activities similar to scientific inquiry and promotes cooperative attitudes and practices of exploration, investigation, interpretation and presentation of results (Blumenfeld et al, 2000; Markula & Aksela, 2022). Also, this type of learning develops investigative, scientific and practical skills (Spence et al., 2020; Achappa et al., 2020). Implementing PjBL can stimulate the development of specific competences 1.2 and 1.3 for seventh-grade students through the study of Biology.

Cooperative learning (CL) promotes social interaction, individual accountability, and shared success (Li & Lam, 2013). In science instruction, CL supports the development of cooperative attitudes (Johnson & Johnson, 1991), scientific competences (Chatila & Husseiny, 2017), and practical skills (Okolje et al., 2021), contributing to the formation of general competence 1 and, in particular, specific competence 1.3 in seventh-grade students.

Chapter II then analyzes how to implement practical activities in the educational approach. These include micro- and macroscopic observations, experiments, demonstrations, investigations and science projects (Biology Curriculum, 2017). The effectiveness of practical activities depends on: the use of formal, non-formal and informal contexts, the application of active methods, the integration of digital technologies and the diversification of the organization of students' learning tasks (Millar, 2010; Marinescu, 2018).

Last but not least, Chapter II investigates both the formative potential and the limitations associated with implementing practical activities in Biology instruction. The formative valences include developing the cognitive and affective dimension, stimulating motivation and deepening conceptual understanding, as well as strengthening inquiry-based learning skills (Wellington, 1998; Babalola et al., 2021; Pols et al., 2021). Nature-based activities extend the formal curriculum and contribute to the development of students' axiological dimension (Bokor et al., 2014; Quave, 2014).

However, the implementation of such activities faces several challenges, including lack of adequate facilities (Chala, 2019; Kenyeres et al., 2022), limited teaching time, curriculum overload (Shana & Abulibdeh, 2020), insufficient in-service teacher training (Moore et al., 2020), and an assessment predominantly focused on theoretical knowledge without integrating practical skills (Shana & Abulibdeh, 2020).

Chapter III. Developing the competence to explore biological systems, processes and phenomena with scientific tools and methods using digital technologies analyzes both the theoretical and practical dimensions of using digital technologies (DT) in Biology teaching and learning, with the aim of developing general competence 1. The term *digital technology* is defined in relation to its hardware components (computers, tablets, smartphones) and software elements (digital applications, simulators, educational platforms, artificial intelligence, augmented and virtual reality) (Selwyn et al., 2016).

This chapter proposes a historical framework for the integration of DT in education, outlining the evolution from the pre-digital era to the current age of personal computers and internet, under the influence of social, economic and geographical factors. The diachronic and synchronic analysis emphasizes the potential of DT to support the formation of scientific competences, especially in inquiry and project-based learning contexts (Howard & Mozejko, 2015). The relevance of DT integration in education is supported by European and national policies, such as digital competence training (Council of the European Union, 2018), the DigCompEdu framework (Redecker, 2017) and the national SMART-Edu strategy 2021-2027 (Ministry of Education and Research, 2020).

The chapter also investigates the particularities of DT-mediated instruction by highlighting features such as accessibility, flexibility, interactivity, personalization of the educational process and facilitation of synchronous and asynchronous communication, which support collaboration between participants (Ceobanu, 2016; Albulescu, 2021). Ceobanu (2016) emphasizes the essential role of restructuring information into symbolic systems and the use of visualization techniques, which are particularly relevant for science education – especially Biology – by enabling clear representations of cellular structures, anatomy, and biological phenomena not accessible to direct observation. These principles align with Mayer's Cognitive Theory of Multimedia Learning (2002), which stresses the effectiveness of integrating words and images coherently in the learning process.

The chapter details the main types of digital technologies used in the teaching-learning of Biology, such as *3D apps* (BioDigital Human, Anatomy Learning App), *augmented reality* (EON-XR), *online simulators* (Gizmos, Edumedia) and *educational platforms* (Mozaweb, iNaturalist), which facilitate the exploration of the living world and understanding of natural processes through direct interaction and visualization (Teplá et al., 2022).

Chapter III also analyzes the types of learning associated with the use of digital technologies: *e-learning* (Albulescu, 2021), which provides flexible and interactive remote learning; *blended learning*, which combines face-to-face and online instruction to increase effectiveness (Graham, 2006); and *m-learning*, which uses mobile devices for continuous access to educational resources in various contexts (Ceobanu, 2016). These forms of learning facilitate individual and collaborative study, supporting the development of exploration competence through simulations, virtual models and online experiments, often accessible only in digital environments.

Subsequently, the chapter highlights the specifics of integrating DT into teaching activities, and their role in facilitating the understanding of abstract concepts and complex biological processes through interactive visualization and virtual experimentation (Hsu et al., 2015). Research indicates that, DT are predominantly used in expository methods, but also in exploratory activities, knowledge application, cooperative learning, production of digital resources, and ICT-assisted communication (Valverde-Berrocoso et al., 2021). The instructional design of these activities is grounded in fundamental educational theories such as: *multimedia learning theory* (Mayer, 2014), *constructivism* (Piaget, 1950), *connectivism* (Siemens, 2005) and *multimodal theory* (Kress & Van Leeuwen, 2001). *Multimodal theory* emphasizes the use and integration of different modes of communication (written, visual, sound, gestures, etc.) for constructing complex meanings, facilitating multiple interpretations of scientific signs in the educational process (Oakes, 2009; Jaipal, 2009; Van Rooy, 2012). Effective implementation of DT depends significantly on the TPACK model, which defines the competences of teachers required for appropriate integration of technology in teaching (Aumann et al, 2024).

Finally, Chapter III highlights the main advantages and limitations of digital technology-mediated learning. Benefits include expanded access to resources, diversification of learning experiences, flexibility, and promotion of online collaboration (Albulescu, 2021). In the context of Biology, DT supports the development of scientific literacy by facilitating the understanding of complex phenomena, providing access to otherwise inaccessible processes, enabling active and collaborative learning, and compensating for the lack of laboratory space or equipment (Higgins et al., 2012; Ceobanu, 2022; Barak, 2017; Wolf, 2009). DT also contributes to the development of practical skills (Valverde-Berrocoso et al., 2021) and to the reinforcement of declarative and procedural knowledge (Akgun, 2013). These benefits stem from the enhanced access to, collection of, and analysis of scientific data made possible through DT (Krajcik & Blumenfeld, 2006).

However, several limitations persist, including high costs, the digital divide in terms of access and technological competences of students and teachers (Catalano, 2021; Ceobanu, 2022), and negative cognitive effects such as digital amnesia or reduced reading comprehension (Sparrow et al., 2011; Adam, 2022). Additional challenges include limited authentic communication, insufficient monitoring of student activity, technical difficulties, and longer time requirements for digital activities compared to traditional methods – all of which may impact educational effectiveness (Ceobanu, 2022).

Part II – Experimental research – presents the methodological design of the study, methods of data collection and analysis, as well as the impact of the systematic use of practical activities and digital technologies on the development of general competence 1 in seventh-grade students. This section is structured in two chapters.

Chapter IV. Research design details the methodological foundations of the scientific approach undertaken, with the aim of analyzing how practical activities and digital technologies support the development of the competence of exploring biological systems, processes, and phenomena. The chapter begins with the presentation of the research premises, organized into three main areas:

- ***curricular***, anchored in the paradigm of competence-based education and the effective implementation of the national curriculum for Biology in the 7th grade;
- ***educational***, which supports the integration of practical activities and digital technologies as a response to the demands of modern and adaptable education;
- ***didactic***, focused on correlating curricular outcomes, current educational trends, and learner-centered teaching strategies in support of the development of scientific competences.

Chapter IV further specifies **the purpose of the research**: to investigate the impact of the systematic use of practical activities and digital technologies on the development of general competence 1: *"exploring biological systems, processes and phenomena with scientific tools and methods"* (Biology Curriculum, 2017) – among seventh-grade students in the study of Biology.

The research objectives were aimed at analyzing the impact of an experimental intervention program, based on the integration of practical activities and digital technologies, on the formation of general competence 1 in seventh-grade students, within the subject of Biology:

- *Objective 1* – To design and implement an experimental intervention program based on the systematic use of practical activities and digital technologies, within the subject of Biology, in the seventh grade, to support the development of general competence 1 and specific competences 1.1, 1.2, 1.3. through the enhancement of knowledge, skills and attitudes associated with them.
- *Objective 2* – To assess the initial level of general competence 1, before the application of the intervention program, in the pre-experimental stage, in the seventh-grade students, for both the experimental and control groups, by measuring scientific knowledge, skills, and attitudes associated with the specific competences 1.1, 1.2, and 1.3.
- *Objective 3* – To determine the level of development of general competence 1, after the implementation of the intervention program, during the post-experimental stage, in seventh grade students, by comparing the results obtained by the experimental and control groups across the subscales of scientific knowledge, skills and attitudes associated with specific competences 1.1, 1.2, 1.3.
- *Objective 4* – To analyze the long-term effectiveness of the intervention program on the formation of general competence 1, by comparing the results of the experimental group across the subscales of knowledge, scientific skills, and attitudes associated with the specific competences 1.1, 1.2, and 1.3, in both the post-experimental and retesting stages.
- *Objective 5* – To propose integrated teaching strategies for the development of general competence 1 and, implicitly, its related specific competences (1.1, 1.2, 1.3) based on the systematic use of practical activities and digital technologies in the teaching-learning process of Biology for seventh-grade students.

In accordance with the aim of the research, the investigative approaches carried out were guided by the following **research questions**:

1. Do practical activities and digital technologies improve the level of development of the general competence 1: "*exploring biological systems, processes and phenomena*

with scientific tools and methods" (Biology Curriculum, 2017), among students of the seventh-grade, through the study of Biology?

2. Does the systematic use of practical activities and digital technologies in Biology lessons increase the level of scientific knowledge, skills and attitudes associated with specific competence 1.1: "*systematizing information from texts, videos, tables, drawings, diagrams, used as sources for exploring biological systems, processes and phenomena*" (Biology Curriculum, 2017), in pupils in seventh-grade?
3. Will the systematic application of practical activities and digital technologies in learning sequences within the Biology subject lead to improved scientific knowledge, skills, and attitudes associated with specific competence 1.2: "*independently carrying out investigative activities based on worksheets developed by the student* " (Biology Curriculum, 2017), for pupils in seventh-grade?
4. Will the consistent application of practical activities and digital technologies in the learning sequences in Biology lead to an increase in the level of scientific knowledge, skills and attitudes associated with specific competence 1.3: "*assuming roles within the team to solve assigned tasks*" (Biology Curriculum, 2017), in seventh-grade students?

To meet the formulated objectives and to provide a substantiated answer to the research questions, the study sought to test the following **hypotheses**:

- **general hypothesis**: *the systematic use of practical activities and digital technologies in the teaching and learning of Biology leads to the effective development of general competence 1: exploring biological systems, processes and phenomena with scientific tools and methods in seventh-grade students.*
- **secondary hypotheses:**

1. The systematic use of practical activities and digital technologies in the teaching and learning of Biology will lead to the effective development of specific competence 1.1: "*systematizing information from texts, videos, tables, drawings, schemes, used as sources for exploring biological systems, processes and phenomena*" (Biology Curriculum, 2017) by increasing students' level of related scientific knowledge, skills, and attitudes.
2. The systematic application of practical activities and digital technologies in the teaching and learning of Biology will lead to the effective development of specific

competence 1.2: "*independently carrying out investigative activities based on worksheets developed by the student*" (Biology Curriculum, 2017) by increasing the level of scientific knowledge, skills and attitudes associated with it in students in seventh-grade.

3. The systematic integration of practical activities and digital technologies in the teaching and learning of Biology will lead to the effective development of specific competence 1.3: "*assuming roles within the team to solve assigned tasks*" (Biology Curriculum, 2017), by increasing the level of scientific knowledge, skills and attitudes associated with it in seventh-grade students.

Further, Chapter IV defines the **research variables** as follows:

- **Independent variable:** the experimental intervention program, which involves the systematic integration of practical activities and digital technologies in the teaching-learning process of the subject Biology, in seventh grade.
- **Dependent variable:** the level of development of the competence: "*exploring biological systems, processes and phenomena with scientific tools and methods*" as reflected through the scientific knowledge, skills, and attitudes associated with the derived specific competences, in seventh-grade students.

The research included a **sample of subjects** composed of 176 seventh-grade students, divided into two groups: experimental (90 students) and control (86 students), from urban secondary schools in Cluj-Napoca and Bistrița, aged between 13 and 14 years. The selection was based on the diversity of prior performance in Biology, as assessed in consultation with the subject teachers. No participant presented any special educational needs.

Chapter IV also describes **the experimental intervention program**, focused on developing general competence 1, through the systematic use of practical activities and digital technologies (Figure IV.1.) The intervention aimed at the development of specific competences 1.1, 1.2 and 1.3 and the strengthening of associated scientific knowledge, skills and attitudes. The rationale for this approach was supported by the previously demonstrated theoretical efficiency of practical activities and digital technologies, the applicative nature of Biology, and the need to adapt to the current digital context.

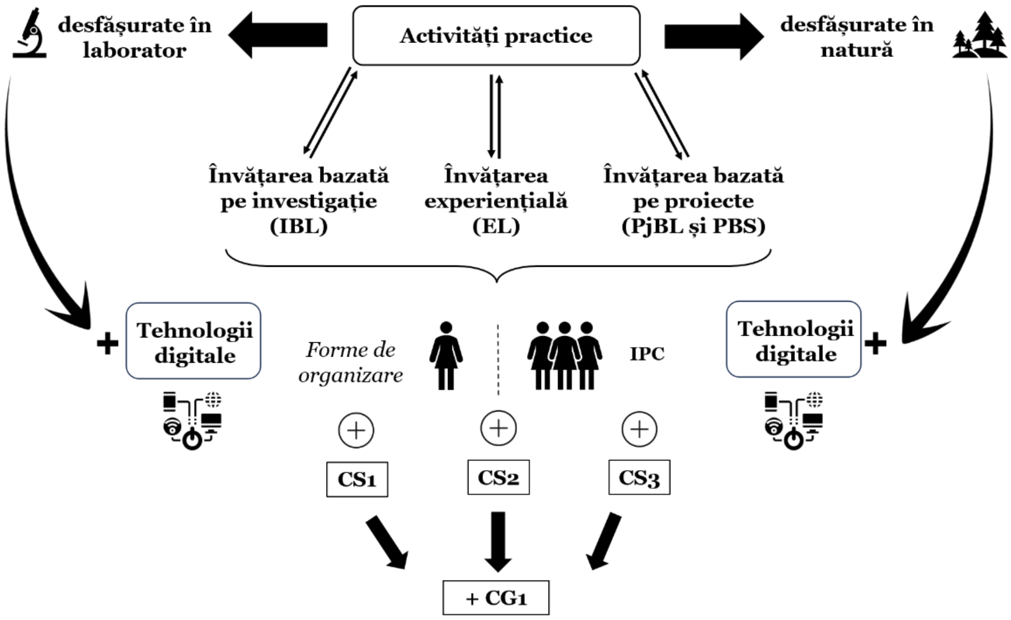

Figure IV.1. The educational intervention model based on the integration of digital technologies and practical activities for developing general competence 1

The intervention program included 40 activities carried out in 20 weeks (October 2023 – May 2024), focusing on topics in the functions of relationships and reproduction, in accordance with the seventh-grade Biology Curriculum. Practical activities were conducted in the laboratory, the classroom and in nature, involving observation of biological processes and structures through experiments, investigations and direct observations. Digital technologies such as 3D applications, augmented reality, educational platforms and simulators were used to support understanding of anatomical structures and physiological processes. The intervention was based on a variety of types of active learning (inquiry-based, project-based, cooperative, experiential, *e-learning*, *m-learning* and *blended-learning*) and promoted an integrated and interdisciplinary approach. The teaching strategy emphasized active-participatory methods, individual and collaborative work, supporting self-assessment, reflection, and active student engagement.

Chapter IV details the **methods and tools used in the research**. The investigation was conducted in a mixed-methods framework, combining quantitative and qualitative approaches to thoroughly assess the impact of the educational intervention. The main methods and tools used include: *curriculum document analysis*; *pedagogical experiment; evaluation instrument; statistical data analysis.* The *analysis of the curricular documents* aimed at examining and comparing the contents and structures of the school curricula for the subject Biology (2008 and

2017) in order to identify the purpose, the targeted competences and instructional pathways. The *pedagogical experiment* consisted in the application of an experimental intervention program for 20 weeks (40 hours) to test the effectiveness of integrating practical activities and digital technologies in the development of specific and general competences in seventh-grade. *The evaluation instrument* consisted of two tests (A and B) (Table IV.2.), which aimed to measure knowledge, skills and attitudes associated with competences 1.1, 1.2 and 1.3. *Test A* assessed the ability to systematize information, while *test B* assessed practical and investigative skills along with collaborative skills.

General competence assessed	Specific competence assessed	Test and type of items
1. Exploring biological systems, processes and phenomena with scientific tools and methods	1.1. Systematizing information from texts, videos, tables, drawings, schemes, used as sources for exploring biological systems, processes and phenomena.	**Test A** ➢ ***Scientific*** (conceptual) ***knowledge***: items 3,4,5;11;12 ➢ ***Attitudes:*** (observation and receptiveness): items: 8;9;14;15; ➢ ***Skills:*** (systematizing information on the basis of pictures, diagrams, texts, etc.): items: 1;2;6;7;10;13
	1.2. Independently carrying out investigative activities based on worksheets developed by the student.	**Test B** ➢ ***Scientific*** (procedural) ***knowledge***: items 1;3;4; ➢ ***Attitudes:*** (collaboration and critical interpretation of information): items: 2;11;12;13;13;14;15; ➢ ***Skills:*** (practical): items: 5;6;7;8;9;10;
	1.3 Assuming roles within the team to solve assigned tasks.	

Table IV.2. Tests used for the assessment of general competence 1 and specific competence 1.1, 1.2, 1.3., in class VII, in the subject *Biology*

Each test was conducted over 50 minutes. **Test A** was administered **individually**, while **Test B** was conducted **in pairs**. The design of the items was based on the recommendations of the European Council (2018), which define competences as a set of knowledge, skills and attitudes, the cognitive objectives formulated by Potolea et al. (2011), and the cognitive dimensions of the Methodological Benchmarks for Biology (2020-2021): knowledge, application and reasoning.

The statistical analysis of the data included the validation of the assessment instrument and the comparison of the results obtained by the experimental and control groups in the three stages of the research: pre-test, post-test and re-test. Data processing and interpretation was performed with IBM SPSS Statistics (v. 29) and graphing was performed in GraphPad Prism (v. 10.2.3).

The assessment tests (Test A and B) were validated in the pre-experimental stage, in September, 2022, on a sample of 52 students in two classes. The statistical validation included the analysis of internal consistency, through the ***Cronbach's Alpha*** coefficient, calculated both for the total sample and for the related subscales (scientific knowledge, skills and attitudes). ***The Pearson correlation*** coefficient was also measured in order to establish the relationship between the items of each subscale. The results confirmed good internal consistency and significant correlations, validating the instrument for measuring the educational intervention's impact.

- Test A (total): **α = 0.91** (very good consistency)

Subscale	Cronbach's Alpha	Pearson correlations	Interpretation of correlations
Scientific knowledge	**α = 0,84** (very good consistency)	- r = 0,741 (items 11 and 12); - r = 0,621 (items 3 and 12); - r = 0,3-0,6 (remaining items); - $p < 0,001$;	Significant and moderate-strong correlations indicate high internal consistency reflecting the similarity of the constructs measured.
Scientific skills	**α = 0,78** (good consistency)	- r = 0.738 (items 1 and 2); - r = 0,693 (items 1 and 13), - r = 0,690 (items 10 and 13); - r = 0,29 - 0,73 (remaining items) - $p < 0,05/0,001$;	All items are significantly correlated; high values confirm the consistency of the measured construct.
Scientific attitudes	**α = 0,73** (good consistency)	- r = 0.846 (items 9 and 14); - r = 0.3-0.7 (rest of items); - $p < 0,05/0,001$; - exception: items 8 and 14 (r = 0.182, not significant);	The items associated with the scientific attitudes subscale, within sample A, measure the same concepts; the lack of correlation between items 8 and 14 can be explained by the different nature of the items (objective vs. semi-objective).

Centralizing table. Statistical validation analysis for test A

- Test B (total): **α = 0.85** (very good consistency)

Subscale	Cronbach's Alpha	Pearson correlations	Interpretation of correlations
Scientific knowledge	**α = 0,78** (good consistency)	- r = 1 (items 3 and 4); - r = 0,48-1 (remaining items); - *p* < 0,001;	Significant-median and very strong correlations indicate conceptual consistency.
Scientific skills	**α = 0,91** (very good consistency)	- r = 0.894 (items 8 and 10); - r = 0,888 (items 7 and 10); - r = 0,826 (items 8 and 9); - r = 0,809 (items 9 and 10); - r = 0.28-0.89 (remaining items); - *p* < 0,05/0,001;	All items are significantly correlated; high values confirm that the items assess a unitary construct.
Scientific attitudes	**α = 0,83** (very good consistency)	- r = 0.974 (items 11 and 12); - r = 0,3 - 0,7 (remaining items); - *p* < 0,05/0,001; - exception: items 2 and 12 (r = 0.224, not significant);	The items associated with the scientific attitudes subscale, in sample B, are moderately and strongly correlated and therefore measure the same concepts; the lack of correlation between items 2 and 12 can be explained by the different nature of the items (objective vs. semi-objective).

Centralizing table. Statistical validation analysis for test B

Chapter IV also describes *the stages of the experimental research*: *pre-experimental, experimental, post-experimental* and *retesting*. In the *pre-experimental stage*, the assessment instrument, consisting of the two tests (A and B) for seventh-grade, was designed and validated using **Cronbach's Alpha** and **Pearson** coefficients (school year 2022-2023); the experimental and control groups were established; an intervention program with 40 activities over approximately 20 weeks was developed and the baseline test was applied (school year 2023-2024). *The experimental phase* (October 2023 - May 2024) consisted of the implementation of the intervention program based on practical activities and digital technologies. *The post-experimental phase* (June 2024) evaluated the immediate impact of the intervention through the final testing of both groups. *The retesting phase* (October-November 2024) measured the sustainability of the results by re-testing only the experimental group.

The entire research considered the respect of ethical principles covering all dimensions of the scientific process: from the formulation of the purpose and the selection of methods, to conducting educational activities, use of the resources, interaction with participants, and the analysis and reporting of results. This has ensured not only the scientific validity of the research, but also the moral responsibility of the researcher towards the field, the institutions involved and the participants.

Chapter V. Results of the experimental research presents a comparative analysis of the results obtained by the experimental and control groups on tests A and B, which assessed the scientific knowledge, attitudes, and skills associated with specific competencies 1.1, 1.2, and 1.3, across the three phases of the research: pre-experimental, post-experimental, and re-testing. Additionally, the results obtained within each group are analyzed and interpreted in order to highlight the evolution of the participants during the research.

In the ***pre-experimental phase***, the aim was to establish the initial performance level of the students in both groups by administering the initial A and B tests, and the results were statistically analyzed, calculating the overall means and those corresponding to each subscale.

<u>Pre-experimental results obtained in test A</u>

The results obtained in the initial test A, which assessed the development level of specific competence 1.1, indicated a similar level of preparedness between the experimental and control groups, thus confirming the sample's homogeneity (Table V.1, Figure V.1). The close means and balanced distribution of scores suggested a low level of initial performance (with scores around 4 out of 10), highlighting the need for an instructional intervention aimed at supporting the development of competence 1.1.

	group	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
mean	**experimental**	90	40,244	19,1618	2,0198
	control	86	42,262	16,1798	1,7447

Table V.1. Means obtained by the experimental group and the control group in test A in the pre-experimental stage

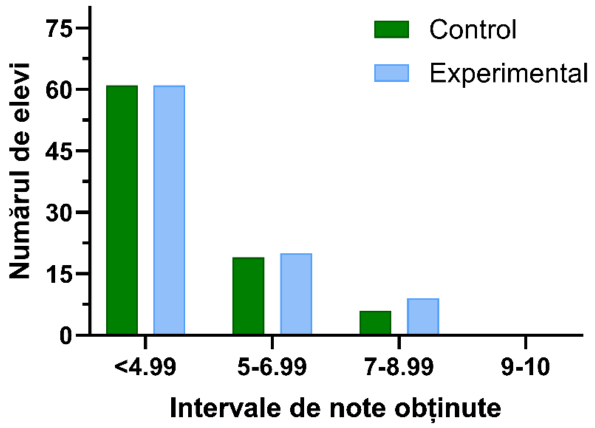

Figure V.1. Mean scores of the experimental and control groups on test A, pre-experimental phase

Although the control group had a slightly higher mean, the difference observed was not statistically significant ($p > 0.05$), according to the independent samples *t-test* (Table V.2). Thus, the null hypothesis (H_0- no significant differences between the groups) was accepted and the alternative hypothesis (H_1- significant differences exist) was rejected. This result confirmed that both research groups started from a comparable level of academic performance, an essential prerequisite for objectively evaluating the effectiveness of the instructional intervention.

Independent Samples Test									
		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
mean	Equal variances assumed	4,513	,035	-,753	,226	,453	-2,0172	2,6793
	Equal variances not assumed			-,756	,225	,451	-2,0172	2,6690

Table V.2. Independent samples t-test results for test A mean scores, pre-experimental phase

The analysis of the scores obtained on the subscales scientific knowledge, attitudes and skills (Figure V.2) revealed a low level of development of competence 1.1 in both groups, with means of approximately 7/17.5, 8/31 and 16/41.5. The absence of significant differences between groups was supported by the results of the independent samples *t-test* (Table V.4), with *p-values* greater than 0.05 for all subscales.

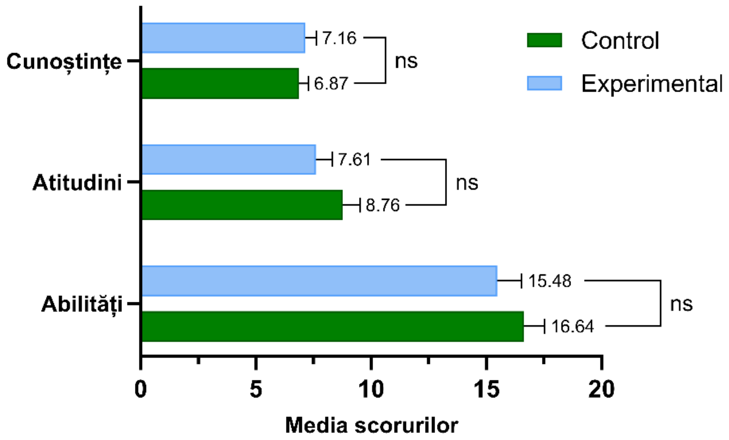

Figure V.2. Average scores of students from the control and experimental groups on the knowledge, skills, and attitude subscales in test A, in the pre-experimental stage

Independent Samples Test								
		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
knowledge	Equal variances assumed	3,641	,058	,454	174	,650	,2893	,6374
	Equal variances not assumed			,455	172,567	,649	,2893	,6354
attitudes	Equal variances assumed	0,252	0,616	-1,111	174	0,268	-1,1447	1,03008
	Equal variances not assumed			-1,11	171,828	0,269	-1,1447	1,03165
abilities	Equal variances assumed	5,041	,026	-,838	174	,403	-1,1618	1,3871
	Equal variances not assumed			-,841	170,599	,401	-1,1618	1,3812

Table V.4. Independent samples *t-test* results for subscale means (knowledge, attitudes, skills) on test A, pre-experimental phase

The results were in line with expectations, considering that the assessment was conducted at the beginning of the seventh grade, after the summer break, and that the targeted competences were yet to be developed. Thus, it was confirmed that both groups initially demonstrated an equivalent level of scientific knowledge, skills, and attitudes associated with competence 1.1, thereby providing a balanced and valid framework for assessing the effectiveness of the intervention.

Pre-experimental results obtained in test B

The results obtained in the initial test B, presented in Table V.5 and Figure V.3, indicated that the experimental and control groups had a relatively equivalent level of training in specific competences 1.2 and 1.3. The balanced distribution of scores across performance intervals (<4.99; 5-6.99; 7-8.99; 9-10) confirmed the homogeneity of the sample and the comparative validity of the intervention.

	group	N	Mean	Std. Deviation	Std. Error Mean
mean	**experimental**	90	53,1389	11,76527	1,24017
	control	86	55,8837	14,72926	1,58830

Table V.5. Mean scores of the experimental and control groups on test B, pre-experimental phase

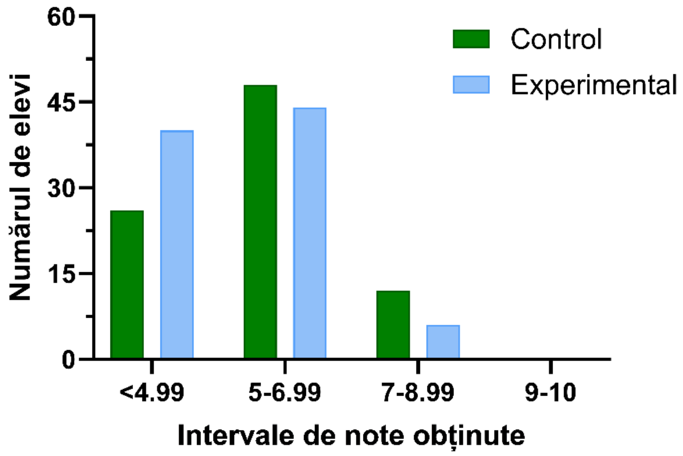

Figure V.3. Scores of the students from the control and experimental groups on test B, pre-experimental phase

The overall averages of the two groups in test B exceeded the threshold of 5 mark, in contrast to the average of about 4 recorded for test A. This difference can be explained by the collaborative nature of test B, which involved team work. Nonetheless, the relatively low level of average performance emphasized the need for instructional intervention and suggested limited prior exposure to practical and inquiry-based activities.

Comparative analysis of the means of the two groups using the independent samples *t-test* (Table V.6) confirmed a statistically insignificant difference ($p > 0.05$). Thus, the null hypothesis (H_0 - no significant difference between the two groups) was accepted and the alternative hypothesis (H_1) was rejected, confirming that both groups had a comparable initial level of preparation.

Independent Samples Test									
		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
mean	Equal variances assumed	3,425	,066	-1,369	174	,173	-2,74483	2,00497
	Equal variances not assumed			-1,362	162,53	,175	-2,74483	2,01512

Table V.6. Independent samples *t-test* results for mean scores on Test B, pre-experimental phase

The scores obtained on the three subscales assessed through test B (Figure V.4) revealed that the control group recorded a statistically significant advantage ($p < 0.05$) only on the knowledge subscale (mean 9.86 compared to 7.57 out of 28), suggesting a higher initial level of procedural knowledge. In contrast, for the attitudes and skills subscales, no significant differences were found between the groups ($p > 0.05$), with the means being similar – approximately 16 out of 32 for attitudes and 19 out of 30 for skills – thus confirming the initial balance between the groups in terms of these subcomponents of competence (Table V.8).

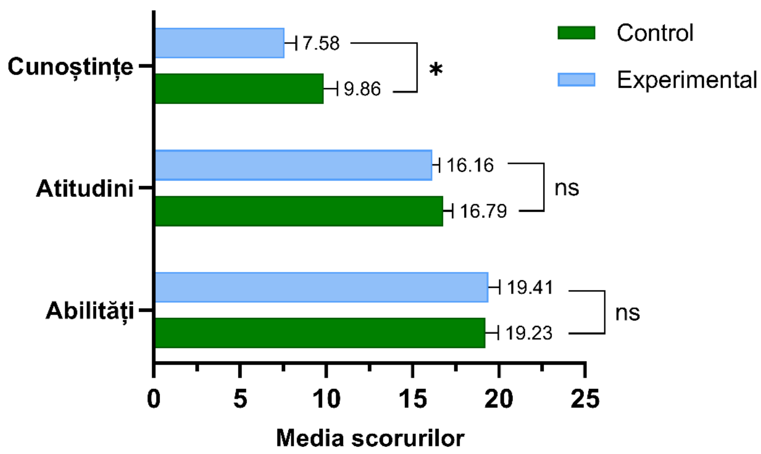

Figure V.4. Average scores of students from the control and experimental groups on the knowledge, attitude, and skills subscales of test B, pre-experimental phase

Independent Samples Test									
		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
knowledge	Equal variances assumed	2,703	,102	-2,189	174	,030	-2,28269	1,04300
	Equal variances not assumed			-2,183	169,377	,030	-2,28269	1,04586
attitudes	Equal variances assumed	4,930	,028	-,947	174	,345	-,63514	,67088
	Equal variances not assumed			-,941	159,986	,348	-,63514	,67475
abilities	Equal variances assumed	1,481	,225	,175	174	,861	,17300	,98875
	Equal variances not assumed			,175	171,031	,862	,17300	,99070

Table V.8. Independent samples *t-test* results for mean scores on the knowledge, attitude, and skills subscales of test B, pre-experimental phase

In conclusion, the data obtained from the initial administration of test B indicated a similar level of development of specific competences 1.2 and 1.3 across the two groups prior to the experimental intervention. At the same time, the relatively low scores emphasized the necessity for a pedagogical approach grounded in practical, investigative, and cooperative activities designed to support the acquisition and consolidation of procedural knowledge, scientific skills, and attitudes.

In the ***post-experimental phase***, the impact of the intervention program on the formation of general competence 1 was assessed by measuring scientific knowledge, attitudes and skills related to the three specific competences, using the final tests A and B. These assessments were applied to both groups and the comparative analysis included both total scores and subscale means. The independent samples *t-test* was used to identify differences between groups, and the paired samples *t-test* was used to assess progress within each group. In addition, Cohen's *d* index was calculated and interpreted to determine the effect size of the intervention.

<u>Post-experimental results obtained in test A</u>

The results of test A in the post-experimental phase indicated a significant performance increase in the experimental group compared to the control group. The difference of 23.71 points between means (71.04 versus 47.32 out of 100) indicates a relevant educational impact.

The *t-test* for independent samples confirmed the statistical significance of the difference (t = 10.01, p < 0.001), and the high effect size (d = 1.51) supports the effectiveness of the teaching intervention based on practical activities and digital technologies in the development of specific competence 1.1.

	group	N	Mean	SD	SEM	t	p	d
media	**experimental**	90	**71,044**	15,31	1,61	10,01	**<,001**	**1,51**
	control	86	**47,326**	16,11	1,73			

Centralizing table: *Comparison of post-test means between control and experimental groups on test A* (Table V.9-V.10)

These differences were also supported by the distribution of scores (Figure V.5): more than 80% of students in the experimental group scored above 5, compared to about 50% in the control group. While the distribution was balanced in the 5–6.99 interval, substantial differences emerged in the 7–8.99 interval, where more than half of the students in the experimental group fell, compared to only five students from the control group. Although only a few students from the experimental group reached the 9–10 range, the complete absence of such scores in the control group nonetheless underlines the positive impact of the intervention.

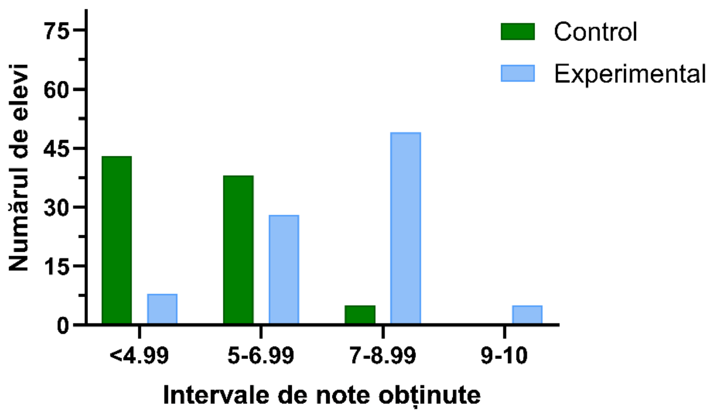

Figure V.5. Scores obtained by students from the control and experimental groups on test A, post-experimental phase

The comparative analysis of subscale scores (knowledge, skills, and attitudes) further demonstrated the efficiency of the intervention program, with students in the experimental group achieving significantly higher results across all three dimensions.

subscales	group	N	Mean	SD	SEM	t	p	d
knowledge	**experimental**	90	11,750	3,43	0,36	9,385	**<,001**	**1,415**
	control	86	6,686	3,72	0,40			
attitudes	**experimental**	90	16,189	6,91	0,72	4,634	**<,001**	**0,699**
	control	86	11,081	7,69	0,82			
skills	**experimental**	90	33,106	7,29	0,76	11,353	**<,001**	**1.712**
	control	86	19,558	8,51	0,91			

Centralizing table: *Comparison of mean scores on the subscales of test A (post-test) between the experimental and control groups* (Table V.11-V.12)

On the knowledge subscale, the experimental group obtained a mean score of 11.75 (out of 17.5), significantly higher than the control group's mean of 6.69. The strong effect size (d = 1.415) further confirms the effectiveness of the intervention. Regarding scientific attitudes, the mean score of the experimental group (16.19 out of 31) exceeded that of the control group (11.08), indicating a moderate impact (d = 0.699), possibly due to the slower pace of attitudinal development and external influencing factors. The greatest differences were observed in the skills subscale, where the experimental group's mean (33.1 out of 41.5) surpassed that of the control group by 13.55 points, highlighting a very strong effect (d = 1.712) on the development of information systematization abilities.

The independent samples *t-test* revealed statistically significant differences between the two groups across all three subscales ($p < 0.001$), supporting the rejection of the null hypothesis (no statistically significant differences). Thus, it can be concluded that the systematic use of practical activities and digital technologies had a positive impact on the development of specific competence 1.1 by enhancing students' scientific knowledge, skills, and attitudes, thereby, supporting ***the validation of secondary hypothesis 1***.

To assess the progress achieved, a within-group analysis was conducted for both groups, comparing performance in the pre- and post-experimental phases. In the case of the control group, the mean score on test A increased from 42.33 to 47.32 (out of 100), indicating modest progress. Although the difference of approximately 5 points was statistically significant (t = 3.523; $p < 0.001$), Cohen's d effect size of 0.38 suggested a small-to-medium magnitude of the intervention's impact. Overall, the results showed that, in the absence of a structured intervention program, improvements remained limited and could be attributed to natural evolution in the educational process.

	test	N	Mean	SD	SEM	t	p	d
media	**Post-test**	86	**47,32**	16,11	1,73	3,52	**<,001**	**0,38**
	Pre-test	86	**42,33**	16,13	1,74			

Centralizing table: *Comparison of pre-test and post-test mean scores for the control group on test A* (Table V.13-V.14)

The score distribution (Figure V.7) indicated a moderate performance improvement in the control group: there was a decrease in the number of students scoring below 4.99 and an increase in those in the 5–6.99 interval, while the proportion of students achieving higher scores (7–10) remained constant. This progress may be associated with continuous practice and the favorable timing of the re-assessment (at the end of the school year).

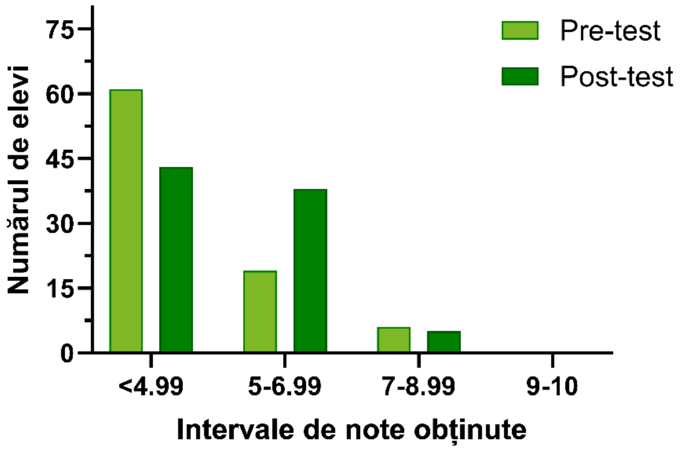

Figure V.7. Scores obtained by students in the control group on test A, pre-test and post-test

In comparison, the subscale analysis showed statistically significant progress only for the subscales 'attitudes' (+2.33) and 'skills' (+2.92), while the average score for 'knowledge' decreased slightly (Figure V.8). The effect sizes support these findings: $d = 0.341$ for skills and $d = 0.295$ for attitudes indicate small to moderate effects, while for knowledge the difference was not significant. The paired samples *t-test* further confirmed these outcomes: $p > 0.05$ and $t = -0.467$ for knowledge (null hypothesis accepted), while for attitudes ($t = 2.733$) and skills ($t = 3.166$), $p < 0.05$ indicated statistically significant differences between pre- and post-test scores (Table V.15).

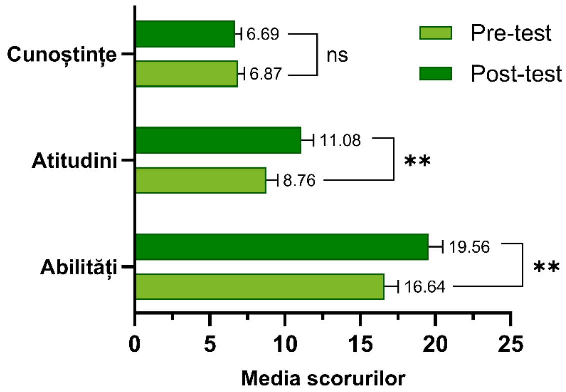

Figure V.8. Mean subscale scores obtained by the control group on test A, pre- and post-test

Paired samples test						
subscale	**Mean**	**SD**	**SEM**	**t**	**df**	**Two-Sided p**
knowledge_posttest-knowledge_pretest	-,1802	3,5817	,3862	-,467	85	,642
attitudes_posttest - attitudes_pretest	2,3256	7,8926	,8511	2,733	85	,008
skills_posttest-skills_pretest	2,9186	8,5501	,9220	3,166	85	,002

Table V.15. Paired samples *t-test* results for comparing mean subscale scores (knowledge, attitudes, skills) obtained by the control group on test A, pre- and post-test

The comparative analysis of scores obtained by the experimental group between the pre-experimental and post-experimental phases revealed a significant increase in student performance, supporting the effectiveness of the implemented intervention program. The mean of the post-test scores (71.04 points) reflected a substantial improvement compared to the pre-test mean (40.24 points), the difference of +30.8 points being statistically significant (t = 14.188; p < 0.001). Also, the high value of the effect size (d = 1.496) indicated a strong impact of the intervention on the students' achievement.

	test	**N**	**Mean**	**SD**	**SEM**	**t**	**p**	**d**
media	**Post-test**	90	**71,044**	15,31	1,61	14,18	**<,001**	**1,49**
	Pre-test	90	**40,244**	19,16	2,01			

Centralizing table: *Comparison of pre-test and post-test mean scores for the experimental group on test A* (Table V.16-V.17)

The distribution of the scores supports the statistical conclusions, since in the pre-experimental stage they were predominantly dispersed in the lower zone of the scale (median around 40), while in the post-experimental stage there was a clear concentration of the values in the upper zone (median around 75), together with a reduction in variability, suggesting a more uniform improvement across participants (Figure V.9).

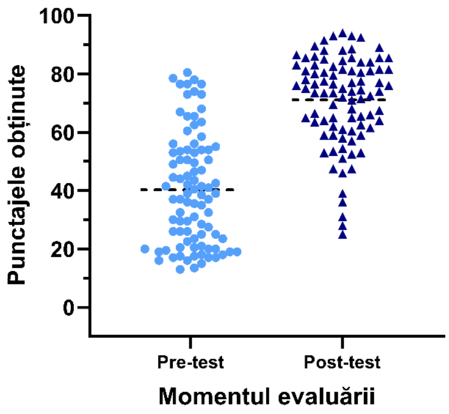

Figure V.9. Score distribution for the experimental group on test A, pre-test and post-test

Significant progress is also evident in the subscale analysis, which shows substantial increases in the mean scores (Figure V.10). Thus, in the knowledge subscale, the average score increased from 7.16 to 11.75 points (out of 17.5), with an effect size of $d = 0.939$, indicating a significant impact of practical activities and digital technologies on the acquisition of conceptual knowledge. For the attitude subscale, the score doubled (from 7.61 to 16.19 out of 31), with d = 1.002, confirming a strong effect on developing scientific receptiveness and observation skills. These results ***validate secondary hypothesis 1***. Nevertheless, since performance levels remain below their maximum potential, the findings suggest the need for long-term consolidation and expansion of such educational strategies.

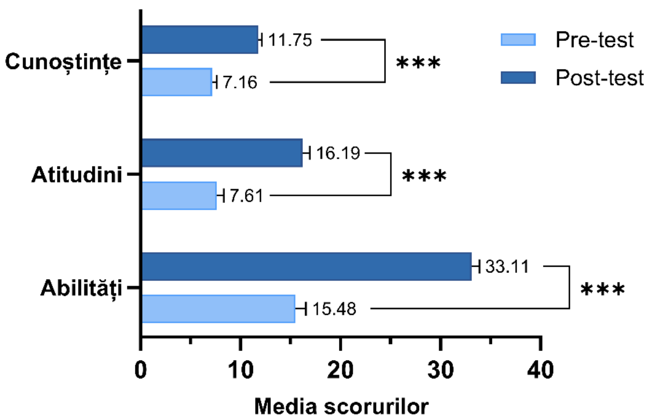

Figure V.10. Mean subscale scores for the experimental group on test A, pre- and post-test

subscale	Mean	N	SD	SEM	t	p	d
knowledge_posttest	11,75	90	3,4325	0,36	8,909	**<,001**	**0,939**
knowledge_pretest	7,15	90	4,4988	0,47			
attitudes_posttest	16,18	90	6,9183	0,72	9,502	**<,001**	**1,002**
attitudes_pretest	7,61	90	6,6039	0,69			
skills_posttest	33,10	90	7,2946	0,76	15,684	**<,001**	**1,653**
skills_pretest	15,47	90	9,9972	1,05			

Centralizing table: *Comparisons between the means of the experimental group, in pre-test and post-test, on the subscales knowledge, attitudes and skills, in test A* (Table V.18-V.19)

Post-experimental results obtained in test B

The results obtained in the final test B, in the post-experimental stage, confirmed the effectiveness of the intervention, indicating a significant impact of the independent variable on the dependent variable, both in overall scores and subscale scores within the experimental group. The mean scores in the experimental group (M = 73.62) exceeded by 17.49 points the mean of the control group (M = 56.13). This difference was statistically significant ($t = 8.918$; $p < 0.001$), reflecting a strong positive effect of the implemented program.

	group	N	Mean	SD	SEM	t	p	d
media	**experimental**	90	**73,62**	12,84	1,35	8,91	**<,001**	**1,34**
	control	86	**56,13**	13,15	1,41			

Centralizing Table: *Comparison of post-test mean scores between the control and experimental groups on test B* (Table V.20-V.21)

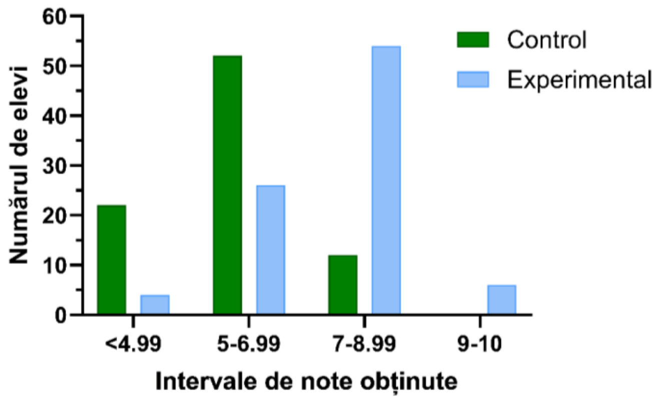

Figure V.11. Scores obtained by students in the control and experimental groups on test B, post-test

The distribution of scores confirms the significant differences between the groups (Figure V.11). In the control group, the majority of students scored below 7 (25% below 5 and 60% between 5-6.99), while only 13% scored between 7-8.99. In the experimental group, only 4% scored below 5, while 60% scored between 7-8.99 and 6.67% between 9-10. These results, supported by a high effect size ($d = 1.345$), indicate a very strong impact of the intervention on the development of specific competences 1.2 and 1.3.

The comparative analysis of subscale scores for knowledge, attitudes, and skills further demonstrated the effectiveness of the intervention. Students exposed to the educational program achieved significantly higher results on all three subscales (Figure V.12).

subscales	group	N	Mean	SD	SEM	t	p	d
knowledge	**experimental**	90	20,05	7,97	0,84	7,558	**<,001**	**1,140**
	control	86	11,09	7,74	0,83			
attitudes	**experimental**	90	19,22	5,53	0,58	5,206	**<,001**	**0,785**
	control	86	14,61	6,19	0,66			
skills	**experimental**	90	24,34	6,17	0,65	4,614	**<,001**	**0,693**
	control	86	20,4302	5,04	0,54			

Centralizing table: *Comparisons between the means obtained by the experimental and control groups, in the post-test, on the subscales knowledge, attitudes and skills, in test B* (Table V.22-V.23)

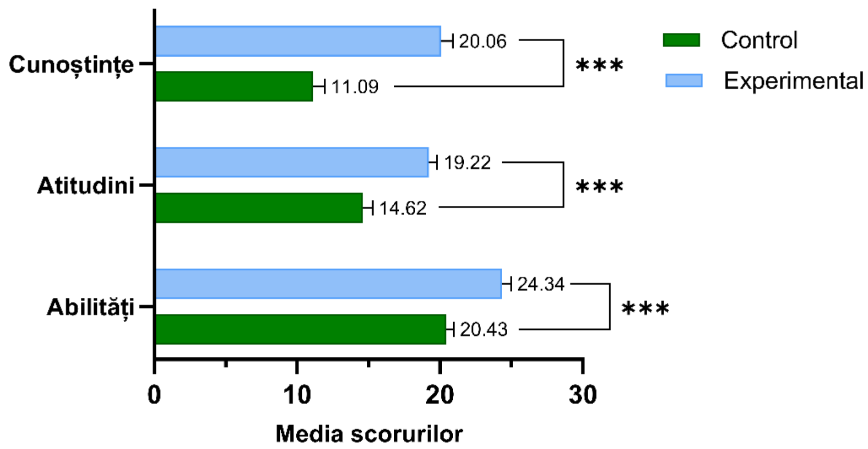

Figure V.12. Mean scores obtained by control and experimental group students on the subscales knowledge, attitudes and skills, at test B, in the post-experimental stage

The greatest difference between groups was in the subscale procedural knowledge, where the experimental group obtained an average of 20.05 out of 28, compared to 11.09 for the control group. The index $d = 1.140$ indicated a strong effect of the intervention, highlighting solid acquisition of procedural knowledge related to formulating scientific investigations and using laboratory instruments. On the attitudes subscale (collaboration and critical interpretation), the mean of the experimental group was 19.22 – 4.61 points higher than the control group (14.61) – with an effect size of $d = 0.785$, indicating a moderate to strong effect. This suggests that the intervention contributed to the development of attitudes of collaboration and critical interpretation, stimulated by team activities and analysis of findings. For practical skills, the mean score was 24.34 compared to 20.43, with a moderate effect ($d = 0.693$), reflecting enhanced ability to apply knowledge in practical and experimental contexts.

All these differences were statistically confirmed by *t-test* for independent samples (t = 7.558; 5.206; 4.614; $p < 0.001$) which supported the rejection of the null hypothesis (no statistically significant difference between means) and ***the validation of secondary hypotheses 2 and 3***. Thus, the intervention based on practical activities and digital technologies positively influenced the formation of specific competences 1.2 and 1.3 through the development of their associated subscales.

Similarly, for test B, an intragroup comparison was conducted between the pre-test and post-test stages for both groups to evaluate progress. In the control group, the analysis of scores revealed no statistically significant differences between the two stages. The post-test mean increased insignificantly (by approximately 0.3 points), remaining around 55 (grade 5.5), and the $d = 0.016$ index indicated a negligible impact of the intervention. The *t-test* for paired samples ($t = 0.151$; $p > 0.05$) confirmed the absence of a significant difference, supporting the null hypothesis (no statistically significant differences between means). These results may be explained by the quantitative and challenging nature of the seventh-grade content, as well as its suboptimal organization and the insufficient time allocated for practical activities.

	Test	N	Mean	SD	SEM	t	p	d
media	**Post-test**	86	**56,13**	13,15	1,41	0,151	**,440**	**0.016**
	Pre-test	86	**55,88**	14,72	1,58			

Centralizing table: *Comparison of pre- and post-test means obtained by the control group on test B* (Table V.24-V.25)

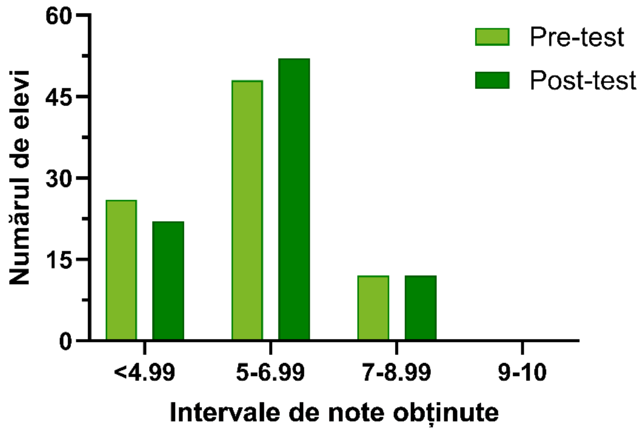

Figure V.13. Grades obtained by students in the control group on test B, at pre-test and post-test

The distribution of grades by interval (<4.99; 5–6.99; 7–8.99; 9–10) showed a decrease in the frequency of grades below 4.99 and an increase in the 5–6.99 range compared to the initial assessment (Figure V.13). However, the number of grades in the 7–8.99 and 9–10 intervals remained unchanged.

The subscale analysis showed a modest increase in the procedural knowledge score (+1.23 points), while the attitude and skill subscales recorded decreases (-1.2 and -2.18 points, respectively), which were not statistically significant (Figure V.14). The only statistically significant difference was observed in the attitude component score ($t = -2.792$; $p < 0.01$) (Table V.26), suggesting a decline in students ' collaboration and critical interpretation of information. This regression may be attributed to the absence of teamwork and practical activities, which are essential for developing these attitudes and skills. The overall scores remain low, underscoring the need for additional educational interventions.

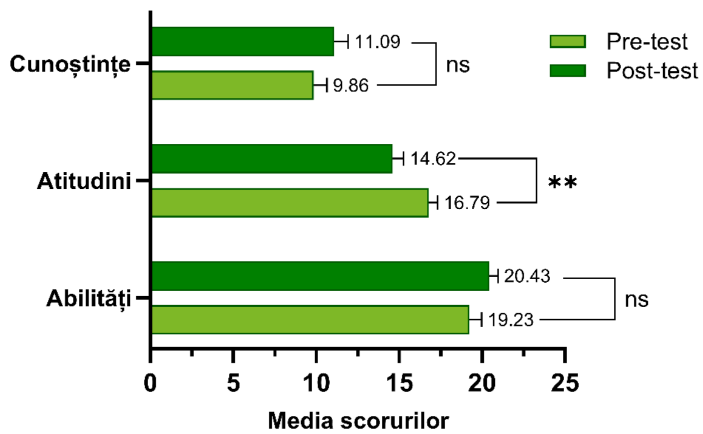

Figure V.14. Mean subscale scores obtained by the control group in the pre- and post-experimental stages on test B

Paired samples test						
	Mean	Std. Deviation	Std. Error Mean	t	df	Two-Sided p
final_knowledge-initial_knowledge	1,23	8,451	,911	1,352	85	,180
final_attitudes - initial_attitudes	-2,17	7,221	,778	-2,792	85	,006
final_skills - initial_skills	1,19	6,175	,665	1,799	85	,076

Table V.26. Paired samples t-test results for the control group on Test B, comparing pre- and post-test subscale scores

Analysis of the results of the experimental group between pre- and post-experimental stages confirmed the effectiveness of the intervention program. The mean scores increased by 20.49 points (from 53.13 to 73.62 out of 100), and the index $d = 1.126$ indicated a strong effect. The recorded differences were statistically significant ($t = 10.681$; $p < 0.001$), showing the overall progress of the students as a result of the experimental intervention.

	test	N	Mean	SD	SEM	t	p	d
media	**Post-test**	90	**73,62**	12,84	1,35	10,68	**<,001**	**1,126**
	Pre-test	90	**53,13**	11,76	1,24			

Centralizing table: *Comparison of pre- and post-test means obtained by the experimental group on test B* (Table V.27-V.28)

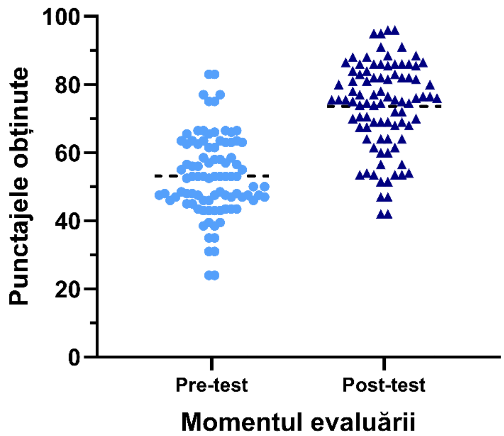

Figure V.15. Distribution of scores obtained by the experimental group on test B at pre-test and post-test

This improvement is also supported by the shift in score distribution, which became more concentrated in the upper intervals in the post-test stage, indicating uniform and meaningful progress at the group level (Figure V.15).

The subscale analysis confirmed the positive impact of the intervention (Figure V.16). As regards the knowledge subscale, the largest increase was recorded (+12.93 points), with a final mean of 20.05 out of a total of 28 points and a strong effect (*d* = 1.279), reflecting the consolidation of procedural knowledge through practical activities. In the skills subscale, the progress was almost 5 points (24.34 compared to 19.4 out of a total of 30 points), with a moderate effect (*d* = 0.493), indicating the development of practical skills. As for the attitudes subscale, the increase was more modest (+3.07 points), with a final score of 19.22 out of 32, suggesting that the development of this dimension requires consistent and long-term implementation of activity-based and digitally supported strategies to effectively support scientific attitudes.

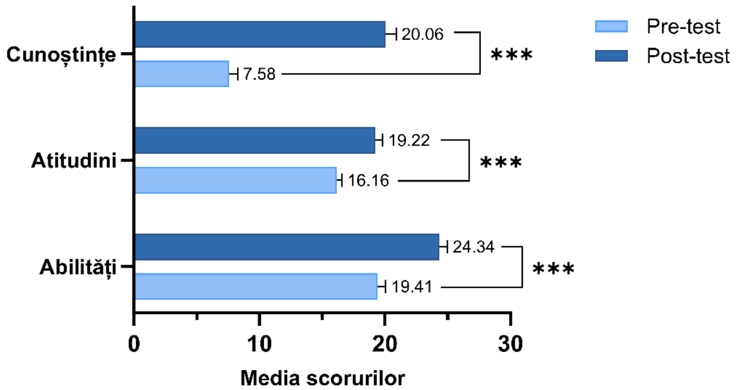

Figure V.16. Mean subscale scores obtained by the experimental group in the pre- and post-experimental stages on test B

subscale	Mean	N	SD	SEM	t	p	d
knowledge_posttest	20,05	90	7,97	0,84	12,135	**<,001**	**1,279**
knowledge_pretest	7,57	90	6,49	0,68			
attitudes_posttest	19,22	90	5,53	0,58	89	**<,001**	**0,480**
attitudes_pretest	16,15	90	3,85	0,40			
skills_posttest	24,34	90	6,17	0,65	4,679	**<,001**	**0,493**
skills_pretest	19,40	90	6,27	0,66			

Centralizing table: *Comparison of pre- and post-test means for the experimental group on test B, by subscale* (Table V.29-V.30)

The differences between the means of the subscale scores were statistically significant according to the paired samples *t-test.* The values obtained (t = 12.135; 8.9; 4.679; $p < 0.001$) validated significant progress between pre-test and post-test on all three dimensions assessed.

In conclusion, the results obtained in test B, both in terms of grade point averages and mean scores, in the post-experimental stage ***confirmed secondary hypothesis 2 and 3***, as well as the effectiveness of the intervention program.

In the ***retesting phase***, the goal was to reassess the subscales (knowledge, attitudes, and skills) associated with the specific competences derived from general competence 1, in order to evaluate the effectiveness and long-term impact of the intervention program. The retesting, conducted exclusively within the experimental group, took place 3–4 months after the completion of the intervention and used the same tests A and B that had been administered in the post-test stage. The comparison between the post-experimental and retesting stages was made using the paired samples *t-test*.

<u>Results obtained on test A in the retesting stage</u>

The results obtained at the retesting stage (M = 69.13) compared to those obtained at the post-experimental stage (M = 71.04) indicated that the positive effect of the intervention was maintained, with a statistically insignificant decrease (t = -0.805; p = 0.423). This slight decline is explainable by the extended school break (summer vacation), during which students did not practice the acquired competences. Therefore, based on the obtained results, it can be concluded that the intervention program's impact on the development of exploratory competence remained stable over time after the program ended.

	Test	**N**	**Mean**	**SD**	**SEM**	**t**	**p**
mean	**Re-test**	90	**69,13**	15,27	1,61	-0,805	**0,423**
	Post-test	90	**71,04**	15,31	1,61		

Centralizing table: *Comparison of post-test and re-test means for the experimental group, on test A* (Table V.31-V.32)

The distribution of scores (Figure V.17) reflected a majority concentration of scores in the 7-8.99 range in both assessments, with minimal differences in the other ranges, suggesting a steady and sustained performance.

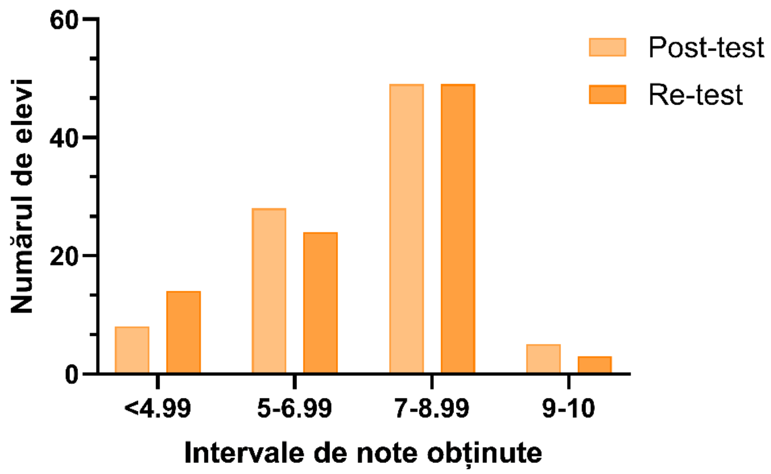

Figure V.17. Post-experimental and retest scores obtained by the experimental group in test A

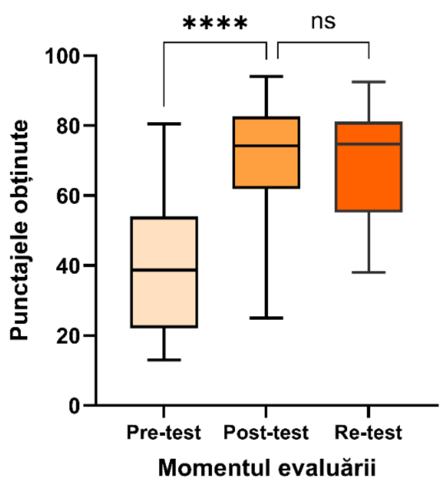

Figure V.20. Score distribution for the experimental group on test A, at pre-test, post-test, and re-test

Figure V.20 highlights a clear performance increase from the pre-test to the post-test, followed by the maintenance of results in the retesting stage. There was a noticeable decrease in the number of students with average scores below 5 and an increase in those scoring between 7 and 8.99, along with reduced score variability and a consistently high median – indicators of performance consolidation.

Comparatively, the analysis of mean scores between the experimental and control groups (Figure V.21) revealed significant progress for the experimental group following the intervention program, whereas the control group's mean scores remained relatively constant. These data support the sustained effectiveness of the program based on practical activities and digital technologies in developing students' competence in exploring biological phenomena.

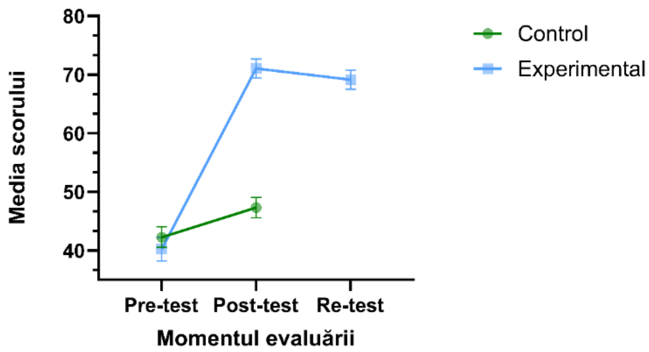

Figure V.21. Evolution of general mean scores on test A for the control and experimental groups, at pre-test, post-test, and re-test

The analysis of the scores obtained by the experimental group in the retesting stage revealed a tendency to maintain the progress recorded in the post-experimental stage on the subscales of knowledge, skills, and attitudes associated with specific competence 1.1 (Figure V.22). The mean score for the knowledge subscale increased slightly (12.49 compared to 11.75), possibly due to initial review sessions that primarily focused on the recall of conceptual content. Moderate decreases were recorded for skills (31.51 vs. 33.10) and attitudes (15.13 vs. 16.18) which may indicate the absence of sustained applied activities. Nevertheless, the scores remained high compared to the initial stage, supporting not only the effectiveness of the intervention program but also the durability of its effects. The results of the paired samples *t-test* ($p > 0.05$) confirmed that the differences between post-test and re-test scores were not statistically significant, thus ***validating secondary hypothesis 1*** regarding the effectiveness of the educational program.

	Mean	N	SD	SEM	t	p
knowledge_retest	12,49	90	3,54	,37372	1,381	0,171
knowledge_posttest	11,75	90	3,43	,36182		
attitudes_retest	15,13	90	6,70	,70652	-1,088	0,280
attitudes_posttest	16,18	90	6,91	,72925		
skills_retest	31,51	90	7,77	,81959	-1,343	0,183
skills_posttest	33,10	90	7,29	,76891		

Centralizing table: *Comparison between the means obtained by the experimental group, in the post-test and re-test, in the subscales knowledge, attitudes and skills, in test A* (Table V.33-V.34)

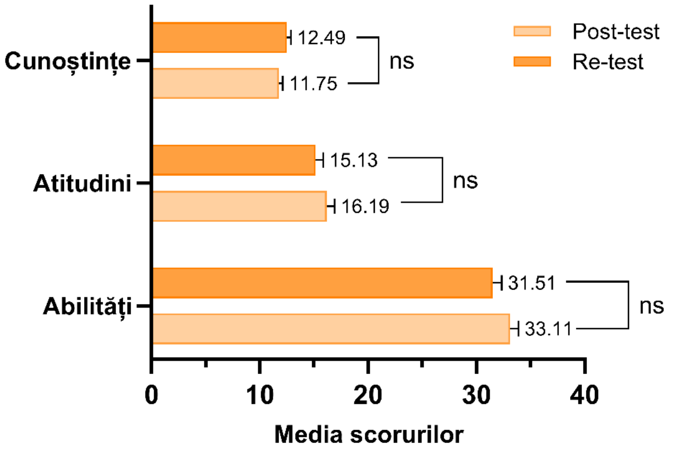

Figure V.22. Mean scores obtained by the pupils in the experimental group, on the subscales knowledge, skills and attitudes, in test A, in the post-experimental and retesting stage

The analysis of the evolution of the scores of the experimental group in test A, in the three stages of the research, showed a significant progress of the subscales related to specific competence 1.1 – knowledge, skills and attitudes – followed by a relative maintenance of these subscales in the retesting stage. The highest scores were recorded at the post-experiment stage, and the greatest progress was noted for the ability subscale (Figure V.24).

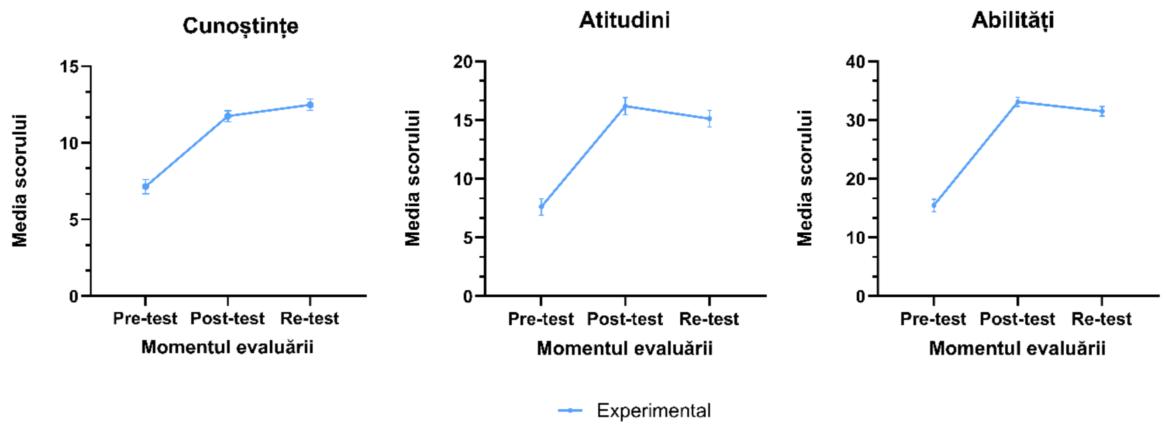

Figure V.24. Evolution of mean scores for the knowledge, skills, and attitudes subscales of test A obtained by the experimental group in the pre-test, post-test, and re-test

The analysis of the evolution of subscale mean scores over the three experimental stages highlighted a significant progression in the experimental group, attributed to the intervention, in contrast with the minor fluctuations in the control group (Figure V.25). The results confirmed the program's effectiveness, particularly in consolidating conceptual knowledge. They also emphasized the need for continued instructional efforts to maintain the developed attitudes and skills.

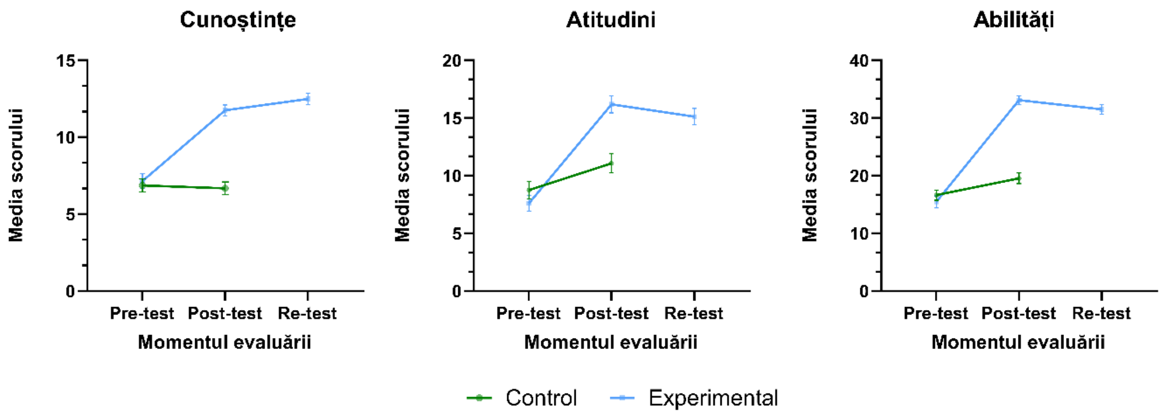

Figure V.25. Evolution of the average scores in test A, on the subscales knowledge, skills and attitudes of the control and experimental groups, at pre-test, post-test and re-test

<u>Results obtained in test B, in the retesting stage</u>

The analysis of the results obtained in test B confirmed the trends observed in test A, showing that a high level of performance was maintained in the retesting stage (70.53 compared to 73.62 in the post-test). The slightly decreasing difference – explainable by the extended school break (summer vacation), during which students did not practice the acquired skills – is not statistically significant (t = -1.565; p > 0.05), according to the paired samples *t-test.* Therefore, the durability of the positive effect of the intervention on the development of specific competences 1.2 and 1.3 was reconfirmed.

	Test	N	Mean	SD	SEM	t	p
mean	**Re-test**	90	**70,53**	11,91	1,25	-1,565	**0,121**
	Post-test	90	73,62	12,84	1,35		

Centralizing table: *Comparison between post-test and re-test means for the experimental group on test B* (Table V.35-V.36)

The distribution of the scores (Figure V.26) showed a maintenance of the performance of the experimental group students between the post-test and the re-test, with the majority of the scores falling in the interval 7-8.99. The differences between ranges were minor and not statistically significant, confirming the stability of the results.

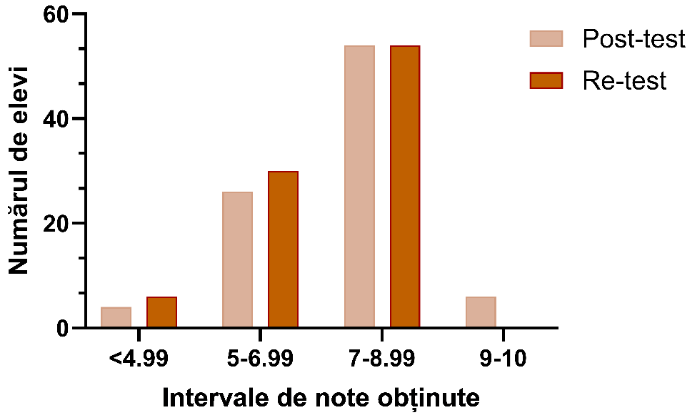

Figure V.26. Grades obtained by students in the experimental group on test B in the post-experimental and retesting stages

The graph in Figure V.29, which displays the score distribution across the three research stages (pre-test, post-test, and re-test), showed that students' performance was moderate and variable in the pre-test, with a mean of 55 (grade 5.5). After the intervention, the post-test mean significantly increased to 75 (grade 7.5), and the score distribution became more homogeneous. In the re-test, performance remained high, with a mean of approximately 70 (grade 7), slightly lower than the post-test, but significantly above the initial level. These data support both the effectiveness of the intervention and the stability of results over time.

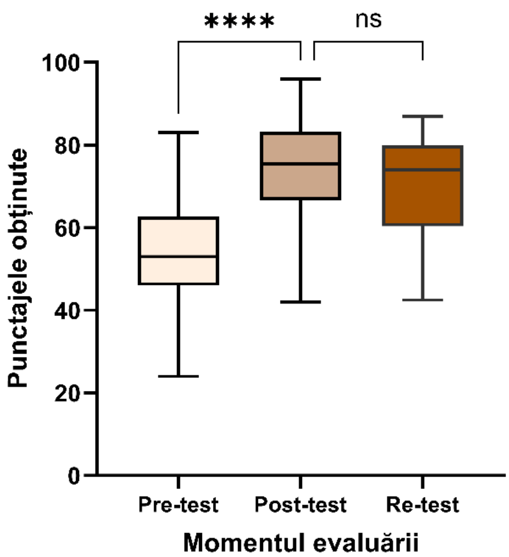

Figure V.29. Distribution of the scores obtained by the experimental group, in test B, at pre-test, post-test and re-test

A comparative analysis of the means between the experimental and control groups revealed the stability of the control group's scores between the pre- and post-test stages, indicating no significant progress. In contrast, the experimental group recorded a significant improvement in performance in the post-intervention stage, largely maintained in the retesting stage six months later. The slight subsequent decrease suggests, however, the need for continuous reinforcement of competences 1.2 and 1.3 through recurring practical activities.

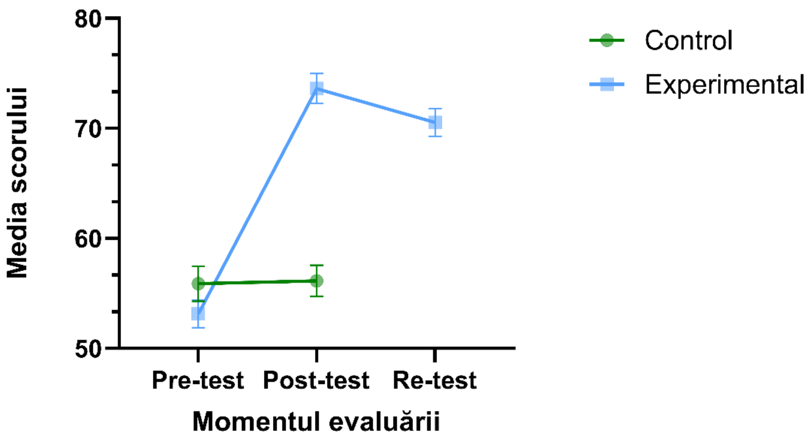

Figure V.30. Evolution of mean scores on test B for the control and experimental groups in the pre-test, post-test, and re-test stages

The collected data revealed that students' performance on the subscales of knowledge, attitudes, and skills associated with specific competences 1.2 and 1.3 remained high, similar to the level recorded in the post-experimental stage (Figure V.31). However, a moderate decrease was observed in the mean scores for procedural knowledge (17.77 compared to 20.05) and for skills (23.14 compared to 24.34), indicating the need for a continuous process of reinforcement and practice in appropriate educational contexts. In contrast, scores for the attitudes subscale slightly increased (19.63 compared to 19.22), a result that may be attributed to contextual and motivational factors. To determine the statistical significance of the observed differences between post-test and re-test mean scores, the paired samples *t-test* was applied. The results indicated that these differences were not statistically significant ($p > 0.05$), supporting the sustained positive effect of the experimental intervention in the medium and long term and ***validating secondary hypotheses 2 and 3***.

	Mean	N	SD	SEM	t	p
knowledge_retest	17,76	90	8,98	0,94	-1,769	0,080
knowledge_posttest	20,05	90	7,97	0,84		
attitudes_test	19,62	90	5,58	0,58	,472	0,638
attitudes_posttest	19,22	90	5,53	0,58		
skills_retest	23,14	90	3,57	0,37	-1,734	0,086
skills_posttest	24,34	90	6,17	0,65		

Centralizing table: *Comparison between post-test and re-test means for the experimental group on the knowledge, attitudes, and skills subscales of test B* (Table V.37-V.38)

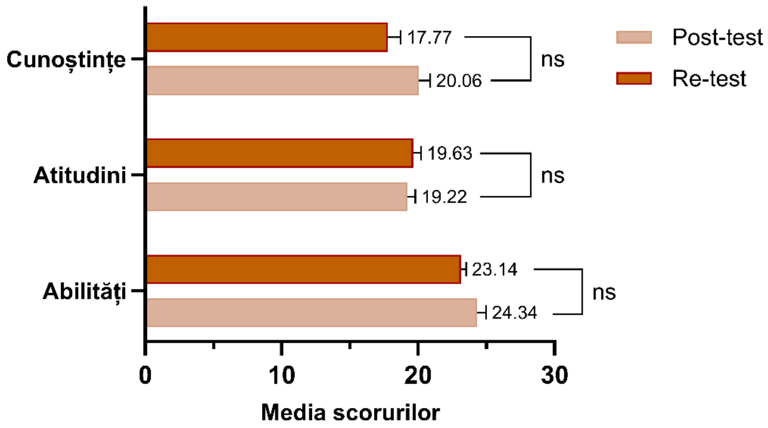

Figure V.31. Mean scores obtained by the students in the experimental group, on the subscales knowledge, skills and attitudes, in test B, in the post-experimental and re-test phase

The evolution of mean scores for the subscales knowledge, attitudes, and skills, related to the specific competences 1.2 and 1.3, revealed a significant increase between the pre-test and post-test stages, confirming the effectiveness of the intervention (Figure V.33). In the re-test stage, a slight and statistically insignificant decrease was observed in the knowledge and skills scores, while the attitudes showed a slight increase, suggesting the stabilization and long-term maintenance of the effects. These results highlighted the importance of continuous reinforcement through practical activities and digital technologies to prevent the decline of the acquired competences.

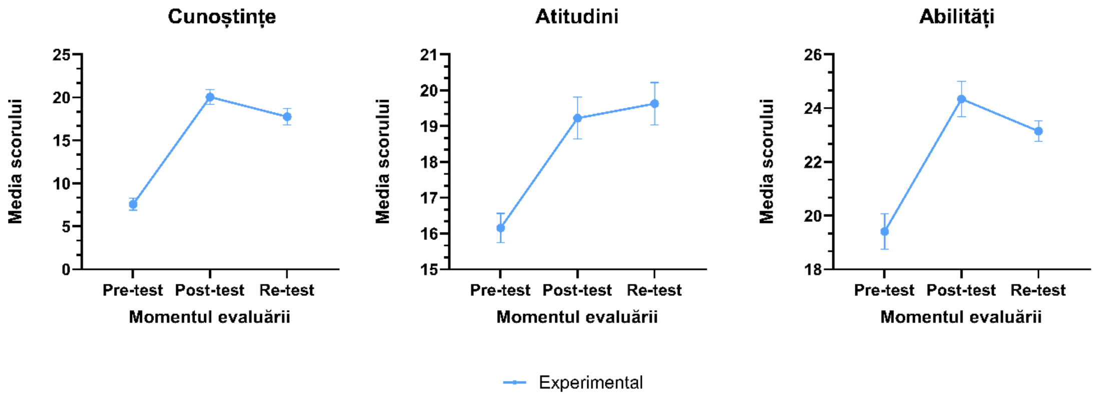

Figure V.33. Evolution of mean scores on the subscales knowledge, skills, and attitudes, in test B, obtained by the experimental group at pre-test, post-test, and re-test

The comparative analysis of the evolution of mean scores by subscale for the experimental and control groups revealed similar initial levels at the pre-test stage (Figure V.34). The experimental group showed a significant increase between pre-test and post-test, which was maintained at the retesting stage, reflecting the positive impact of the intervention on the development of specific competences 1.2 and 1.3. In contrast, the control group exhibited only minor, statistically insignificant variations, with a slight decrease in the attitude scores. The results support the effectiveness of the experimental program.

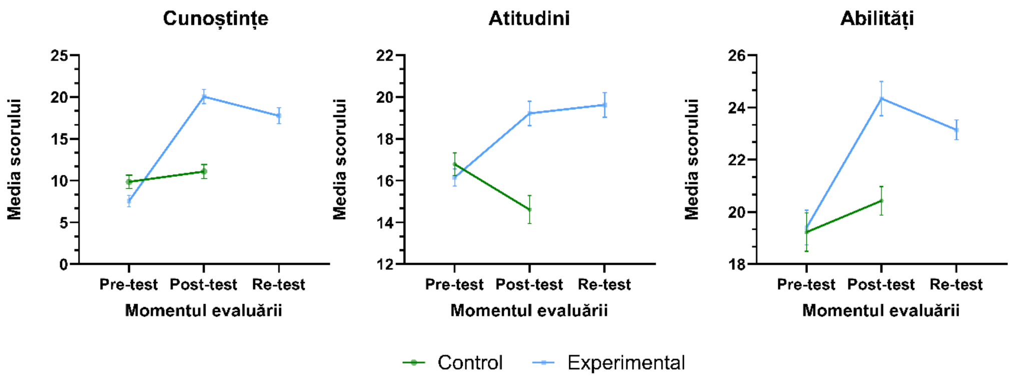

Figure V.34. Evolution of mean scores in test B, on the subscales knowledge, skills, and attitudes, in the control and experimental groups, at pre-test, post-test, and re-test

Conclusions

The doctoral thesis entitled *"Developing the competence to explore biological systems, processes, and phenomena with scientific tools and methods through practical activities and digital technologies. Applications in the 7th grade"* investigated the impact of the systematic use of practical activities and digital technologies on the formation of general competence 1 – *"Exploring biological systems, processes and phenomena with scientific tools and methods"* (Biology Curriculum, 2017) – among seventh-grade students. In the current educational context, Biology is a fundamental subject, which contributes to the formation of scientific competences. This research examined how practical activities and digital technologies enhance students' knowledge, skills, and scientific attitudes associated with the specific competences derived from general competence 1.

The data analysis and interpretation confirmed that the intervention program, based on the systematic integration of practical activities and digital technologies, effectively supported the formation of the targeted specific competences by developing the associated knowledge, attitudes, and skills.

The results from test A, aimed at assessing specific competence 1.1, confirmed the effectiveness of the proposed intervention program. The experimental group showed significant increases in both general means and subscale scores, compared to both the control group and their own pre-experimental stage. These improvements, evident in both the post-experimental and retesting stages, demonstrate the durability of the educational effect. The most notable progress was observed in the scientific skills subscale – systematizing information based on images, texts, and diagrams. Results from the re-test confirmed not only the strength but also the lasting effect of the intervention, with both grades and construct scores remaining at levels similar to those measured after the intervention. Therefore, ***secondary hypothesis 1 is validated.***

Likewise, the results obtained by the experimental group in test B indicated a positive impact of the intervention on the development of specific competences 2 and 3. Students in the experimental group achieved significantly higher scores both in overall means and across all subscales compared to the control group and their initial assessment. The most substantial improvement over the control group was recorded in the procedural knowledge subscale. At re-test, the scores remained high, indicating the stability of the intervention's effects. Among the intra-group comparisons, the highest score was recorded in the skills subscale (practical and critical interpretation skills). These results support the ***validation of secondary hypotheses 2 and 3.***

In conclusion, the conducted research ***validates the general hypothesis*** that the systematic use of practical activities and digital technologies contributes significantly to the development of general competence 1, through the formation of knowledge, attitudes and skills related to specific competences, in seventh-grade students. Within the context of the current educational reform, these results support the transition towards teaching models centered on experience, inquiry and active learning, in order to form students capable of scientifically exploring the biological world around them.

The research objectives were fully achieved, each stage contributing to the development of a modern pedagogical perspective oriented towards competence development. The intervention program proved to be effective in transforming traditional educational practices, stimulating active student participation, collaboration and scientific exploration of biological systems, processes and phenomena.

This research has made a number of significant theoretical, methodological and applied contributions to science teaching and learning at secondary school level. It provided a clear conceptualization of scientific competences, defined as integrated structures of knowledge, skills, and attitudes required for scientific exploration and conducting investigations. The theoretical foundation analyzed how general competence 1 can be developed in relation to learning theories and strategies associated with practical activities and digital technologies, shaping a theoretical and applicative framework for its development.

From a methodological, empirical, and applicative standpoint, the study proposed and validated an intervention program integrating practical activities and digital technologies, aimed at developing exploration competence in 7th grade students. In addition to formulating an effective methodological strategy, the empirical research also included the design and validation of an assessment tool to evaluate exploration competence by measuring the knowledge, attitudes, and skills associated with the specific competences derived from it. Thus, the thesis offers a rigorous model for evaluating educational outcomes, addressing existing shortcomings in this area.

The post-experimental and re-test results confirmed both the immediate and long-term effectiveness of the intervention program, validating the secondary hypotheses and, implicitly, the general hypothesis. These findings highlight the importance of combining initial interventions with subsequent reinforcement actions. In this regard, it emphasizes the need to develop methodological guidelines to support lesson design at micro level. The program proposed in this research can function as a practical model, providing examples of active methods, interactive resources and effective forms of organization, with a positive impact on the development of exploratory competence in the 7th grade through the study of Biology. The results of the research can be used to optimize the school curriculum by supporting the integration of practical activities and digital technologies in the educational process, with the aim of developing scientific competences at lower secondary school level.

The proposed study makes a relevant contribution to the formation of the competence to explore biological systems, processes and phenomena in seventh-grade students, though certain limitations must be considered when interpreting and generalizing the results. The research focused exclusively on secondary school students (7th grade), which limits the extension of the conclusions to other school levels, given the particularities of age and development. The size of the sample (90 pupils) and its exclusively urban origin restrict the transferability of the conclusions, particularly in relation to rural areas. Moreover, the applicability of the program depends on available infrastructure, teachers' digital skills and access to educational resources. Although the assessment tool was validated, limitations may exist regarding the objectivity of measurement, particularly in group activities. Nonetheless, the research provides a valuable framework for optimizing educational practices and opens directions for future investigations.

Extending the study to other classrooms or levels of education would allow a deeper understanding of age-dependent competence development and facilitate the development of differentiated teaching strategies. Investigating other types of educational technologies, integrating interdisciplinary approaches and separately assessing the effects of practical and digital activities could provide a more holistic and flexible perspective on competence development. Additionally, validating the assessment instrument in diverse educational contexts is essential for ensuring its relevance and applicability.

In conclusion, the conducted research demonstrates the importance and effectiveness of the systematic use of hands-on activities and digital technologies in developing exploration competence in seventh-grade students through study of Biology. Implementing an innovative teaching strategy focused on interactive methods and aligned with current technological advances significantly contributes to deeper and more relevant learning. The results of this study provide a solid foundation for operationalizing the curriculum, assessing competences, and improving educational practices in line with the learning outcomes defined by the current national curricula.

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