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Science Self-Efficacy and Gender Differences in Primary School: Development of the SE-IS Questionnaire and Evaluation of an ISLE-Based Teaching-Learning Sequence on Energy

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Table of Contents

INTRODUCTION 1

CHAPTER 1 5

GENDER GAP IN STEM 5

1.1 STEM disciplines 6

1.1.1 Woman in STEM pathways: European and Italian data 7

1.2 Socio-cultural and motivational factors in the choice of STEM pathways 11

1.2.1 The role of stereotypes 11

1.2.3 The role of play 14

1.2.3 The role of model 15

1.3 The SAFE 17

1.4 Combating gender stereotypes in STEM 19

1.5 Conclusion 22

Bibliography 24

CHAPTER 2 31

PEDAGOGICAL APPROACHES 31

2.1 Behaviourism, cognitivism, constructivism 31

2.2 Teaching and learning: a pedagogical perspective 34

2.2.1 The affective dimension of learning 37

2.3 Science education 38

2.3.1 Physics education 40

2.3.2 The relevance of the affective dimension in physics learning 41

2.4 Educational Recostrution 42

2.5 Learning methodologies 43

2.5.1 IBSE: the 5E model 44

2.5.2 Investigative Science Learning Environment – ISLE approach 48

2.5.3 Affective-motivational effects of inquiry-based methodologies: IBSE and ISLE ... 51
2.6 Teaching Learning Sequences ... 54
2.7 Conclusion ... 56
Bibliography ... 58

CHAPTER 3 ... 67
SELF-EFFICACY ... 67
3.1 Self-efficacy: definition ... 67
3.2 Self-efficacy in the school context ... 70
3.3 Sources of self-efficacy ... 73
3.4 The role of self-efficacy in learning processes ... 79
3.5 Scientific self-efficacy ... 80
3.6 Gender differences in scientific self-efficacy ... 83
3.7 Conclusion ... 85
Bibliography ... 87

CHAPTER 4 ... 93
ENERGY ... 93
4.1 What energy is? ... 94
4.2 Energy in education: an educational challenge ... 97
4.3 Key aspects in the teaching of energy ... 98
4.3.1 The role of system specification in energy analysis ... 98
4.3.2 Forms, transfer, transformation, dissipation and conservation ... 100
4.4 Issues and debates on the teaching of energy ... 102
4.4.1 Energy as a quasi-material substance ... 103
4.4.2 The role of forms of energy in teaching ... 104
4.5 Common-sense knowledge ... 107
4.5.1 Common knowledge about energy ... 108
4.6 Examples of teaching pathways in primary school ... 110
4.7 Teaching guidelines for primary school ... 112
4.8 Conclusion ... 115
Bibliography ... 117

CHAPTER 5 ... 123

RESEARCH DESIGN 123
5.1 Research objectives 124
5.2 Structure of the research 124
5.3 Conclusion 126
Bibliography 127

CHAPTER 6 129
THE PILOT STUDY 129
6.1 Research aims and pilot study design 129
6.2 Research questions and methodological approach 130
6.3 Research context and participants 131
6.4 Designing the Teaching and Learning Sequence (TLS) 132
6.4.1 Learning outcomes and objectives 132
6.4.2 Learning content 133
6.4.3 Methodological choices: ISLE and the promotion of Science Self-Efficacy 134
6.5 Data collection and analysis methodology 135
6.5.1 The knowledge questionnaire 136
6.5.2 The Self-Efficacy in Science Questionnaire 140
6.6 Classroom teaching activities 142
6.6.1 DAY 1 144
6.6.2 DAY 2 146
6.6.3 DAY 3 147
6.6.4 DAY 4 149
6.6.5 DAY 5 150
6.7 Results 151
6.7.1 Results of the knowledge questionnaire 151
6.7.2. Results of the Self-Efficacy in Science (SE-IS) questionnaire 158
6.8 Discussion of results: knowledge questionnaire 162
6.9 Discussion of results: Science Self-Efficacy (SE-IS) questionnaire 164
6.10 Conclusion 166
Bibliography 168

CHAPTER 7 173
QUESTIONNAIRE SELF-EFFICACY IN SCIENCE 173

7.1 Measuring the sources of self-efficacy 173
7.2 Instruments for measuring scientific self-efficacy 175
7.3The research 177
7.4 Research design and phases 178
    7.4.1 Analysis methodology 181
7.5 Initial development of the SE-IS 183
7.6 Study 1: pilot study 185
    7.6.1 Participants and procedure 186
    7.6.2 Analysis methodology 186
    7.6.3 Results of Study 1 187
    7.6.4 Discussion and modifications to the SE-IS 188
7.7 Study 2 190
7.7.1 Participants and procedure 191
7.7.2 Results of Study 2 191
7.7.3 Discussion and modifications to the SE-IS 195
7.8 Study 3 196
    7.8.1 Participants and procedure 196
    7.8.2 Results of Study 3 197
    7.8.3 Convergent and Discriminant Validity 201
    7.8.4 Discussion and modifications to the SE-IS 202
7.9 Study 4: confirmatory factor analysis 204
    7.9.1 Participants and procedure 204
    7.9.2 Analysis methodology 205
    7.9.3 Results of Study 4 205
    7.9.4 Discussion 207
7.10 Conclusion 207
Bibliography 211

CHAPTER 8 217
  EXPERIMENTAL STUDY: DESCRIPTION 217
    8.1 Choice of the experimental design 217
    8.2 Data collection and analysis methodology 218
    8.3 The study sample 219
        8.3.1 The macro-context 219
        8.3.2 The micro-context: control group 220

8.3.3 The micro-context: experimental group 220
8.4 Design of a TLS 221
8.5 Data collection 222
8.5.1 The Knowledge questionnaire 223
8.5.2 The SE-IS questionnaire 224
8.6 Implementation of the TLS 225
8.6.1 Methodological choices: Experimental Group 226
8.6.2 Methodological choices: Control Group 227
8.7 Classroom activities 228
8.7.1 DAY 1 234
8.7.2 DAY 2 238
8.7.3 DAY 3 242
8.7.4 DAY 4 244
8.7.5 DAY 5 249
8.8 Conclusion 252
Bibliography 253

CHAPTER 9 257
EXPERIMENTAL STUDY: RESULT 257
9.1 Knowledge questionnaire: analysis methodology 257
9.2 Knowledge levels and emerging categories 259
9.3 Results of the knowledge questionnaire 270
9.3.1 Qualitative results – Control Group (CG) 271
9.3.2 Qualitative results – Experimental Group (EG) 277
9.3.3 Quantitative results: Linear Mixed Models 285
9.4 Discussion of the results: knowledge questionnaire 287
9.5. SE-IS questionnaire: analysis methodology 290
9.6. Results of the SE-IS questionnaire 291
9.7 Discussion of the results: SE-IS questionnaire 297
9.8 Discussion of the results 299
9.9 Conclusion 303
Bibliography 306

CHAPTER 10 311
CONCLUSION 311

10.1 Gender differences, scientific self-efficacy and the school contex 312
10.2 Development and validation of the SE-IS 314
10.3 The ISLE methodology and the role of TLS 315
10.4 Results of the Teaching-Learning Sequences 317
10.5 Strengths and contributions of the research 319
10.6 Limitations of the research and future prospects 321
Bibliography 325

Appendix A 317
Appendix B 319
Appendix C 321
Appendix D 323

INTRODUCTION

> *"Reality cannot be changed overnight, but no reality will ever begin to change if the need for change does not become evident to everyone. As long as women cannot be there to count, it is essential that they continue to count in order to be."*

These words by Michela Murgia introduce the profound meaning of this research, which stems from a reflection on female participation in STEM disciplines and the difficulties that women still encounter today in accessing certain scientific, technological, and professional fields. STEM disciplines (Science, Technology, Engineering, and Mathematics) occupy a central position in the social, cultural, and economic development of contemporary societies. However, female presence in some of these areas continues to be lower than male presence, especially in the sectors closest to the so-called "hard sciences," such as physics, engineering, computer science, and technology.

This underrepresentation cannot be interpreted as the result of lesser skills or abilities on the part of women, but must be traced back to a complex set of socio-cultural, educational, and motivational factors. From the early years of life, girls and boys grow up in contexts where social expectations, role models, toys, languages, and cultural representations can help shape interests, aspirations, and perceptions of competence. This is often an implicit and non-coercive process, yet capable of progressively influencing educational and professional choices, contributing to educational and occupational segregation.

Within this framework, the construct of self-efficacy assumes a central role. In the field of science education, science self-efficacy represents a fundamental dimension for understanding how students relate to science and scientific activities. It does not merely coincide with the skills actually possessed, but concerns the perception students have of their own capabilities, influencing motivation, participation, perseverance, and the management of difficulties.

Studying science self-efficacy from primary school onwards appears particularly relevant. During this phase, in fact, students begin to build their first representations of themselves as as having different levels of competent subjects in different disciplinary areas. Intervening early allows for identifying potential vulnerabilities, countering gender stereotypes, and promoting a more conscious, motivated, and inclusive participation in scientific activities.

Primary school, therefore, constitutes a privileged context for analyzing the relationship between scientific learning, perception of competence, and gender differences.

The school has the task of promoting not only cognitive development but the integral growth of the person, building inclusive learning environments capable of enhancing the attitudes, interests, and potential of each student. From this perspective, science education can play a fundamental role, especially when it employs active, collaborative, and laboratory-based methodologies capable of involving students in the progressive construction of scientific knowledge.

Based on these premises, this research set the objective of investigating science self-efficacy in primary school through a pathway structured in two complementary lines. The first line involved the development and validation of a questionnaire to measure science self-efficacy in primary school pupils: the Self-Efficacy in Science (SE-IS) questionnaire. The second line involved the design, implementation, and evaluation of Teaching-Learning Sequences (TLS) on energy, with the aim of promoting conceptual change and the development of science self-efficacy through the Investigative Science Learning Environment (ISLE) methodology.

The theme of energy was chosen for its relevance in science education and its conceptual complexity. Energy indeed represents one of the fundamental concepts of science, but it is also a topic often characterized by intuitive, fragmentary conceptions linked to everyday experience. Furthermore, it is a highly topical issue, connected to environmental sustainability, climate change, and the transition toward renewable sources.

The use of the ISLE methodology allowed for structuring activities based on observation, experimentation, hypothesis formulation, discussion, and the progressive construction of scientific explanations. In this way, students were involved in active and collaborative pathways, in which their initial conceptions of energy were made explicit, discussed, and progressively reworked. The research then analyzed the effects of these pathways both in terms of conceptual learning and science self-efficacy, comparing the ISLE approach with a traditional teaching methodology in the main experimental phase.

The thesis is organized into ten chapters.

In Chapter 1, we address the issue of gender differences in STEM disciplines. After describing the main European and Italian data regarding female and male participation in different scientific sectors, we analyze some sociocultural factors that contribute to shaping the interests and ambitions of young women. We pay particular attention to the role of gender stereotypes and cultural representations that tend to associate men with the hard sciences and women with the humanities or caregiving fields.

In Chapter 2, we describe the pedagogical and didactic approaches underpinning the research. Specifically, we present the main elements of constructivism, Educational Reconstruction, Inquiry-Based Science Education (IBSE), and the ISLE methodology. Furthermore, we explore the role of affective and motivational components in learning processes and introduce the concept of the Teaching-Learning Sequence as an instructional design tool.

In Chapter 3, we delve into the construct of self-efficacy, with particular reference to Bandura’s socio-cognitive theory and the sources of self-efficacy. We then focus on science self-efficacy, analyzing its role in scientific learning processes and discussing the gender differences that have emerged across different educational levels.

In Chapter 4, we introduce the theme of energy from a didactic perspective. We analyze students' main common conceptions of energy as highlighted in the literature, and we discuss some useful guidelines for teaching this concept in primary school.

In Chapter 5, we present the overall research design. We describe the objectives, the two lines of investigation, the tools used, and the main phases of the work carried out.

In Chapter 6, we describe the design, implementation, and evaluation of the pilot study conducted in a primary school. We present the first TLS on energy, the tools used, the activities carried out, and the preliminary results obtained, both regarding students' conceptions and their science self-efficacy.

In Chapter 7, we present the construction and validation process of the SE-IS questionnaire, developed to measure science self-efficacy in primary school pupils. We describe the various studies conducted, the modifications made to the items, and the path that led to defining the final version of the instrument.

In Chapter 8, we describe the second TLS on energy, designed on the basis of the results obtained in the pilot study. We present the objectives, goals, tools, and educational activities implemented in both the experimental group and the control group.

In Chapter 9, we present the results of the main experiment. In particular, we analyze the effects of the TLS on students' conceptual change and science self-efficacy, also considering the role of gender and the comparison between the experimental group and the control group.

Finally, in Chapter 10, we discuss the main conclusions of the research. We summarize the most relevant results, highlight the theoretical, methodological, and didactic contributions of the work, acknowledge its limitations, and propose potential prospects for further study

CHAPTER 1
GENDER DIFFERENCES

If a child were asked to draw a scientist, as in the classic ‘Draw a Scientist’ task, it would be common to see a depiction of a man in a white coat, with a beard or tousled hair, and some laboratory equipment, such as test tubes or microscopes. Similarly, if an adult were asked to think of a person who has made a significant contribution to science, it is likely that male names, such as Albert Einstein or Stephen Hawking, would spring to mind. In the collective imagination, therefore, the figure of the scientist still tends to be associated predominantly with the male gender and with specific physical, cognitive and professional characteristics.

A similar process, but running in the opposite direction, can be observed in other fields. If asked to imagine a primary school teacher, many people would probably think of a woman. This is no coincidence: certain occupational sectors and disciplines are historically and culturally associated with a specific gender. Scientific and technological fields are often portrayed as more masculine, whilst educational and care professions are more frequently associated with women. Such representations help shape society’s perception of different professional fields, influencing what is considered more ‘suitable’ for men or women.

From this perspective, STEM disciplines take on particular significance. They represent a set of scientific, technological and professional fields in which, even today, persistent gender disparities to the detriment of women are observed. In a society increasingly characterised by digital transformation and technological innovation, STEM sectors offer significant educational and career opportunities; however, it is precisely in these fields that women often continue to be under-represented. Understanding the reasons for this gap therefore means examining not only individual choices, but also social representations, stereotypes and educational factors that help shape interests, perceptions of competence and future aspirations from an early age.

1.1. STEM disciplines

The STEM disciplines (Science, Technology, Engineering, and Mathematics) represent the scientific and technological fields of science, technology, engineering and mathematics. In recent years, these fields have taken on increasing educational, social and economic significance, as they are closely linked to technological development, the digital transition and countries’ ability to respond to changes in the labour market.

According to an estimate reported in the World Economic Forum's Future of Jobs Report (2025), a significant proportion of today's children will in future hold jobs that do not yet exist. Whereas up to ten years ago, technology was part of our lives but did not overwhelm them, this is no longer the case: the digital transition is changing the way we work, and the demand for skilled professionals in scientific fields is ever-increasing. According to the latest study by the Digital Skills Observatory (AICA et al., 2025), the number of job vacancies in the IT and technology sectors is roughly double the number of professionals currently working in these fields, confirming the existence of a significant gap between the skills demanded by the market and those actually available.

STEM disciplines underpin many of the technological innovations driving progress in society; they are responsible for the development of new technologies, software, medical devices, energy solutions and much more. Studying these disciplines offers unprecedented opportunities for personal and professional development. Promoting and supporting STEM education is essential not only to underpin technological innovation and economic growth, but also to encourage citizens' informed participation in the scientific and technological changes of contemporary society.

It is therefore essential to strengthen students' skills in STEM subjects and promote wider and fairer access to these educational pathways.

According to data from the Ministry of Universities and Research, in the 2024/25 academic year, students enrolled in STEM subjects accounted for approximately 28% of the total (MUR-USTAT, 2025b), a figure in line with that of recent years and with the EU average. However, despite the progress made in increasing women's interest and involvement in STEM disciplines, they continue to be under-represented and to experience less equity and inclusion in certain STEM sectors (Schmader, 2023).

Today, research is heavily focused on this issue for several reasons. Firstly, women's participation in STEM fields is a matter of educational and social equity: promoting the inclusion of women in these fields helps to create a more equitable and inclusive society (Schmader, 2023). Secondly, jobs in engineering and technology offer the highest earning potential of any professional category (Smith, 2021); consequently, the under-representation of women in these sectors accounts for a substantial part of the gender pay gap (Blau & Kahn, 2017). Finally, greater inclusion of women and under-represented groups in STEM sectors is also significant from an economic and innovation perspective: it can help address the shortage of skilled personnel, broaden the diversity of perspectives, and promote richer innovation processes and a more comprehensive knowledge base (Fehr, 2011; Levanon et al., 2014).

1.1.1 Women in STEM pathways: European and Italian data

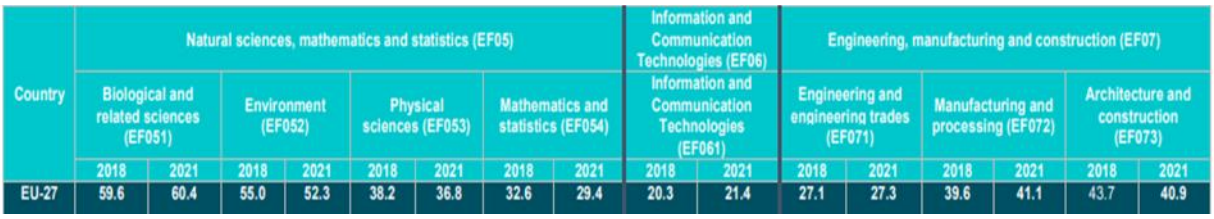
Gender inequality in academia and research has long been the subject of observation and monitoring, both in terms of horizontal segregation and vertical segregation. Horizontal segregation concerns the concentration of women and men in different disciplinary fields, sectors or professions; in education, it manifests itself, for example, in the over- or under-representation of a gender in specific fields of study, such as STEM and non-STEM. Vertical segregation, on the other hand, refers to the different distribution of women and men across the hierarchical levels of a career, with a progressive reduction in the number of women in top positions. This phenomenon is also observed in fields where, in the early stages of education or professional training, there is substantial gender parity or even a female majority.

At European level, a detailed analysis of the situation of women and men in research and academic careers is provided by the She Figures report, published periodically by the European Commission (European Commission, 2025).

According to the She Figures 2024 report, in 2022 women accounted for the majority of university students at Bachelor's and Master's levels: 55% of those enrolled and 58% of graduates at ISCED levels 6 and 7. However, this representation is not evenly distributed across academic disciplines. In science and engineering fields, in fact, women accounted for only 32% of students enrolled in Bachelor's and Master's programmes and 35% of graduates at the same levels, compared with 68% and 65% of men respectively.

As regards PhD programmes, data from the She Figures report (European Commission, 2025) show that women continue to account for around half of PhD graduates in the EU, at 48%, and that gender balance is observed in most countries. However, this overall balance masks gender gaps in specific subject areas. Women are over-represented in the field of Education, whilst they remain under-represented in Information and Communication Technologies and in Engineering, Manufacturing and Construction. In particular, in the more specific STEM sectors, the proportion of women among PhD graduates remains below the gender-balance threshold in several fields, including Mathematics and Statistics, Engineering and Engineering Professions, ICT and Physical Sciences. Table 1 shows the percentage of women who completed a PhD in the various STEM fields between 2018 and 2021.

Table 1 Proportion (%) of female PhD graduates, by narrow field of study, Natural Sciences, ICT and Engineering, 2018 and 2021 (She Figures, 2024.)



Country	Natural sciences, mathematics and statistics (EF05)								Information and Communication Technologies (EF06)		Engineering, manufacturing and construction (EF07)					
	Biological and related sciences (EF051)		Environment (EF052)		Physical sciences (EF053)		Mathematics and statistics (EF054)		Information and Communication Technologies (EF061)		Engineering and engineering trades (EF071)		Manufacturing and processing (EF072)		Architecture and construction (EF073)	
	2018	2021	2018	2021	2018	2021	2018	2021	2018	2021	2018	2021	2018	2021	2018	2021
EU-27	59.6	60.4	55.0	52.3	38.2	36.8	32.6	29.4	20.3	21.4	27.1	27.3	39.6	41.1	43.7	40.9

At European Union level, there is also a clear under-representation of women in the highest academic positions. Although gender balance is achieved at Bachelor's, Master's and PhD levels and among academic staff in grades C and B, women account for only 30% of grade A staff, equivalent to the level of full professor. Compared to previous years, there has been a slight increase in the number of women in these positions, but the gap with men remains significant (European Commission, 2025).

The under-representation of women in grade A affects all disciplinary fields. Women account for 38% of grade A staff in the Humanities and the Arts, 35% in the Social Sciences and 33% in the Medical and Health Sciences, i.e. in sectors where gender balance is achieved at earlier stages of the career. The gap is even more evident in STEM sectors: women make up 24% of grade A staff in the Natural Sciences and 19% in Engineering and Technology.

Fig. 1 shows the proportion of women and men in a typical academic career in STEM fields, from students at ISCED levels 6–7 up to Grade A academic staff.

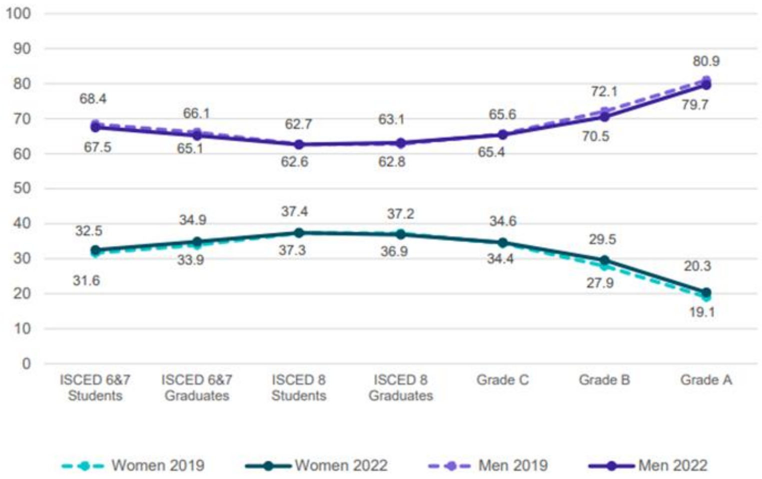


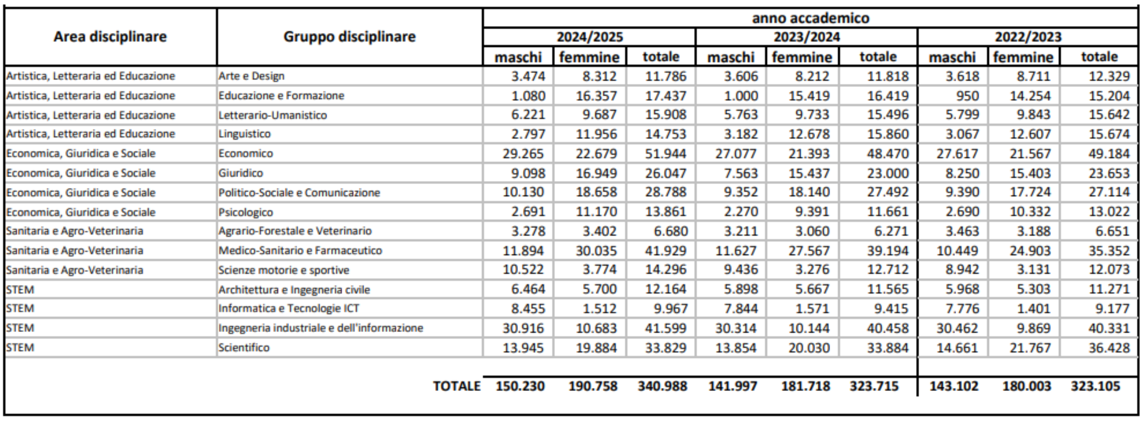
Fig. 1 proportion (%) of women and men in a typical academic career in science and engineering students and academic staff, 2019–2022 (She Figures, European Commission, 2025)

A similar picture is observed in Italy. According to MUR-USTAT data on enrolments for the 2024/2025 academic year, women represent the majority of university entrants, accounting for approximately 55.9% of the total. However, they are not evenly distributed across subject areas.

In the MUR-USTAT Focus on women's careers in academia, based on enrolment figures for the 2023/2024 academic year, the highest proportion of female students is found in the Humanities and the Arts, at 78.6%, whilst the lowest is recorded in Engineering and Technology, at 27.9%; within the latter, the proportion of women falls further to 16.7% in Information and Communication Technologies courses (MUR-USTAT, 2025b), as can be seen in Table 2.

Looking instead at the data on first-year students for the 2024/2025 academic year, among women enrolling at university for the first time, only 19.8% are enrolled in courses in the STEM field, comprising the groups of science, computer science and ICT, architecture and civil engineering, and industrial and information engineering (MUR-USTAT, 2025b). This figure is derived from the sum of female enrolments in STEM groups, amounting to 37,779, out of the total number of female enrolments, amounting to 190,758 (Table 2).

Table 2. Number of enrolments by academic year, subject group of the degree programme and gender (MUR-USTAT, 2025).



Area disciplinare	Gruppo disciplinare	anno accademico								
		2024/2025			2023/2024			2022/2023		
		maschi	femmine	totale	maschi	femmine	totale	maschi	femmine	totale
Artistica, Letteraria ed Educazione	Arte e Design	3.474	8.312	11.786	3.606	8.212	11.818	3.618	8.711	12.329
Artistica, Letteraria ed Educazione	Educazione e Formazione	1.080	16.357	17.437	1.000	15.419	16.419	950	14.254	15.204
Artistica, Letteraria ed Educazione	Letterario-Umanistico	6.221	9.687	15.908	5.763	9.733	15.496	5.799	9.843	15.642
Artistica, Letteraria ed Educazione	Linguistico	2.797	11.956	14.753	3.182	12.678	15.860	3.067	12.607	15.674
Economica, Giuridica e Sociale	Economico	29.265	22.679	51.944	27.077	21.393	48.470	27.617	21.567	49.184
Economica, Giuridica e Sociale	Giuridico	9.098	16.949	26.047	7.563	15.437	23.000	8.250	15.403	23.653
Economica, Giuridica e Sociale	Politico-Sociale e Comunicazione	10.130	18.658	28.788	9.352	18.140	27.492	9.390	17.724	27.114
Economica, Giuridica e Sociale	Psicologico	2.691	11.170	13.861	2.270	9.391	11.661	2.690	10.332	13.022
Sanitaria e Agro-Veterinaria	Agrario-Forestale e Veterinario	3.278	3.402	6.680	3.211	3.060	6.271	3.463	3.188	6.651
Sanitaria e Agro-Veterinaria	Medico-Sanitario e Farmaceutico	11.894	30.035	41.929	11.627	27.567	39.194	10.449	24.903	35.352
Sanitaria e Agro-Veterinaria	Scienze motorie e sportive	10.522	3.774	14.296	9.436	3.276	12.712	8.942	3.131	12.073
STEM	Architettura e Ingegneria civile	6.464	5.700	12.164	5.898	5.667	11.565	5.968	5.303	11.271
STEM	Informatica e Tecnologie ICT	8.455	1.512	9.967	7.844	1.571	9.415	7.776	1.401	9.177
STEM	Ingegneria industriale e dell'informazione	30.916	10.683	41.599	30.314	10.144	40.458	30.462	9.869	40.331
STEM	Scientifico	13.945	19.884	33.829	13.854	20.030	33.884	14.661	21.767	36.428
	TOTALE	**150.230**	**190.758**	**340.988**	**141.997**	**181.718**	**323.715**	**143.102**	**180.003**	**323.105**

The under-representation of women in STEM is also evident when considering the entire educational and academic pathway. According to MUR-USTAT data on typical academic careers in STEM fields, women account for 37% of ISCED 6–7 students and 39% of ISCED 6–7 graduates; their presence remains lower than that of men even at subsequent levels and reaches its lowest point in full professor positions, where women account for 24% of grade

A staff. (MUR-USTAT, 2025a). Even in the transition from undergraduate to PhD studies, the female presence in STEM remains limited: according to the AlmaLaurea Gender Report 2026, women account for 36.7% of STEM PhD graduates in 2024, whilst in other subject areas they make up over 50% of the cohort (AlmaLaurea, 2026).

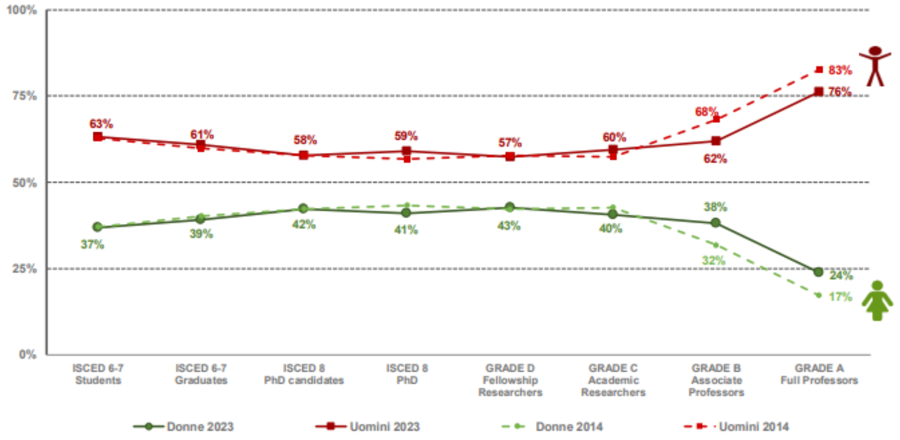


Fig. 2. Proportion of women and men in a typical academic career in STEM fields: students and teaching and research staff – 2014 and 2023

A specific analysis of the Physics degree programme provides a clearer picture of the female presence in this discipline. When referring to the ‘Physics degree programme’, a distinction must be made between the three-year degree, which belongs to class L-30, Physical Sciences and Technologies, and the master’s degree, which belongs to class LM-17, Physics.

In Italy, according to AlmaLaurea data on 2024 graduates, in the three-year degree class in Physical Sciences and Technologies, women account for 35.1% of graduates, compared with 64.9% of men (AlmaLaurea, n.d-a). The gap appears even more pronounced at Master’s level: in the LM-17 class, Physics, women account for only 28.2% of graduates, whilst men represent 71.8% of the total (AlmaLaurea, n.d-b.).

Overall, the data highlight the persistence of a dual form of segregation. On the one hand, horizontal segregation is evident in the different distribution of women and men across academic disciplines, with a particularly low female presence in STEM fields, especially in engineering, technology and ICT. On the other hand, vertical segregation is evident in the progressive decline in the number of women as academic rank increases, right up to top-level positions. This trend reflects two phenomena widely discussed in studies on gender equality: the ‘leaky pipeline’, i.e. the gradual dropout of women from academic and scientific pathways at various stages of their careers, and the ‘glass ceiling’, i.e. the invisible barrier that hinders women’s access to positions of greater prestige and responsibility. The ‘scissor-like’ trend observable in the graphs on academic careers visually represents precisely this progressive divergence between the presence of women and men throughout their educational and professional paths.

1.2 Socio-cultural and motivational factors in the choice of STEM pathways

Based on the data presented, a number of questions naturally arise: why do women tend to choose technical and scientific fields less often? Do men have a greater innate aptitude for STEM disciplines? Are women less interested in or capable of STEM subjects?

The literature does not suggest differences in ability sufficient to justify the under-representation of women in STEM fields (Schmader, 2023). Therefore, the lower number of women in these fields is not due to a lack of ability or skill (Hill et al., 2010). Rather, it is a combination of socio-cultural factors that have influenced, and continue to influence, the way we think and view the world around us for centuries (Master et al., 2025a).

In the following sections, we will explore the role of various factors that may influence, either directly or indirectly, women’s interest in STEM subjects. In particular, we will examine the roles of gender stereotypes, early childhood play, role models and the media.

1.2.1 The role of stereotypes

A fundamental developmental task of childhood involves learning about the social world. Children progressively learn the characteristics associated with people and social groups, developing expectations about how others might think, feel and behave. To carry out this complex task, children learn to rely on stereotypes to draw inferences and make predictions that help them understand and develop social interactions (Master et al., 2025a).

Stereotypes are cognitive representations that summarise the traits, abilities, attributes and preferences perceived as being associated with one group rather than another (Ellemers, 2018). Stereotypes can be explicitly stated, representing a person’s conscious beliefs about a group. Conversely, they can be implicit, that is, concepts that are automatically activated when thinking about a group category due to strong cognitive associations. Although such stereotypes exist in individuals’ minds, they are also a product of the surrounding culture and context (Diekman & Schmader 2021, Payne et al., 2017).

As children develop their sense of self and their identity, they also learn the stereotypes that apply to their groups. These stereotypes can significantly shape their attitudes and behaviours, contributing to the formation of gender inequalities (Tobin et al., 2010).

Some of the most deeply ingrained stereotypes in young children's lives relate to gender. From the age of two, many children begin to demonstrate an awareness of gender stereotypes (Leaper, 2023). As time goes on, children pay increasing attention to cues linking gender to other objects and activities. Gender associations begin to influence their preferences for toys, playmates, clothing, colours and activities (Halim et al., 2014; Kanka et al., 2019; Davis & Hines, 2020; Master et al., 2025a).

In the field of science and technology, traditional gender stereotypes associate STEM subjects with the male gender. The results of a meta-analysis conducted on 145,204 children across 33 countries over a 40-year period found that, on average, STEM stereotypes favour male abilities (Miller et al., 2024). The opposite trend is observed with stereotypes regarding verbal abilities: the meta-analysis conducted by Miller et al. (2024) found that, on average, most children held traditional stereotypes favouring female abilities. Similarly, the general academic stereotype associates girls with higher academic achievement; that is, the belief persists that girls perform better than boys (Hartley & Sutton, 2013; Heyder & Kessels, 2013).

STEM stereotypes are evident as early as the age of 6 (Cvencek et al. 2011; Master et al., 2017) and show a general trend towards becoming more entrenched by the age of 16. When children are asked to draw a scientist, they are more likely to draw a man than a woman (Miller et al. 2018). However, stereotypes differ depending on the specific STEM field (McGuire et al., 2020; Tang et al., 2024; Master et al., 2025b). Stereotypes favouring male abilities are found primarily in physics, engineering and computer science, whilst those relating to biology strongly favour female abilities, and those relating to chemistry are on average gender-neutral (Miller et al., 2024). In a dataset comparing stereotypes across different STEM fields, children and adolescents held strong stereotypes that boys were more interested in and capable of computer science and engineering than girls (Master et al., 2021; Tang et al., 2024).

A very common stereotype, among both adults and children, is the idea that high-level cognitive abilities (e.g., brilliance, genius) are associated with men, an idea relevant to careers in fields equated with brilliance, such as physics (Meyer et al., 2015; Bian et al., 2017; Storage et al., 2020). Since the ability to solve problems innovatively is the hallmark of STEM careers, the tendency to associate men with exceptional intelligence is likely linked to the over-representation of men in fields that assume brilliance is necessary for success (Leslie et al., 2015). Across all academic disciplines, these stereotypes may favour men's career advancement (Witteman et al., 2019; Gruber et al., 2021; Schmader, 2023). Interestingly, these stereotypes about men's exceptional intelligence coexist with the belief that, on average, women are just as intelligent as men (Eagly et al., 2020).

Gender stereotypes influence students' interest, self-efficacy and motivation, laying the foundations for reinforcing gender disparities in many sectors (Master et al., 2021, 2025).
The more girls perceive STEM fields as being more suitable or interesting for boys, the lower their own interest may be; similarly, the more they internalise the idea that boys are more competent in these fields, the more their perception of their own abilities may diminish (Passolunghi et al., 2014; Master et al., 2021). Girls often have fewer practical experiences in technological and scientific fields, and this contributes to their lower self-efficacy in STEM subjects (Master et al., 2017).
Stereotypes associating boys with STEM subjects can influence expectations of success, more positive value-based beliefs (Starr et al. 2023), a sense of belonging (Master et al., 2021), academic aspirations and course choices (Steffens et al., 2010; Sansone et al., 2019; Makarova et al., 2019). Furthermore, some studies have demonstrated a causal link between stereotypes and self-perception, as well as related motivational beliefs and behaviours (Master et al., 2025a). For example, when 8-year-old girls were introduced to a new activity perceived as more interesting for boys, they showed less interest in it compared to a non-stereotyped activity (Master et al. 2021). Similarly, girls in Year 9 reported less interest in a computer science course associated with a stereotype favouring boys' interest compared to a non-stereotyped course (Master et al., 2025a).

In short, stereotypes that associate men more than women with mathematics and science also lay the groundwork for reinforcing horizontal segregation, encouraging girls and boys to self-select into pathways consistent with gender expectations. At the same time, stereotypes that associate genius and brilliance with masculinity can contribute to vertical segregation, supporting the over-representation of men in positions of greater prestige and leadership. (Schmader, 2022).

It is important to emphasise that gender stereotypes vary over time and across cultures, revealing themselves to be historical constructs (Charlesworth & Banaji, 2020). In recent years, the stereotypical portrayal of science as a male activity has faded over time; however, such gender stereotypes still persist (Schmader, 2023). Statistical models estimate that, at the overall rate of decline observed between 2007 and 2018, it would take between 37 and 74 years to completely eradicate the association between science and men (and it would take twice as long to eliminate the association between men and careers and women and family) (Schmader, 2023).

1.2.2 The role of play

Childhood is characterised by play and recreational activities that play a fundamental role in children's cognitive, social and emotional development (Bruner, 1966). Play is not merely a form of leisure, but constitutes a privileged means through which children explore the world, construct meaning, experiment with social roles and develop skills useful for understanding the surrounding reality. Through play, in fact, children learn rules, causal relationships, ways of interacting with others and forms of problem-solving, gradually developing representations of themselves and their place in the social world (Bruner, 1966).

However, the games offered to boys and girls are often different. Boys are frequently associated with construction toys, vehicles, technical tools, video games, and physical or competitive activities; girls are more often offered games related to caregiving, relationships, aesthetics, or symbolic play, such as dolls, domestic accessories, and social imitation activities. The literature has highlighted that boys and girls tend to show preferences for culturally gender-typed games from an early age, and these preferences are progressively reinforced through family, school, social and commercial expectations (Todd et al., 2017; Leaper, 2023; Master et al., 2025a).

Games such as building sets, jigsaw puzzles, blocks, assembly activities, obstacle courses, mechanical objects and strategy games can stimulate spatial skills, logical reasoning, mental manipulation of objects, planning and problem-solving. These skills are considered important for various STEM fields and can be linked to better performance in spatial reasoning tasks (Jirout & Newcombe, 2015).

If boys are more frequently encouraged to engage in manipulative, constructive, technical and spatial activities, whilst girls are steered towards more relational or care-related play, this can lead to differentiated early experiences that influence how children develop familiarity, interest and confidence in certain fields (Todd et al., 2018; Moè et al., 2018; Eisen et al., 2021). Girls who have fewer opportunities to familiarise themselves with technical objects, construction toys and problem-solving activities may develop a lower sense of competence in these areas, which can discourage their interest in technological and scientific activities (Uttal et al., 2013; Jirout & Newcombe, 2015; Moè et al., 2018). Conversely, more frequent exposure to spatial and technical-scientific activities can foster the development of skills, interest and confidence in one's own abilities.

When games are culturally presented as 'for boys' or 'for girls', they can perpetuate gender stereotypes: girls, in particular, may perceive technological games, construction, robotics or engineering activities as less suitable for themselves, and this can contribute to reducing their sense of belonging and interest in certain STEM fields (Todd et al., 2018; Master & Meltzoff, 2020; Master et al., 2021).

1.2.3 The role of role models

A further factor capable of influencing girls' interest in STEM subjects is the presence, or absence, of role models (Bandura, 1986). These role models do not merely act as individual examples, but help to define what boys and girls perceive as possible, desirable and consistent with their own identity.

In the STEM fields, the visible under-representation of women as scientists can discourage girls from pursuing academic and professional careers in these areas (Wang et al., 2025). In media portrayals such as films or books, scientists, engineers, computer scientists and inventors are often depicted predominantly as men (Collins, 2011; Wille et al., 2018). Such portrayals reinforce the idea that STEM disciplines are male dominated (Tang et al., 2024), and girls may internalise the notion that these fields are less suitable or less accessible to women.

The constant portrayal of the scientist as a male figure can therefore contribute to reducing girls' sense of belonging in scientific contexts and, consequently, their interest and willingness to envisage themselves pursuing STEM academic and professional pathways (Wang et al., 2025). This mechanism is consistent with what was discussed in the previous paragraph: stereotypes operate not only through explicit beliefs about the abilities of males and females, but also through images, expectations and social representations that implicitly define who 'belongs' to a particular field.

For centuries, women's access to higher education and scientific institutions has been severely restricted. The few fortunate women who were able to study science were the daughters, sisters or wives of scientists, or came from privileged family backgrounds. Even when some women managed to stand out, their contributions were often regarded as exceptional, isolated or poorly recognised. This was the case, for example, with the Italian physicist Laura Bassi who, given her exceptional intellect, was educated by her family and went on to become the first woman in the world to hold a university chair. The inability to study at university made careers in science virtually inaccessible to women until the early 20th century, and even once they gained access, there was talk of women trying to fit into entirely male environments, within a strongly male-dominated society where the prevailing view was that women were inferior.

This long-standing exclusion has contributed to the perception of science as a field historically associated with men, in which the presence of women was considered an exception. Although the number of women in scientific fields has increased today and many women have made fundamental contributions to the advancement of knowledge, their visibility in school curricula, textbooks, the media and the collective imagination often remain lower than that of their male colleagues. The lack of recognisable female role models can therefore affect girls' expectations, leading them to perceive STEM as fields in which it is more difficult to identify with and feel legitimate (Wang et al., 2025).

Female role models in STEM thus take on a counter-stereotypical function. They demonstrate in concrete terms that women can succeed in fields traditionally perceived as male-dominated, helping to strengthen a sense of belonging, interest and beliefs in self-efficacy (Master et al., 2017; Master & Meltzoff, 2020).

It is important to emphasise that a role model's effectiveness depends not only on their success, but also on whether they are perceived as relatable and attainable (Jourden et al., 1991; Usher & Pajares, 2008). Excessively exceptional role models, presented as isolated or genius figures, may in fact prove difficult for female students to identify with, especially if they reinforce the idea that extraordinary qualities are necessary to succeed in STEM. This type of media representation plays a significant role in shaping and perpetuating gender stereotypes (Master et al., 2017). Conversely, role models perceived as realistic—similar in age, background, interests or the challenges they have faced—can be more effective, as they demonstrate that scientific success does not depend solely on innate talent (Jourden et al., 1991; Usher & Pajares, 2008).

The activities proposed in schools can promote the dissemination of female role models in STEM: without adequate exposure to counter-stereotypical examples in their daily experiences, initial gender stereotypes often remain unchanged and difficult to alter (Master et al., 2017; Master & Meltzoff 2020).

1.3 The SAFE model

To provide a comprehensive explanation of the influence of gender stereotypes on women's participation in STEM disciplines, it may be useful to refer to the SAFE model proposed by Schmader (2023). This model interprets attraction to, engagement in, and persistence within a given field not merely as the result of individual abilities or interests, but as the outcome of the perceived fit between the individual and the context. In particular, the model argues that individuals are more motivated to enter and persist in environments where they can feel authentic, that is, free to express their true selves without perceiving a disconnect between their identity and the characteristics of the context.

According to the SAFE model (Fig. 3), this perception of authenticity depends on three forms of fit: self-concept fit, goal-fit and social fit. Individuals seek environments that correspond to our perception of ourselves (self-concept fit), to our way of working (goal fit) and in which people accept and validate us (social fit).

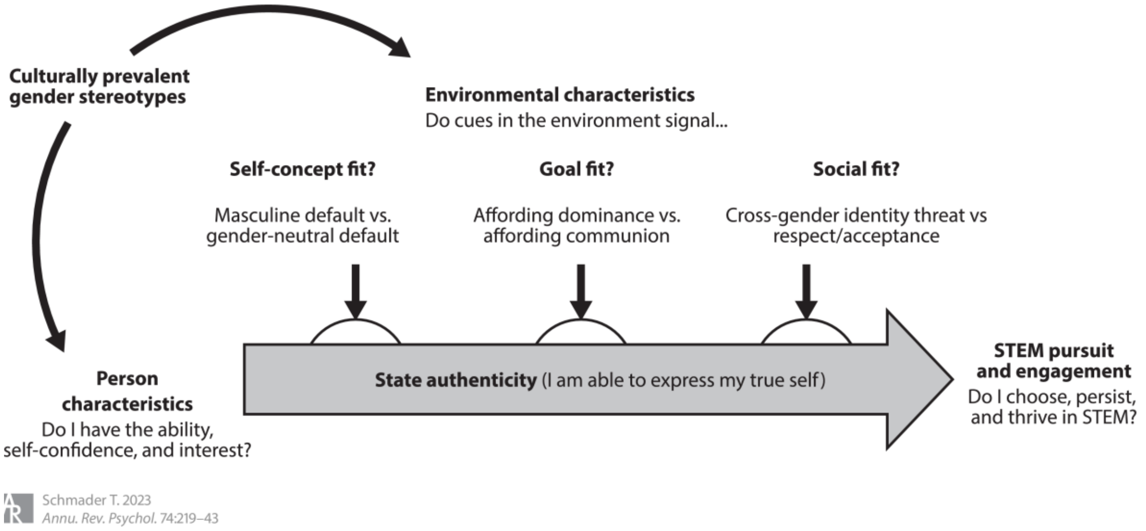

Culturally prevalent gender stereotypes
Environmental characteristics
Do cues in the environment signal...
Self-concept fit?
Masculine default vs. gender-neutral default
Goal fit?
Affording dominance vs. affording communion
Social fit?
Cross-gender identity threat vs respect/acceptance
State authenticity (I am able to express my true self)
STEM pursuit and engagement
Do I choose, persist, and thrive in STEM?
Person characteristics
Do I have the ability, self-confidence, and interest?
Schmader T. 2023
Annu. Rev. Psychol. 74:219–43

Fig. 3 SAFE model (By Schmader, 2023)

Self-concept fit refers to the extent to which a person perceives their own abilities, characteristics and interests as consistent with a particular field. Prevailing gender stereotypes, when internalised by girls, can shape their beliefs about fit and undermine their self-perception of being suited to these fields. Furthermore, gender stereotypes are likely to lead to differential treatment by parents and teachers, which in turn influences children's perceptions of their own abilities and expectations of success (Eccles, 1983; Gunderson et al., 2012; Muenks et al., 2018; Master et al., 2021). A third way in which stereotypes can shape the self-image of girls and women is through stereotype threat. This can occur when certain aspects of a situation evoke the concern that one's behaviour or performance will be evaluated through the lens of a negative stereotype (Steele & Aronson 1995). Therefore, the threat of stereotyping could be an indirect mechanism through which gender stereotypes shape women's lower self-esteem and interest in STEM subjects (Deemer et al. 2016; Woodcock et al. 2016).

The second form is goal fit, that is, the extent to which a context is perceived as consistent with one's own values and aspirations.

Women tend to be equally represented in certain areas of STEM, such as the biological, medical and social sciences, fields in which the objective is often clearly to serve others and is therefore easily perceived as capable of satisfying the community-oriented goals and values that are more deeply rooted in women (Croft et al., 2015; Falk & Hermle, 2018). On the other hand, women are under-represented in physics, computer science and engineering, fields that in some ways focus more on abstract understanding or the design of objects, technologies or structures (Diekman et al., 2011; McPherson & Park, 2021). This representation may reduce the appeal of these pathways for female students, particularly when they fail to recognise a connection between scientific and technological disciplines and their personal, social or community goals.

The third form is social fit, which concerns the sense of belonging, acceptance and recognition within a group or context.

STEM environments, particularly those with a male majority, tend to exhibit characteristics and attributes that suggest a greater suitability for men than for women (Schmader, 2023). Some studies have shown that women working in male-dominated STEM sectors often experience a lower level of social integration than their male colleagues (Fouad et al. 2011) and are more likely to experience a threat to their social identity, that is, to be conscious of their gender at work and to fear being judged on the basis of their gender (Hall et al. 2018). Simply imagining themselves at a scientific conference with a male majority (rather than one with gender parity) leads women, more so than men, to experience a physiological threat (Murphy et al. 2007).

The SAFE model therefore provides an integrated framework for understanding the various factors discussed in the preceding paragraphs. Genderstereotypes, differentiated play experiences, the scarcity of female role models and social representations of STEM professions do not operate in isolation, but contribute to defining the extent to which girls perceive STEM as consistent with their own identity, their own goals and their own sense of belonging (Schmader, 2023).

1.4 Combating gender stereotypes in STEM

Efforts to combat gender stereotypes in STEM disciplines must take place at multiple levels: institutional, cultural, educational and interpersonal. Reducing disparities, in fact, cannot be left solely to the individual motivation of female students, but requires broader transformations in the contexts where stereotypes are formed, maintained and transmitted.
At the institutional level, sociological research has highlighted the effectiveness of certain policies aimed at increasing gender, racial and intersectional representation. In particular, Dobbin and Kalev (2016) emphasise the role of diversity officers or working groups, tasked with overseeing organisational changes, and of recruitment initiatives aimed at increasing the presence of under-represented groups. Such interventions can contribute not only to increasing female representation in STEM fields, but also to making study and work environments more inclusive.

However, institutional policies risk being ineffective if they are not accompanied by broader cultural change. Increasing the presence of women in STEM fields is not enough if environments continue to convey implicit norms, expectations and models that make these sectors appear predominantly male. For this reason, it is necessary to promote more inclusive social norms capable of conveying a sense of belonging, recognition and integration to women and other under-represented groups in STEM disciplines (Schmader, 2023). From this perspective, the aim should not be to push women to adapt to an implicit male norm, but to transform contexts so that they are genuinely open and accessible to a diversity of identities, experiences and backgrounds (Cheryan & Markus, 2020).

The implementation of inclusive policies and social norms requires action by individuals, especially those in positions of power. Diversity training is one of the most widely used strategies for promoting awareness of gender bias; however, mere awareness-raising is not sufficient to reduce its expression. The most effective programmes should not merely inform people of the existence of stereotypes, but should provide practical strategies for recognising them, challenging them and changing everyday practices, language, expectations and modes of interaction (Schmader, 2023).

Moving from the institutional to the individual level, we have highlighted that girls and women often express less confidence in their mathematical and scientific abilities and show less interest in STEM subjects. Therefore, to bridge the gender gap in STEM subjects, it is necessary to implement educational interventions aimed at increasing young girls' self-efficacy and interest (Schmader, 2023).

Although children may initially ignore or reject evidence that contradicts an ingrained stereotype, if exposed to sufficient evidence, they may eventually unlearn that stereotype (Master et al., 2025a). Countering gender stereotypes requires targeted and carefully designed interventions that promote positive changes in perceptions.

Given that gender stereotypes can distort girls' perceptions of their own abilities and interests in mathematics and science from a young age, interventions targeting primary school play a central role: acting at a stage when beliefs about oneself and about these subjects are still forming can help prevent the consolidation of stereotypical expectations (Schmader, 2023; Master et al., 2021).

A key strategy involves providing girls and boys with early, meaningful and non-stereotypical STEM experiences (Master et al., 2025a). Robust science curricula, laboratory activities, problem-solving experiences and inclusive educational pathways can help reduce stereotypes and promote girls' self-efficacy in STEM subjects, countering the notion that boys are inherently better suited to these subjects. Some studies suggest, for example, that in contexts where boys and girls are more exposed to STEM courses, smaller gaps are observed in subsequent participation in these pathways (Charles & Bradley, 2009). Furthermore, it has been found that primary school pupils' stereotypes can change over time, particularly in fields where they have had more direct classroom experience (Tang et al., 2024).

As described in the preceding paragraphs, gender stereotypes in children are also formed through the observation of the roles, behaviours and characteristics associated with men and women. Consequently, one way to counter gender stereotypes in STEM is to provide positive role models that can weaken implicit gender stereotypes over time (Dasgupta & Asgari, 2004; Lawner et al., 2019; Cvencek et al., 2020). Mentoring and collaboration with women who have been successful in STEM fields can foster self-efficacy, identification with the sector, and women's commitment to pursuing a STEM career (Dasgupta, 2011; Stout et al., 2011). Although implicit stereotypes are generally resistant to experimental change, exposure to positive role models appears to have one of the strongest effects, which, when aggregated at a cultural level, could drive the overall trend towards weaker stereotypical associations over time.

Observing female role models in STEM fields, particularly in the early stages of development, can provide concrete evidence that counters traditional biases (Olsson & Martiny, 2018), fostering a sense of belonging.

The effectiveness of role models, however, is not automatic. Research shows that it may depend on variables such as perceived similarity, the possibility of identification, and the attainability of the role model (Gladstone & Cimpian, 2021). Role models presented as exceptional and unattainable figures may prove less effective than realistic role models who are close to students' own experiences and capable of demonstrating that success in STEM does not depend solely on innate talent or genius, but also on commitment, practice, collaboration and educational opportunities.

Collaborative activities can also help to counteract stereotypes. Group projects, laboratory activities and STEM competitions can offer boys the opportunity to witness girls' success in these fields, encouraging recognition of their skills and challenging stereotypical beliefs about gender-based abilities (Kuchynka et al., 2022; Riegle-Crumb et al., 2017). At the same time, such experiences can strengthen female students' confidence in their own abilities, their sense of belonging and their willingness to participate in scientific activities.

In this context, schools play a central role in promoting female students' interest in and self-efficacy in science. Teachers can help counter gender stereotypes from early childhood onwards through inclusive teaching choices, non-stereotypical language, collaborative activities, the celebration of individual progress and the presentation of female role models in STEM (Gunderson et al., 2012; Master & Meltzoff, 2020). In this way, the school environment can become a prime setting for introducing girls and boys to scientific and technological fields, reducing the fear of not being capable enough and fostering more equitable and informed participation.

1.4 Conclusion

Gender differences in science are a highly topical issue and a significant challenge for the European Union, which has included the overcoming of gender inequalities in educational, academic and professional contexts among its objectives. In particular, the European Commission's European Strategy for Universities (2022) aims to support universities in addressing issues related to inclusion and gender equality, with a specific focus on the under-representation of women in STEM fields, as also highlighted by the She Figures report (European Commission, 2025).

In recent decades, the European Union has made significant progress on gender equality through measures aimed at women's empowerment, the integration of the gender dimension into public policies, and the promotion of specific legislation. However, despite the improvements achieved, significant inequalities still persist: women continue to be over-represented in certain lower-paid sectors and under-represented in decision-making positions and senior roles (Schmader, 2023). Against this backdrop, this analysis has focused on women's participation in STEM fields, areas that today represent a significant educational and professional opportunity, as they are closely linked to technological innovation, economic growth and the transformation of the labour market. The under-representation of women in these sectors constitutes a significant loss not only in terms of social equity, but also in economic, scientific and cultural terms (Schmader, 2023).

Statistical analyses show that women, both at European and Italian level, are not evenly distributed across the various scientific fields. They are more prevalent in certain areas, such as the biological and medical-health sciences, whilst remaining under-represented in sectors such as engineering, physics, computer science and information technology. This distribution is linked to the persistence of stereotypical representations that associate the so-called 'hard sciences' with the male gender.

The studies examined highlight, in fact, the role of gender stereotypes in shaping students' interest, self-efficacy, sense of belonging and motivation towards STEM subjects. These stereotypes begin to develop from childhood and can progressively influence subsequent educational, academic and career choices (Cvencek et al. 2011; Master et al., 2021). Overall, the cited studies suggest that boys are more likely to excel in maths and science not

necessarily because of greater innate talent, but rather because they have greater confidence in their abilities and a stronger preference for careers in STEM. The observed gaps appear to be linked to socio-cultural, educational and motivational factors that influence how girls and boys perceive their own abilities, develop their interests and envisage their future (Starr et al., 2023; Master et al., 2025).
From this perspective, gender stereotypes operate at multiple levels: cultural, institutional, interpersonal and individual. They can contribute to shaping distinct pathways, encouraging the self-selection of men and women into fields consistent with societal gender expectations (Diekman & Schmader 2021; Payne et al., 2017). Horizontal segregation in STEM pathways and the subsequent vertical segregation in academic and professional careers cannot therefore be interpreted as isolated phenomena, but as the result of a complex set of factors operating over time.

In light of these considerations, schools play a central role in combating gender stereotypes. Through inclusive teaching practices, meaningful scientific activities, positive female role models, collaborative experiences and opportunities for success, it is possible to foster the development of scientific interest and self-efficacy from the earliest years of schooling (Gunderson et al., 2012; Master & Meltzoff, 2020). Intervening at an early stage means offering girls and boys the chance to build a freer, more informed and non-stereotypical relationship with STEM subjects, thereby helping to promote more equitable and inclusive participation in scientific and technological pathways.

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CHAPTER 2
PEDAGOGICAL APPROACHES

For a long time, learning was conceived as a largely passive process, in which the student was primarily expected to listen to and memorise what the teacher conveyed. Even today, the most widespread conception of the ‘classic lesson’ is that of the lecture, in which the teacher’s words are the main vehicle for the transmission of knowledge (Frabbroni, 2007). However, this approach is limited, as the teacher’s explanation is unable to control or trigger the deeper processes of understanding and processing information (Florin, 2017). In this sense, the traditional lesson tends to stimulate predominantly reproductive cognitive processes, such as the reception, memorisation and repetition of content, without fostering genuine active student participation or the construction of meaningful learning (Ausubel, 2012).

Theories of learning that developed during the 20th century, particularly within the fields of cognitivism and constructivism, have progressively challenged this transmissive model, re-evaluating the active role of the learner in the processes of knowledge construction. Research has highlighted how the child’s mind exhibits specific characteristics, both qualitatively and quantitatively, compared to that of an adult, profoundly influencing learning processes and requiring teaching methods suited to these particularities (Piaget, 1970; Vygotsky, 1978).

In light of these contributions, contemporary pedagogy has developed as a field of research aimed at designing and testing approaches, methodologies and strategies capable of promoting meaningful and inclusive learning across different areas of knowledge. From this perspective, learning is increasingly conceived as a multifactorial process in which cognitive, social and affective dimensions interact, all of which are involved in the student’s active construction of knowledge (Pessoa, 2008)

2.1 Behaviourism, cognitivism, constructivism

Behaviourism emerged in the early decades of the 20th century in the United States and focuses on the study of observable behaviours in response to stimuli from the environment (Skinner, 1953; Calvani, 2014).

According to this perspective, learning is a modification of behaviour that occurs when a subject consistently associates a stimulus (S) with a response (R).

The earliest experimental theories of learning were dominated by two main approaches, both centred on the observation of behaviour: classical conditioning and operant or instrumental conditioning. The former stems from the studies of Ivan Pavlov, whilst the latter developed from the research of Edward Lee Thorndike and Burrhus Skinner (Skinner, 1953; Schunk, 2020; Rehman, 2024).

The classical conditioning paradigm is well known thanks to Pavlov's experiments on dogs, which were shown food (unconditioned stimulus – US) that elicited salivation (unconditioned response – UR). The presentation of the food was accompanied by the sound of a bell, which in itself does not cause any salivation in the dogs and is therefore a neutral stimulus. After several presentations of the two stimuli in succession, the dogs began to salivate at the mere sound of the bell. This experiment demonstrates that the neutral stimulus (the sound of the bell) determines the unconditioned response (salivation) even in the absence of the unconditioned stimulus (the food). The new response is defined as a conditioned reflex or conditioned response (CR) because it is not spontaneous but induced, and is therefore the result of learning. The sound of the bell, which was a neutral stimulus as it did not elicit any response in the dogs, becomes a conditioned stimulus after a learning phase (Domjan, 2005). This process demonstrates how behaviour can be learned through the association between stimuli (Schunk, 2020; Domjan, 2005).

In operant conditioning, however, learning occurs through a process of trial and error, in which behaviour is influenced by the consequences that follow it. Thorndike formulated the law of effect, according to which behaviours followed by positive consequences tend to be repeated, whilst those followed by negative consequences tend to diminish (Thorndike, 1898; Schunk, 2020). Skinner expanded on this model by introducing the concept of reinforcement, distinguishing between positive and negative reinforcement (Skinner, 1953; Schunk, 2020). Numerous studies have shown that positive reinforcement is generally more effective in promoting learning (Hattie, 2009; Schunk, 2020) than punishment: children learn more and faster if they are praised or rewarded every time they respond correctly to a stimulus or follow instructions well (Pierce & Cheney, 2017; Santrock, 2018).

Classical conditioning, therefore, appears to occur independently of the subject's will, whereas in operant conditioning the individual voluntarily produces that response.

Overall, in behaviourism, learning is strongly determined by the environment, which plays a central role in shaping behaviour. The subject is considered relatively passive and internal mental processes are not analysed, as they are not directly observable; the mind is therefore described as a ‘black box’ (Skinner, 1953; Calvani, 2014).

Cognitivism represents a shift away from behaviourism, as it shifts the focus from the study of observable behaviour to the study of internal mental processes. Learning is understood as an active process of information processing, in which the individual constructs mental representations of reality (Neisser, 1967; Bruner, 1966; Rivoltella, 2020). From this perspective, the mind is often described as an information-processing system, analogous to a computer, which receives input from the environment, processes it through various cognitive processes, and produces output in the form of behaviour (Atkinson & Shiffrin, 1968; Schunk, 2020).

Within cognitivism, processes such as attention, perception, memory and thought take on particular significance (Skinner, 1953; Domjan, 2005). Learning is no longer seen as a simple stimulus-response association, but as a process involving the selection of information, its organisation, and its integration with existing knowledge (Calvani, 2014). In this sense, memory is not understood as a simple repository, but as a complex dynamic system (sensory memory, short-term memory and long-term memory) that enables the encoding, storage and retrieval of information.

A significant contribution is also made by theories of observational and social learning (Bandura, 1977), according to which the individual can learn not only through direct experience, but also by observing the behaviour of others and its consequences. From this perspective, learning involves complex cognitive processes, such as attention to the model, retention of information, reproduction of behaviour and motivation to act.

Compared to behaviourism, therefore, the individual takes on an active role: they interpret, organise and rework information, constructing personal meanings. Teaching, consequently, cannot be limited to the presentation of stimuli and reinforcements, but must foster deep cognitive processes, such as understanding, reflection and problem-solving (Schunk, 2020).

In the second half of the twentieth century, constructivism emerged, describing learning as a dynamic process, and no longer as a mere accumulation of information by the learner (Piaget, 1970; Vygotsky, 1978; Von Glasersfeld, 1995). Individuals do not merely receive information, but construct meaning through interaction with the environment and the integration of new knowledge with pre-existing cognitive structures (Vygotsky, 1978; Rivoltella, 2020).

In this paradigm, pupils are the protagonists of their own learning and construct knowledge based on their own experiences, whilst the teacher takes on the role of facilitator and guide in the learning process. Social interaction and collaborative learning play a fundamental role, as knowledge is also constructed through interaction with others (Lave & Wenger, 1991; Florin, 2017; Rivoltella, 2020).

Learning is therefore understood as an active and constructive process, in which the individual attributes meaning to experiences based on their own mental schemas. Knowledge is thus personal and situated, as it depends on past experiences and individual ways of interpreting reality (Lave & Wenger, 1991; Florin, 2017).

Knowledge is no longer understood as a set of static and objective notions, but as a dynamic and constantly evolving process (Von Glasersfeld, 1995; Calvani, 2014). There is, therefore, no such thing as right or wrong knowledge. Knowledge is a process of 'making meaning', that is to say, it is an act of creative interpretation that a learner engages in whenever they wish to understand the reality around them, transforming learning from a mechanical process into meaningful learning (Ausubel, 2012).

2.2 Teaching and learning: a didactic perspective

Pedagogical theories provide a fundamental interpretative framework for understanding the cognitive and behavioural processes involved in the acquisition of knowledge. However, these models need to be translated into concrete teaching practices capable of guiding the teacher's actions and structuring effective learning environments.

From this perspective, didactics takes on a central role as a mediating field between theory and practice, emerging as the arena where learning principles are translated into methodological, organisational and relational choices.

Didactics is defined as 'the science of the relationship between teaching and learning, within a context' (Calvani, 2014; Rivoltella, 2020). In this definition, the relationship between teacher and learner takes on particular significance, as does the importance of the context in which learning takes place.

From a didactic perspective, learning can be understood as an intentional process that takes place within specific educational contexts through the interaction between the student, the content and the teacher's mediation (Rivoltella, 2020; Calvani, 2014). It is not limited to the mere acquisition of information, but involves the personal reworking of content, its integration with prior knowledge and its application in meaningful contexts.

Teaching analyses the multiple factors that influence the relationship between teacher and pupil and that contribute to the realisation of meaningful learning. The latter contrasts with rote learning, in that it encourages the reworking and recontextualisation of knowledge (Ausbel, 2012). Meaningful learning is defined as the type of learning that enables knowledge to be given meaning, allowing new information to be integrated with what is already known and applied in different contexts and situations. It requires the full engagement of the learner, as it aims to involve them on both cognitive and affective-emotional levels (Ausubel, 2012; Illeris, 2018).
Today, it is recognised that it is not enough to analyse teaching content, select the essential aspects and devise a graded and structured curriculum in which learning objectives represent clearly defined stages. Instead, it is necessary to also consider the ways in which such content is presented and constructed by students (Rivoltella, 2020).

Pedagogical reflection has led teaching to shift from a largely transmissive and traditional approach towards a student-centred perspective, that is, a school that places the learner at the centre of the teaching relationship (Bruner, 1966; Rivoltella, 2020). In this approach, the adult is seen as a facilitator of learning, within a conception of teaching as the art of guidance or encouragement. The teacher therefore assumes a central role in selecting and organising content and in creating teaching situations that stimulate cognitive engagement and critical reflection. In this sense, teaching is based on the ability to relate subject content to the characteristics of the students, taking into account their prior knowledge, their learning needs and the contexts in which learning takes place (Ausubel, 2012; Rivoltella, 2020).

It seems important to shift the focus to the teaching methods employed, viewed as the tools the teacher uses to facilitate learning. Whilst the lecture has long been the preferred method, teaching has now revealed all its limitations: it favours processes such as memorisation and the passive reception of information, proving less effective in stimulating critical thinking and deep reflection among students (Hattie, 2009; Calvani, 2014). Traditional models of knowledge transmission have proven insufficient for fostering competent individuals—that is, those capable of meeting the challenges of future society. The issue of teaching methodology is particularly pressing: theoretical reflection offers no simple answers, but makes it clear that there is no perfect method that suits everyone in every situation. In fact, a good teaching method is one that facilitates meaningful learning (Calvani, 2014; Fiorin, 2017).

In this context, in recent years there has been a growing focus on teaching strategies that promote active student participation and the shared construction of knowledge. New research trends highlight how learning is facilitated or hindered by emotions and how modern views of intelligence challenge long-established teaching methodologies (Pekrun et al., 2002; Illeris, 2018).

Collaborative methodologies, such as cooperative learning and peer tutoring, are gaining prominence, as they value peer interaction as a resource for learning. These approaches are based on the idea that knowledge is not simply transmitted, but constructed through discussion, the negotiation of meanings and collaboration among students (Johnson & Johnson, 2009; Rivoltella, 2020). At the same time, strategies aimed at developing critical thinking, such as problem-solving, are becoming widespread; these encourage pupils to reflect actively, formulate hypotheses and seek solutions independently. We therefore speak of active and collaborative teaching strategies, which place the student at the centre of the learning process and involve them meaningfully in the construction of knowledge, promoting not only the acquisition of knowledge but also the development of cognitive and social skills (Hmelo-Silver, 2004; Calvani, 2014).

The teaching-learning process is thus a multidimensional phenomenon in which cognitive, motivational, emotional and social components interact. The quality of learning depends not only on the structure of the content presented, but also on the degree of student engagement, the perceived significance of the activities, and opportunities for interaction and discussion within the classroom (Pekrun et al., 2002; Illeris, 2018). In particular, the opportunity to actively participate in the process of knowledge construction fosters the development of deeper and more lasting skills, moving beyond a view of learning as a mere accumulation of information (Bruner, 1966; Ausubel, 2012).

In light of these considerations, there is a clear need to adopt teaching approaches that value student activity and promote forms of active and meaningful learning. In this regard, instructional design is increasingly moving towards models that integrate cognitive and social dimensions, fostering the shared construction of knowledge and the exchange of different perspectives.

2.2.1 The affective dimension of learning

From a constructivist perspective, the affective dimension plays a key role in the construction of knowledge: in this sense, we speak of holistic learning, understood as the integration of cognitive, social and emotional aspects. Learning, in fact, does not involve solely the cognitive sphere, but also the affective and socio-relational spheres, as extensively highlighted in the literature (Pekrun et al., 2002; Park, 2022). The affective domain (from the Latin affectus, meaning 'feelings') encompasses a range of constructs, such as attitudes, values, beliefs, opinions, interests and motivation (Koballa, 2007).

In this sense, learning can be described as a motivated and purposeful behaviour, not reducible to a simple mechanism of assimilating content devoid of any emotional connection. Learning is a complex and multifactorial process, comprising verbal, emotional, motor, perceptual and problem-solving skills (Fiorin, 2017).

Neuroscience has progressively shed more light on the relationship between cognition and affect, highlighting their closely intertwined nature. In particular, it has been demonstrated that emotional processes play a decisive role in cognitive processing, making it clear that meaningful learning arises from the integration of the rational dimension and emotional experience (Pessoa, 2008).

In light of this evidence, educational psychologists distinguish learning activities into three main categories: cognitive, metacognitive and affective (Vermunt, 1996). Cognition encompasses the set of mental processes involved in the acquisition of knowledge; metacognition concerns the awareness and control of these processes (Tanner, 2012). Affective learning, on the other hand, refers to those activities 'aimed at managing the emotions that arise during learning […] and which lead to an emotional state capable of influencing the learning process positively, negatively or neutrally' (Vermunt, 1996, p. 26).

Research conducted in the classroom suggests that positive emotions among students are associated with engagement in stimulating projects and creative problem-solving, whilst negative emotions have been linked to poor academic performance and school dropout (Bellocchi, 2015; Pekrun & Linnenbrink-García, 2012).

Attitudes, values and emotions, therefore, play an active role in the construction of knowledge: they do not merely influence the student's readiness to learn, but also affect the quality and depth of the cognitive processes involved (Skinner et al., 2014; Potvin & Hasni, 2014). Furthermore, the affective dimension encompasses various constructs, including motivation, a sense of belonging and identity, which interact with one another, helping to shape students' commitment, interests and academic success (Koballa, 2007).

In light of these considerations, the affective component can be regarded as structural within teaching-learning processes, capable of fostering students' active engagement and a deeper, more lasting construction of knowledge (Pessoa, 2008; Potvin & Hasni, 2014).

2.3 The teaching of scientific subjects

Teaching is an intentional activity aimed at facilitating learning on the part of a student (Bruner, 1966; Gagné et al., 2005; Calvani, 2014). The didactics of a subject studies teaching and learning in terms of what is specific to that subject; it differs from pedagogy and the psychology of learning in that it analyses phenomena and problems specifically linked to the subject content being taught and learnt. Subject didactics, therefore, is based on the idea that it is necessary to study problems and solutions relating to the learning of specific content (Chevallard, 1985; Sensevy, 2011; Rivoltella, 2020).

The didactics of science and mathematics emerged as an autonomous discipline in the 1970s, with the development of research into students' alternative conceptions. It developed within the context of the pedagogical debate of the time, initially influenced by behaviourism and cognitivism and, subsequently, by constructivism (Besson, 2015). These theories influenced the very concept of learning, leading to a reform of science teaching, particularly in the United States.

Behaviourism focused on stimulus-reinforcement mechanisms, the decomposability and sequential nature of content, and the operational definition of objectives, skills and outcomes. Teaching must, therefore, define the objectives to be achieved and the educational experience suitable for achieving them.

Cognitivism has emphasised the active role of the mind, and it is in this context that the importance of the learner's prior knowledge is recognised; this knowledge forms the foundation upon which new learning is built, and it is considered that new learning only acquires meaning for the learner if it is integrated into the context of knowledge already possessed. Cognitivism stands in opposition to behaviourism in that it holds that learning cannot be regarded as a stimulus-response process, but involves higher cognitive processes (Piaget, 1970; Vygotsky, 1978). The learner incorporates the information obtained (whether through reception or discovery) into their pre-existing cognitive structure: for meaningful learning to occur, the new content must be linked to concepts already present in the learner's cognitive structure. Learners' pre-existing knowledge is often defined as common sense, as opposed to scientific knowledge (Novak, 1977; Ausbel, 2012).

This leads to a discussion of possible strategies for conceptual change, which facilitate the transition from common knowledge to knowledge consistent with current science (Driver et al., 1994; Posner et al., 1982). Some scholars emphasise the elements of continuity between common ideas and scientific knowledge and regard preconceptions as resources to be restructured and enriched (Vicentini & Mayer, 1999); others, such as Bachelard (1995), argue that the learning of modern science is built in opposition to what the child spontaneously thinks. In this case, it involves a genuine restructuring of ways of thinking, because modern scientific thought is by no means natural, but is often counterintuitive and contradicts appearances and common ideas.

Finally, according to constructivism, knowledge is the product of an active construction by the individual. Learning environments must now be grounded in the real world and foster the cooperative construction of knowledge, through social negotiation within the group and with the teacher. The research framework for the teaching of experimental sciences is dominated precisely by the constructivist model of learning (Besson, 2015).

In this vein, there is discussion of conceptual change, that is, the transition from common knowledge to scientific knowledge in new terms: learning becomes a process of modifying and restructuring students' representational schemas, through a progressive adjustment of cognitive structures that prove inadequate for the new situations that arise (Vicentini & Mayer, 1999). From the perspective of meaningful learning, the two different types of knowledge must integrate, but this does not always happen; indeed, sometimes a total rejection may occur. Generally, people tend to hold on to their beliefs for as long as possible, provided they remain compatible with one another (diSessa, 1993; Vosniadou 2013). Conceptual change must therefore take on a new and important meaning: by this we mean the construction of a knowledge framework capable of encompassing both spontaneous knowledge frameworks and scientific knowledge frameworks, and the definition of their respective rules of application in relation to contexts of action (Vicentini & Mayer, 1999). The new knowledge must satisfy certain specific characteristics for the learner: the learner must be able to recognise its validity, whether explanatory or predictive; it must enable them to solve problems previously unsolvable; and it must be comprehensible.

Studies on alternative conceptions and conceptual change have helped to explain why students do not understand and what obstacles they encounter. The challenge then arises of using the findings to construct teaching situations that enable students to understand and improve their learning.

Educational research has focused particularly on the development and testing of Teaching-Learning Sequences (TLS), designed on the basis of evidence emerging from studies on students' conceptions and learning processes relating to specific scientific content (Méheut & Psillos, 2004; NRC, 2000).

From this perspective, the teaching of scientific disciplines presents itself as a broad and complex field of research, concerned with multiple dimensions of teaching and learning, including the study of the processes through which students construct meaning in relation to specific content and the design of teaching strategies suitable for promoting meaningful learning.

2.3.1 The teaching of physics

Physics is an experimental science: this nature implies a constant relationship between theoretical models and phenomena observable in the natural world. Teaching physics means not only developing knowledge and understanding of physical laws, but also observational and practical skills and, more generally, scientific behaviours and attitudes (Besson, 2015). For this reason, it is necessary to promote education in the experimental sciences from an early age, thereby fostering the development of behaviours, attitudes, and observational and practical skills (National Research Council, 2000; Osborne & Dillon, 2008).

The teaching of physics, and of science in general, should be viewed as an ongoing process of inquiry that proceeds by trial and error, whether to tackle new problems or to critically review what has already been learnt (Various Authors, 1994; Redish, 2003; Osborne, 2014). The observation of facts and a spirit of inquiry should characterise effective physics teaching, which should be implemented through the direct involvement of pupils, encouraging them – without imposing a rigid chronological order or forcing the stages of the process – to ask questions about phenomena, formulate hypotheses, design experiments or explorations, and construct interpretative models (National Curriculum Guidelines, 2012).

Experiments therefore play a central role in physics teaching (Besson, 2015). Such experimental activities can be introduced with very different functions and objectives: in some cases, the main objective may be to train students in the use of particular instruments or to accustom them to carrying out reasoned practical activities, or to foster students' motivation and interest. In other cases, the aim may be to introduce a topic or explore a given phenomenon (Various Authors, 1994). Furthermore, experiments can be used to generate cognitive conflict in students, with the aim of helping them overcome misconceptions and bring about conceptual change (Posner et al., 1982; Driver et al., 1994). Constructivist perspectives have, however, criticised the use of rigidly structured experiments, as in the case of guided worksheet activities. In such cases, the experiment tends to lose some of its educational value; on the contrary, the activity must allow students the opportunity to observe and hypothesise independently, in some cases even having the students design the experiments themselves (Etkina & Van Heuvelen, 2007; Hmelo-Silver et al., 2007).

It is important, however, that the experiment does not constitute a segment separate from schoolwork, but is an integral part of a scientific and educational discourse unfolding in the classroom, in a dialogue between theory, hypotheses and experiments. In this context, discussion must play an essential role (Viennot et al., 2005).

As Galileo already emphasised, the understanding of natural phenomena is based on the integration of 'sensible experiences and certain demonstrations' (Besson, 2015).

Physics, like other experimental sciences, is neither pure reasoning nor pure experimentation, but rather the coordinated combination of these two activities (Redish, 2003; National Research Council, 2000). It is not an individual activity, but a social one; it is the result of the work of a community that communicates both internally and externally. Something similar should also take place in school classrooms, where students should engage with one another and work as a genuine scientific community. In this sense, research in physics education has developed teaching models and approaches that emphasise the role of experience, inquiry and the active participation of students, promoting learning contexts in which pupils are called upon to progressively construct their own knowledge through interaction with phenomena and engagement with others (National Research Council, 2000; Osborne, 2014).

2.3.2 The importance of the affective dimension in physics learning

Within physics education, the affective dimension of learning has long received less attention than other research topics, such as subject content, students' alternative conceptions, conceptual change and the effectiveness of teaching methodologies (Koballa, 2007). The learning of physics has often been interpreted primarily in cognitive terms, as a process of understanding, conceptual restructuring and the development of explanatory models. However, in recent years, the need to also consider the emotional, motivational and identity-related dimensions that accompany students' relationship with the subject has become increasingly clear (Potvin & Hasni, 2014; Li et al., 2020; Whitcomb et al., 2023). Recent literature shows, in fact, that variables such as emotions, interest, sense of belonging, scientific identity and self-efficacy contribute significantly to shaping students' engagement, persistence in the task, scientific aspirations and, more generally, the quality of learning (Hazari et al., 2010; Pekrun et al., 2012; Whitcomb et al., 2023). In particular, these dimensions should not be regarded as incidental or secondary elements, but as components closely intertwined with cognitive processes, capable of either supporting or hindering the construction of scientific knowledge.

This perspective is particularly relevant in physics, a subject frequently perceived by students as abstract, difficult and highly selective (Osborne et al., 2003; Potvin & Hasni, 2014). This perception can have a negative impact not only on performance, but also on motivation, interest and the way in which students perceive their own chances of success. The perceived difficulty of physics often has an emotional and affective impact as well, generating feelings of anxiety, frustration, detachment from the subject, or a lack of identification with it (Osborne et al., 2003). Conversely, when teaching promotes experiences of active participation, a sense of competence and meaningful engagement, students are more likely to develop a positive relationship with physics and scientific practices (Ganajová et al., 2025). In this context, discussing affectivity in physics education means recognising that scientific learning does not depend solely on the accuracy of the content presented or the effectiveness of methodological strategies, but also on the way in which students emotionally experience their encounter with the subject (Potvin & Hasni, 2014).

2.4 Educational Reconstruction

The Educational Reconstruction (ER) approach emerged in the early 1990s within the field of science education, with the aim of bridging the gap between scientific knowledge and school practice, whilst avoiding an excessive and decontextualised simplification of subject content (Kattmann et al., 1997; Duit et al., 2012). It represents a theoretical and methodological model geared towards instructional design, based on the need to link the reworking of scientific knowledge with consideration of students' conceptions and their cognitive difficulties.

Developed by a German research group led by Kattmann (1996), the approach is situated within the constructivist paradigm (Driver et al., 1994; Posner et al., 1982) and is closely linked to research on conceptual change and evidence-based instructional design. Underpinning ER is the idea that science teaching cannot be limited to the transmission of expert knowledge, nor can it reproduce the language and level of abstraction characteristic of academic science (Kattmann et al., 1997). At the same time, however, it cannot ignore the epistemic structure of the discipline, which must be maintained and reworked so as to be comprehensible and meaningful to students.

From this perspective, ER acts as a bridge between disciplinary epistemology and teaching-learning processes (Komorek & Kattmann, 2009): on the one hand, it requires a careful analysis of the key concepts, theoretical models and problems specific to the discipline; on the other, it involves understanding students' prior knowledge, their representations and the cognitive obstacles that may arise during learning (Duit et al., 2012). On this basis, teaching strategies are developed that mediate between expert knowledge and students' knowledge, through the use of meaningful contexts, appropriate tools and opportunities for discussion and guided reflection (Pannullo, 2025).

This approach fosters a continuous dialogue between subject-specific research, educational research and teaching practice, offering a flexible framework for lesson planning (Komorek & Kattmann, 2009). Despite its theoretical soundness, the application of ER requires high levels of subject-specific and pedagogical expertise, adequate planning time and particular attention to translating complex concepts into accessible forms without compromising their meaning (Kattmann et al., 1997).

Overall, Educational Reconstruction represents a significant reference model for science teaching, as it allows for the integration of disciplinary rigour and attention to learning processes, linking content, students and the educational context.

2.5 Learning methodologies

Every teaching methodology is developed on the basis of advances in educational research and experience gained in teaching and learning processes. It can be understood as a set of strategic actions that must remain flexible, so as to enable the teacher to adapt them to specific educational contexts and the characteristics of the pupils (Calvani, 2007; Calvani, 2014). In general terms, methodology concerns the practical operational methods through which educational activity is carried out.

Active methodologies share certain fundamental characteristics: valuing pupils' experiences, promoting exploration and discovery, encouraging collaborative learning, developing metacognitive awareness, and implementing workshop-based learning pathways (Rivoltella, 2012).

Numerous studies have highlighted a positive correlation between the use of active methodologies and the promotion of meaningful learning (Prince, 2004; Ausubel, 2012; Freeman et al., 2014). In particular, within the field of physics education, these studies have fostered the development of approaches based on a constructivist perspective, characterised by student-centredness, the importance of direct experience, and the fundamental role of experimental and laboratory activities.

Meltzer and Thornton (2012), in their review of research-based active-learning instruction in physics, define these approaches as instructional methods grounded in research on the teaching and learning of physics, assessed through research, and validated by evidence of student learning. A central feature of these methods is that students are actively involved in the learning process, particularly during class time, through activities that require them to express, discuss, test and revise their own thinking rather than merely listening to explanations or reproducing procedures. It is within this context that two of the most widely used methodologies are situated: Inquiry-Based Science Education (IBSE) and the Investigative Science Learning Environment (ISLE), which will be analysed in the following sections. Furthermore, in light of the growing focus on the affective dimension in physics education, the effects of inquiry-based methodologies on the motivational, social and relational aspects of learning have been analysed (Potvin & Hasni, 2014; Whitcomb et al., 2023).

2.5.1 IBSE: the 5E model

Inquiry-Based Science Education (IBSE) is a widely used teaching methodology in the field of science education, based on inquiry as the primary tool for knowledge construction.

A fairly common definition in the literature is that provided by Linn et al. (2004): "Inquiry is an intentional process of problem identification, critical analysis of situations, distinguishing between various possible alternatives, planning study and exploration activities, formulating conjectures, seeking information, constructing models, peer discussion and developing coherent arguments”.

In this thesis, the term inquiry is used with two related but distinct meanings. First, scientific inquiry refers to the epistemic practices through which scientists construct, test and revise knowledge about the natural word. Seondo, Inquiry-Based Science Education (IBSE) refers to a pedagogical approach that translates some of these practices into classroom activities, with appropriate levels of guidance and structure. Although these two meanings are closely connected, they should not be considered identical: students’ inqiry activities are educational reconstructiona of scientific practices, rather than direct reproductions of scientists’ work.

In IBSE, inquiry is understood as a process of active exploration, through which critical, logical and creative skills are employed to ask questions about situations of specific interest and to engage in providing answers to those questions. The Inquiry process helps to link prior knowledge with new experiences, to modify and accommodate preconceived ideas and conceptual models, and to construct new knowledge (Llewellyn, 2002; Bybee, 2006).

The term ‘inquiry’ therefore refers to the work of scientists, which can be understood as the study of the natural world aimed at identifying explanations for natural phenomena based on evidence from the world itself. At the same time, inquiry also concerns students’ activities, such as asking questions, planning investigations and revising prior knowledge in the light of experimental evidence—activities that mirror what scientists do (Martin-Hansen, 2002).

Generally, in an inquiry-based classroom, students are engaged in the so-called ‘inquiry cycle’ (Fig. 1), which is based on thinking strategies designed to develop conscious inquiry processes. An inquiry-based learning approach is effective when students explicitly understand how and why scientists think in a certain way, and not just what they investigate (Dobber et al., 2017).

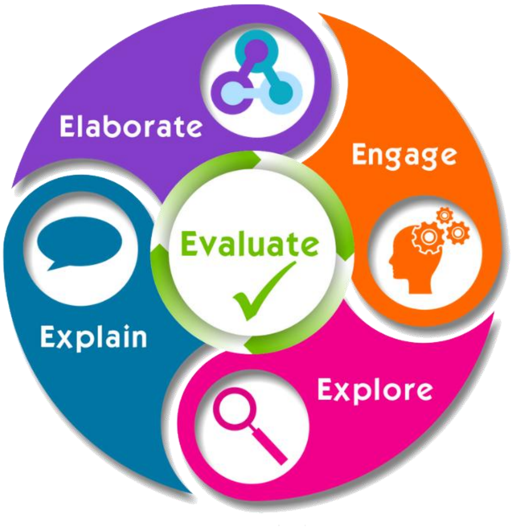

Fig. 1 The inquiry cycle based on the 5E model by Bybee (Bybee et al. 2006)

The inquiry cycle can be divided into different phases, depending on the model considered. Table 1 shows the five-phase cycle as formulated by Bybee (Bybee et al., 2006).

Table 1 Stages of the inquiry cycle

5E Instructional Model (Bybee et al., 2006)	
Engage	The teacher assesses the students' prior knowledge and engages them in new contexts and situations, introducing activities that stimulate curiosity and allow existing knowledge to emerge.
Exploration	Students carry out exploratory activities through which their current concepts, processes and skills are identified, promoting conceptual change. They may be involved in practical activities that help them use prior knowledge to generate new ideas and to design and carry out an initial investigation.
Explanation	The explanation process allows students and teachers to share a common understanding of terms in relation to learning tasks.
Elaboration	Once students have acquired explanations and appropriate terminology, they are engaged in further experiences that allow them to broaden and deepen the concepts, processes and skills they have learnt. This phase facilitates the transfer of knowledge to new contexts and situations.
Evaluation	This phase represents an important opportunity for students to apply the skills they have acquired and assess their own understanding and abilities. At the same time, teachers can assess students' progress towards achieving educational objectives.

The inquiry methodology aims to develop in students both the ability and the inclination to investigate, fostering the construction of knowledge and understanding through forms of active learning. It also promotes the acquisition of specific skills related to scientific processes and supports the ability to formulate and communicate scientific explanations (Martin-Hansen, 2002). In this context, inquiry also serves as an effective tool for conceptual change, acting on both cognitive skills and abilities related to scientific processes (Sahhyar & Nst, 2017).

It is possible to distinguish different levels of inquiry in relation to the degree of centrality assumed by the teacher or the student in the learning process. The different types of inquiry are in fact employed to meet specific pedagogical needs within science teaching (Martin-Hansen, 2002). Table 2 summarises the main characteristics of the phases and the different levels of inquiry.

Table 2 Levels of Inquiry (Martin-Hansen, 2002; National Research Council, 2000).

Inquiry Phase	Level of Inquiry			
	Confirmatory Inquiry	Structured Inquiry	Guided inquiry	Open Inquiry
Engage	The student engages with questions posed by the teacher and uses materials or other sources provided by the teacher.	The student refines or clarifies the questions posed by the teacher and uses materials or other sources provided.	The student examines the proposed questions and formulates new ones.	The student formulates questions independently.
Exploration	The student is provided with data; the teacher explains how to analyse it.	The student is provided with data and is asked to analyse it.	The student is guided through the data collection process.	The student independently identifies and collects the data.
Explanation	The student is provided with the evidence.	The student is given suggestions on how to use the evidence to formulate explanations.	The student is guided through the process of formulating explanations based on the evidence.	The student formulates explanations independently after summarising the evidence.
Elaboration		The student is presented with possible connections.	The student is guided towards scientific knowledge.	The student independently explores the resources and

				makes connections with the explanations.
Evaluation	The student is provided with procedures and steps to communicate the results.	The student is provided with general guidelines to improve communication.	The student is supported in developing their communication skills.	The student constructs logical and well-founded arguments to communicate their explanations.

Within the paradigm of IBSE, the teacher supports students in understanding physics and in gradually engaging with scientific culture. Furthermore, this model fosters the development of critical thinking and enables students to construct knowledge in ways analogous to those of scientists (Bao, 2013; Ali & Spencer, 2012).

From this perspective, an understanding of scientific inquiry represents a fundamental component of so-called scientific literacy, now considered a central objective of science education (Lederman et al., 2013). Scientific inquiry also has a significant impact on students' ability to apply physical concepts to real-world situations (Dumbrajs, 2011; Hussain et al., 2011).

2.5.2 Investigative Science Learning Environment – ISLE approach

The Investigative Science Learning Environment (ISLE) methodology refers to an intentional and holistic learning environment (Etkina et al., 2019). It is defined as intentional in that it attaches equal importance to both the content learned and the processes through which students learn (Brookes et al., 2020); at the same time, it is holistic in that it views the learning of physics as a unified and coherent system, in which the various elements of knowledge are closely interconnected (Etkina, 2015a).

The ISLE approach aims to actively involve students in the construction of knowledge through activities that reproduce, in simplified and educationally structured forms, the processes through which physicists develop, test and refine explanations of natural phenomena. It can therefore be understood as a broader framework for physics learning, in which epistemological, cognitive, social and affective dimensions are integrated into a coherent learning environment. From this perspective, the teaching of physics concerns not only the development of cognitive skills, but also the way in which students experience the learning process. These two dimensions – how one learns and how one feels whilst learning

– form the core of the ISLE approach and guide pedagogical and methodological choices (Etkina et al., 2021).

These dimensions are reflected in a series of elements that characterise the ISLE approach, which concern both the learning process and assessment and classroom organisation. Table 3 summarises some of these aspects.

Table 3 Main characteristics of the ISLE approach (Etkina et al., 2019; Etkina, Warren et al., 2006)

Learning process and tools	The development of physical concepts takes place through a series of *knowledge*-generating *activities*, which reproduce, in simplified form, the practices of scientific research. In this context, multiple representations of physical processes constitute fundamental tools for concept construction, reasoning and evaluation.
Assessment and learning communities	Assessment is designed to assess students' ability to reason like physicists and, at the same time, to foster the development of these skills. Social interactions and the sharing of ideas become an integral part of the learning process, contributing to the collective construction of knowledge.
Need to know and the moment of explanation	Intrinsic motivation is also supported through the initial activation of forms of extrinsic motivation. Within the classroom, opportunities are created for students to compare, discuss and reflect on their own ideas, relating them to those of the scientific community.

These elements highlight how the ISLE approach integrates cognitive, epistemological and socio-relational aspects into the process of learning physics.

The main objective of ISLE is to actively involve students in the process of knowledge construction, bringing them closer to the way scientists work. In this sense, students are not regarded as mere consumers of content, but as active participants who learn by 'doing physics', through a process that reproduces, in simplified form, the logical progression typical of scientific activity (Brookes et al., 2020). This active involvement contributes not only to the development of subject-specific skills but also to students' well-being in the learning process.

The activities proposed within the ISLE framework unfold according to a non-linear, but cyclical and recursive, process that supports students' reasoning and encourages the continuous revision of their own ideas (Etkina, 2015a; Brookes et al., 2020). In this context, experiments play a central role, but are distinctly different from traditional demonstrative or guided activities. Unlike so-called *'cookbook experiments'*, in which students follow pre-established procedures, in the ISLE approach they are involved in activities that highlight the interaction between observation, hypothesis formulation, experimental verification and theoretical construction (Brookes et al., 2020).

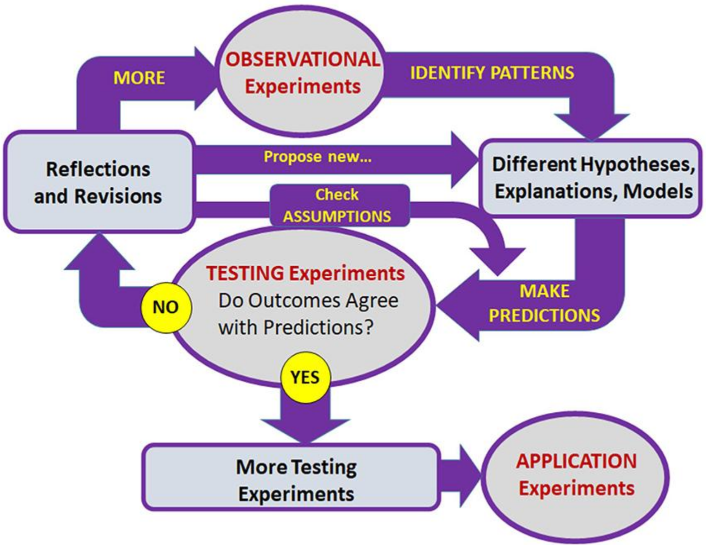
OBSERVATIONAL Experiments
MORE
IDENTIFY PATTERNS
Reflections and Revisions
Propose new...
Different Hypotheses, Explanations, Models
Check ASSUMPTIONS
TESTING Experiments
Do Outcomes Agree with Predictions?
NO
YES
MAKE PREDICTIONS
More Testing Experiments
APPLICATION Experiments

Fig. 2 The Investigative Science Learning Environment (ISLE) approach

Students are therefore encouraged to start from the observation of phenomena to develop explanations, to formulate and compare different hypotheses, and to test their ideas through experiments. This process leads them progressively to revise their initial conceptions and to construct interpretations that are increasingly consistent with the scientific model. In this process, a fundamental role is played by the use of models and representations, which enable the description, explanation and prediction of physical phenomena. Representations are not merely used to formalise results, but become cognitive tools for constructing meaning and linking empirical experience to mathematical formalisation (Etkina, 2015b; Van Heuvelen, 1991).

The learning process develops through various forms of reasoning. In the initial stages, an inductive approach prevails, based on the observation of phenomena; subsequently, students formulate explanations by also drawing on analogical reasoning, grounded in prior knowledge and experience (DiSessa, 1993). Hypotheses are then tested through targeted experiments, engaging in hypothetico-deductive reasoning. Finally, the knowledge acquired is applied to new contexts, promoting the transfer and generalisation of learning (Etkina, 2015a).

In this way, students develop skills that reflect the practices of the scientific community, such as model building, experimental design, data analysis, and the ability to argue and communicate scientifically (Etkina, Brookes, et al., 2019). Consequently, assessment also plays a central role and must be consistent with these objectives, prioritising forms of formative assessment that consider not only outcomes but also reasoning processes.

The ISLE approach is based on a variety of theoretical perspectives – cognitive, epistemological, socio-cultural and humanistic – which help to shape a teaching model in which the teacher takes on the role of guide and facilitator of the learning process. In this context, students are encouraged to reflect on their own learning journey, to review and improve their work, and to develop a greater awareness of their own learning.

The defining features of the ISLE approach are particularly relevant to this research. In particular, the use of different types of experiments, the use of multiple representations, the focus on psycho-cognitive aspects, and the adoption of teaching tools such as open-ended questions, interrogative approaches, and self-assessment practices constitute fundamental references for the design of the teaching programme, as will be illustrated in the following chapters.

2.5.3 Affective and motivational effects of IBSE and ISLE approaches

The scientific literature has extensively investigated the effects of inquiry-based methodologies on the motivational, social and relational aspects of learning (Škoda et al., 2015; Buggé & Etkina, 2020; Park, 2022).

Emotions are not merely an incidental element of learning, but play a central role in the process of constructing scientific knowledge (Hufnagel & Radoff, 2019). In particular, through inquiry-based methodologies, students experience a variety of emotional states — including confusion, frustration, surprise and interest — which actively contribute to the process of sense-making (Hufnagel & Radoff, 2019). Particularly relevant is the role of so-called ‘negative’ emotions, such as frustration, which do not hinder learning but, on the contrary, stimulate perseverance and cognitive engagement (Hufnagel & Radoff, 2019). In this sense, affect emerges as an intrinsic component of scientific reasoning, closely intertwined with cognitive processes and fundamental to sustaining investigative activity, especially in contexts characterised by open-ended problems and situations of uncertainty (Pekrun et al., 2002; Lock, 2013).

IBSE significantly influences students' motivation, promoting greater engagement compared to traditional teaching. In particular, inquiry-based learning activates motivational processes that vary according to individual characteristics but are generally associated with an increase in interest and personal investment in the task (Škoda et al., 2015; Teplá & Distler, 2025). At the same time, these effects do not manifest linearly over time: in the initial stages, particularly in more complex contexts or at higher levels of inquiry, a reduction in interest and an increase in the perception of difficulty may emerge; however, with prolonged exposure, a significant increase in motivation and commitment is observed. This highlights how the affective dimension of inquiry is closely linked to the student's active role—requiring them to formulate hypotheses, verify evidence and construct meaning—as well as to the level of s r structuring of activities and the gradual manner in which they are introduced (Škoda et al., 2015; Teplá & Distler, 2025).

Research shows that IBSE supports critical thinking, creativity, problem-solving, communication and collaboration. Even at primary school level, IBSE stimulates curiosity and motivation by starting with meaningful and real-world questions and engaging pupils in practical and active experiences (Ölçer, 2025). Ölçer (2025), in a review dedicated to inquiry-based science teaching in primary schools, emphasises how IBSE can foster the development of problem-solving skills, active participation and scientific thinking among pupils. Through exploratory activities, pupils are required to formulate hypotheses, test solutions and review their strategies, thereby developing a flexible and active approach to problem-solving. At the same time, the non-rigidly structured nature of inquiry-based activities stimulates the generation of diverse ideas and strategies, contributing to the enhancement of creative thinking (Ölçer, 2025).

Park's (2022) study analyses the relationship between emotions and scientific identity in an inquiry context, showing how positive emotions such as interest, pride and satisfaction are associated not only with engagement but also with the development of a stronger identification with the scientific discipline. In this sense, the emotional experience contributes to the construction of the student's identity as a competent scientific subject, whilst negative emotions emerge when the perceived level of challenge exceeds available skills.

Alongside IBSE, the Investigative Science Learning Environment (ISLE) also fits within the same theoretical framework, demonstrating similar effects on the affective dimension of learning. The study conducted by Buggé & Etkina (2020) showed that students involved in ISLE programmes develop, over time, perseverance, autonomy in reasoning and a growth mindset, as well as recognising the value of the experience for their educational and professional development. It is interesting to note that, in the early stages, students may perceive the approach as complex and sometimes frustrating, due to the requirement for active participation in the construction of knowledge; however, this initial difficulty gradually evolves into an increase in confidence in their own abilities, manifesting as a development of perceived self-efficacy in tackling complex scientific tasks.

Similar results also emerge from more recent studies, which highlight an increase in student engagement and a positive perception of experimental activities, attributable to the opportunity to actively participate in the construction of the learning experience (Tufino et al., 2020).

From a theoretical perspective, the ISLE approach explicitly integrates the affective dimension into its educational objectives, positing that the learning process should not only facilitate the construction of knowledge but also promote student well-being, motivation, a sense of belonging and confidence in one’s own abilities (Etkina, 2015a). These effects are closely linked to the structural characteristics of the methodology, such as the active involvement of students in authentic scientific practices, the cyclical nature of the inquiry process and the collaborative dimension of learning. These characteristics contribute to improving both skills related to scientific processes and students’ attitudes towards science (Ergül, 2011; Turpin & Cage, 2004).

Overall, the literature suggests that inquiry-based learning, as it is grounded in exploratory and collaborative activities, can positively influence the affective aspects of learning and foster scientific aspirations among young students (Cairns & Areepattamannil, 2019; Kang & Keinonen, 2017), as well as interest, self-efficacy and outcome- d expectations (Jeffries et al., 2020; Kang et al., 2021a; Potvin & Hasni, 2014). From this perspective, the affective dimension is closely intertwined with the development of scientific identity and self-efficacy, contributing not only to student engagement but also to the construction of an active and conscious relationship with scientific knowledge (Lock et al., 2013; Hazari et al., 2013; Gupta et al, 2018).

2.6 Teaching Learning Sequences

Teaching Learning Sequences (TLS) are a tool designed to guide students' cognitive pathways intentionally and coherently. They can be defined as a structured and intentional sequence, designed to promote meaningful learning through an intentional and coherent articulation of teaching and learning situations (Geminard, 1987; Méheut & Psillos, 2004). TLS are widely regarded as an effective pedagogical strategy for teaching scientific content, as they are empirically aligned with students' reasoning processes (Psillos & Kariotoglou, 2016).

The development of TLS is strongly influenced by the pedagogical approaches discussed previously, which have inspired both their structure and their educational aims. In particular, constructivism has helped to spread the idea of knowledge as an active construction, the result of interaction between the individual, the environment and the cultural context (Duit & Treagust, 1998). Educational Reconstruction has provided a theoretical framework conducive to the design of teaching sequences based on active exploration, hypothesis formulation and argumentative dialogue. In parallel, the ISLE (Investigative Science Learning Environment) model by Etkina et al. (2019) has promoted teaching practices based on observation, experimentation and reflection. These approaches share the idea that scientific learning must be based on direct experience, interaction and the active construction of meaning.

From this perspective, the TLS are designed to organise teaching pathways capable of stimulating reflection, discussion and the negotiation of meanings, helping students move beyond naive conceptions and promoting conceptual change (Méheut & Psillos, 2004).
Their development is based on the idea that teaching should be structured as a sequence of carefully designed activities that stimulate a gradual reorganisation of students' conceptions and the restructuring of cognitive barriers, leading towards more advanced, shared and scientifically grounded conceptual models. The organisation of activities within a TLS follows a logic that integrates conceptual, cognitive and metacognitive dimensions (Duit et al., 2005; Etkina et al., 2019). Furthermore, it is progressively refined through iterative implementations and is supported by research data that guide its improvement and enrichment (Lijnse, 2004).

The TLS is therefore designed to promote meaningful learning through a coherent progression of stages, each geared towards specific cognitive and educational objectives: the structuring of the sequence into progressive steps with clear objectives; the identification and utilisation of students' prior knowledge; the introduction of activities that encourage cognitive conflict and metacognitive reflection; the integration of authentic or simulated teaching materials; the consolidation and formalisation of constructed knowledge. This organisation proves particularly effective in promoting conceptual change, understood as the transition from common knowledge to scientific knowledge (Vicentini & Mayer, 1999).
The design of a TLS is neither a random nor a linear process: it requires careful reflection on subject content, a solid understanding of students' prior knowledge, and a clear definition of learning objectives (Von Glasersfeld, 1995; Bruner, 1966).
Furthermore, the design and implementation of TLSs require the teacher to play an active and reflective role, one that is not limited to selecting content, but involves designing learning environments, anticipating difficulties, observing the cognitive processes at work, and intervening with targeted support strategies (Psillos & Kariotoglou, 2016). This implies a renewed vision of teaching professionalism, integrating subject-specific knowledge, an understanding of cognitive processes, and the ability to mediate learning.

The effectiveness and relevance of TLS as tools for designing, analysing and evaluating teaching-learning processes have been highlighted by several studies in the field of science education (Buty et al., 2004; Leach & Scott, 2002), which emphasise their contribution to fostering conceptual change and greater awareness of learning processes.
TLS have proven effective in overcoming the fragmentation of traditional teaching practices, ensuring greater continuity and coherence in learning pathways, particularly in subjects such as physics and chemistry, where the transition from naive conceptions to scientific understanding requires systematic guidance (Psillos & Kariotoglou, 2016; Vicentini & Mayer, 1999).

It can therefore be said that Teaching Learning Sequences represent one of the most mature and structured expressions of the constructivist approach to science education. They allow for the integration of subject content, teaching strategies and pedagogical reflection within a coherent and intentional framework, centred on the student's cognitive experience (Méheut & Psillos, 2004). In this sense, they constitute genuine models of instructional design, capable of transforming teaching into a shared and transformative process of knowledge construction (Psillos & Kariotoglou, 2016).

2.7 Conclusion

In conclusion, learning cannot be reduced to a mere passive acquisition of content, but must be interpreted as a complex, dynamic and multidimensional process in which cognitive, social and affective components interact. The evolution of pedagogical perspectives has progressively redefined the role of the student, recognising their centrality in the active construction of knowledge and emphasising the importance of context, interaction and teaching mediation.

In the context of science education, and in particular physics, these considerations take on even greater significance, as learning requires not only conceptual understanding and a shift in spontaneous conceptions, but also engagement, participation, motivation and a sense of competence. From this perspective, inquiry-based methodologies, such as IBSE and ISLE, emerge as particularly significant approaches, as they are capable of enhancing both the cognitive and affective dimensions of learning (Bybee, 2006; Etkina, 2015).

Finally, Teaching Learning Sequences (TLS) represent suitable and functional operational tools that integrate theoretical and practical aspects, enabling the organisation of structured and intentional learning pathways, geared towards conceptual change and the meaningful construction of knowledge (Méheut & Psillos, 2004).

In light of this evidence, it appears necessary to explore in greater depth those constructs that help shape the student's relationship with scientific learning. Among these, self-efficacy plays a central role, understood as a factor capable of influencing commitment, persistence, motivation and success in learning contexts, which will be explored in the next chapter (Bandura, 1997).

The term 'inquiry' therefore refers to the work of scientists, which can be understood as the study of the natural world aimed at identifying explanations for natural phenomena based on evidence from the world itself. At the same time, inquiry also concerns students' activities, such as asking questions, planning investigations and revising prior knowledge in the light of experimental evidence—activities that mirror what scientists do (Martin-Hansen, 2002).

Generally, in an inquiry-based classroom, students are engaged in the so-called 'inquiry cycle' (Fig. 1), which is based on thinking strategies designed to develop conscious inquiry processes. An inquiry-based learning approach is effective when students explicitly understand how and why scientists think in a certain way, and not just what they investigate (Dobber et al., 2017).

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CHAPTER 3

SELF-EFFICACY

In the 1970s, Albert Bandura introduced the concept of self-efficacy, opening up a new perspective in the study of human behaviour and educational processes. Since then, psychological and pedagogical research has progressively explored this construct, highlighting its multidimensional, dynamic and situated nature, as well as its role in various life and learning contexts.

In the school setting, self-efficacy is a central variable, as it influences how students approach tasks, interpret successes and failures, regulate their motivation, and persevere in the face of difficulties. Promoting positive beliefs in one's own efficacy, therefore, means supporting not only academic performance, but also active participation, autonomy and motivation.

This influence is particularly significant in scientific disciplines, which are often perceived as complex and selective. In this context, numerous studies have highlighted the existence of gender differences in scientific self-efficacy, frequently to the detriment of female students. These differences do not necessarily reflect lower ability, but may be fuelled by gender stereotypes, social expectations, anxiety and insecurity regarding one's own scientific skills. A lower perception of efficacy can thus affect interest, engagement and perseverance in scientific activities, contributing over time to driving many female students away from STEM pathways.This section describes the general idea of Teaching/Learning Sequence (TLS), and the theoretical and pedagogical frameworks and methodologies on which a TLS can be based.

3.1 Self-efficacy: definition

The concept of self-efficacy was theorised by Albert Bandura, who defined self-efficacy as 'beliefs about one's ability to organise and execute the sequences of actions necessary to produce specific outcomes' (Bandura, 2000, p. 23).

The key aspect of this theory is that it concerns an individual's perception of their own abilities, rather than their actual abilities (Webb-Williams, 2018). Self-efficacy concerns the belief that one possesses the necessary abilities and knows how to organise them appropriately to influence the course of events in the desired manner. This construct is not a given fact or a skill that a person either possesses or does not possess, but is a belief, a generative capacity that encompasses cognitive, social, emotional and behavioural sub-skills, which must be organised and coordinated appropriately to fulfil a multitude of purposes. It is therefore worth bearing in mind that self-efficacy is not limited to the belief that one possesses the skills necessary to perform (Bandura, 1997, 2006).

Beliefs in self-efficacy are not a general trait, but rather a differentiated set of self-beliefs linked to distinct spheres of functioning (Bandura, 1986). This means that self-efficacy varies according to the domains in which one engages. Furthermore, within individual domains, self-efficacy can be differentiated according to sub-domains, relating to specific aspects of the skill in question. The multidimensional approach does not preclude the existence of a generalised degree of self-efficacy that applies to sub-skills common to different activities. Self-efficacy, therefore, is established and documented as domain-specific, meaning that one may have high self-efficacy in one discipline, but that level of self-efficacy does not necessarily transfer to a related discipline (Pajares, 1996; Bong, 2001).

The concept of self-efficacy underpins the theory of agency, also developed by Bandura, who defines it as “the ability to make things happen, to intervene in reality, to exert causal power” (Bandura, 2000, p. 17). Thus, agency consists of the awareness of being able to exercise control over the course of events, of having causal power over external reality. The concept of self-efficacy is based on this theory, according to which the individual does not respond passively to environmental stimuli, but acts as an active agent, capable of influencing the course of events (Bandura, 1986). From this perspective, human behaviour is not determined by a single cause, but is the result of the dynamic interaction between multiple factors.

In this regard, a fundamental theoretical assumption is triadic reciprocal determinism (Bandura, 1986, 2001). It is important to emphasise that the term ‘determinism’ does not indicate linear causality, but rather a complex system in which the final event is the product of the interaction between three mutually influencing dimensions: personal factors (cognitive, affective and biological), behavioural factors and environmental factors (external and social context). According to the theoretical model of triadic reciprocal determinism, on which the concept of self-efficacy is based (Bandura, 1986, 2001), human behaviours (C) can influence the external environment (E) by altering it; the external environment, in turn, imposes constraints and offers opportunities that influence human behaviours. Cognitive aspects (P) influence human behaviour by determining which actions to carry out (intentionality); in turn, behaviour influences our ways of thinking. Finally, society dictates rules and imposes limits that influence personal factors, but it is precisely humans, through their cognition, who have created society (Bandura, 1986). In this model, human behaviour emerges from the mutual and continuous influence of these factors and is closely linked to the beliefs that individuals develop regarding their own ability to act effectively in different contexts. Self-efficacy therefore occupies a central position within this system, capable of guiding choices, the level of commitment, perseverance in the face of difficulties and, more generally, the regulation of behaviour (Zimmerman, 2000; Schunk & DiBenedetto, 2020).

Within this theoretical framework, self-efficacy can also be understood as an attributional characteristic of an affective nature, susceptible to change (Lamb et al., 2014). This implies that it does not depend exclusively on the person's internal characteristics, but is also influenced by external and contextual factors, which can be addressed.

Attributional theory highlights, in fact, that individuals tend to seek explanations for the outcomes of their actions, especially when these are unexpected (Weiner, 1985; Graham, 2020). The way in which these outcomes are interpreted represents a key element in the construction and modification of beliefs regarding personal efficacy.

Furthermore, when defining the concept of self-efficacy, it is necessary to clarify the distinction between self-efficacy and certain related concepts with which it might be mistakenly confused. The concepts of self-efficacy and self-esteem are often mistakenly used interchangeably, yet they are in fact two distinct concepts. Self-esteem is a global assessment of the self, detached from context; it is a value judgement (positive or negative) on one's own person in general, regardless of the specific situation one finds oneself in (Marsh & Craven, 2006). In contrast, as mentioned above, self-efficacy is the personal belief that one possesses the necessary skills to achieve success in a given area; therefore, the assessment of efficacy is domain-specific and varies according to the specific situational context in question. The same individual may have high self-efficacy in some areas and low self-efficacy in others (Harter, 1990).

Self-esteem and self-efficacy are, therefore, two related but distinct concepts. There is, however, a link between them. In some cases, self-efficacy can influence self-esteem: having high self-efficacy in an area we consider central to our lives (an area that defines who we are) leads to an increase in our self-esteem, just as having low self-efficacy in an area we consider central to our lives leads to a decrease in our self-esteem. Conversely, having low self-efficacy in an area that is not considered central to our lives has no influence on self-esteem: it is therefore possible to have low self-efficacy in certain areas whilst maintaining high self-esteem (Bandura, 2000).

Self-efficacy is closely related to the concept of growth mindset (Dweck, 2014; Burnette et al., 2013). Growth mindset refers to the belief that abilities and intelligence are not fixed traits, but can be developed through effort, effective strategies, feedback, persistence and learning experiences (Dweck, 2014; Yeager & Dweck, 2012). Students with a growth mindset tend to interpret mistakes and difficulties not as evidence of a lack of ability, but as part of the learning process; consequently, they are more likely to accept challenging tasks, persist after failure and revise their strategies when needed. The literature suggests a positive relationship between these two constructs: students who believe that their abilities can improve are more likely to develop stronger beliefs in their own capability to succeed in specific tasks (Bandura, 1997; Burnette et al., 2013). However, self-efficacy and growth mindset do not coincide (Rhew, 2018). Self-efficacy refers to individuals' beliefs about their capability to perform specific tasks or achieve particular goals in a given domain, whereas growth mindset concerns more general beliefs about the malleability of abilities and intelligence. Thus, growth mindset may support the development of self-efficacy, but the two constructs describe different dimensions of students' motivation and learning (Rhew, 2018).

Overall, self-efficacy is a complex and multidimensional construct, relating to an individual's beliefs about their ability to organise and utilise personal resources in relation to specific tasks and contexts (Bandura 1986, 2000). It is characterised by its situated and dynamic nature, varying in relation to the contexts of functioning and lived experiences (Usher & Pajares, 2008).

In light of these characteristics, it is particularly important to analyse how self-efficacy manifests itself within educational contexts, where beliefs about personal efficacy take on specific forms linked to learning activities (Usher & Pajares, 2008; Schunk & DiBenedetto, 2016).

3.2 Self-efficacy in the school context

As highlighted in the previous chapter, learning is not an exclusively cognitive process, but also involves the affective and emotional dimensions (Pekrun et al., 2002; Park, 2022). It can be defined as a complex and multifactorial process, comprising verbal, emotional, motor and perceptual components (Fiorin, 2017). From this perspective, the affective dimension plays a structural role in teaching and learning processes, fostering the student's active engagement and a deeper, more lasting construction of knowledge (Pessoa, 2008; Potvin & Hasni, 2014).

Within this framework, academic self-efficacy forms part of a complex system of relationships with other affective-motivational variables, such as interest, intrinsic motivation, anxiety and a sense of belonging to the school environment (Pekrun et al., 2002; Usher & Pajares, 2008). Although distinct, these factors are strongly interlinked and jointly contribute to the student's development. In particular, beliefs about personal efficacy influence the way in which students interpret their own school experiences, shaping their expectations of success and the level of cognitive and emotional effort invested in tasks (Bandura, 2005; Schunk & DiBenedetto, 2020).

The term 'academic self-efficacy' refers to students' perception of their own ability to successfully tackle learning tasks and achieve specific academic goals (Bandura, 2000). It does not concern the skills actually possessed, but the beliefs the student holds regarding their ability to use those skills effectively within the demands of the educational context (Bandura, 2000; Schunk & Pajares, 2002).

In an educational context, self-efficacy is a significant variable because it helps shape the way students interpret their learning experiences, approach tasks and respond to difficulties. Beliefs in personal efficacy are, in fact, associated with motivation, engagement, perseverance, performance and self-regulated learning (Zimmerman, 2000; Schunk & DiBenedetto, 2016; Bernacki et al., 2015; Peura et al., 2019; DiBenedetto & Schunk, 2022). School represents one of the main contexts in which beliefs in self-efficacy are formed: throughout their school career, pupils have the opportunity to engage in authentic learning experiences, to interact with their peers and to face the judgement of adults (Bernacki et al., 2015). In this sense, self-efficacy is not a stable, unchanging trait, but a dynamic construct that develops over time through the interaction between the student and the learning environment (DiBenedetto & Schunk, 2022; Akhmedjanova, 2024). The teacher's role is therefore central in fostering the development of positive beliefs in one's own efficacy, through the provision of appropriately structured activities, constructive feedback and opportunities for active participation (Bandura, 1997; Schunk & DiBenedetto, 2020).

School activities should be designed in such a way as to support and reinforce students' sense of self-efficacy. In particular, it is important to promote the development of an intrinsic interest in the subjects, as self-motivation fosters greater commitment and more active participation in tasks. Intrinsic interest develops when activities are perceived as meaningful and linked to personal goals, the achievement of which produces satisfaction and a sense of competence (Bandura, 1986).

Assessment practices also play a fundamental role. Tests, exercises and oral examinations provide students with opportunities to assess their own skills and represent direct experiences that contribute to the development of a sense of efficacy. For this reason, assessment should not be based solely on the final outcome of performance (success or failure), but should highlight individual progress relative to previous levels (Schunk, 1996). In the absence of such conditions, the school environment can contribute to reinforcing a low sense of self-efficacy, particularly among students who already have learning difficulties.

It is essential to emphasise that academic self-efficacy develops from the earliest years of schooling (Bandura, 2005; DiBenedetto & Schunk, 2022). Even during primary school, children actively construct their beliefs about self-efficacy through the interplay of successful experiences, observation of peers, feedback from teachers and emotional states, all of which are directly influenced by the school environment (Usher et al., 2023).

Furthermore, research has shown that children's self-efficacy changes with age: younger children tend to overestimate their abilities and display higher levels of self-efficacy (Akhmedjanova, 2024). However, as they grow older and their cognitive development progresses, pupils' assessment of their own ability to perform tasks improves. There is a general trend whereby, as pupils grow older and progress through school years, their self-efficacy decreases (Schunk & DiBenedetto, 2016) and becomes more stable (Talsma et al., 2018). Self-efficacy is dynamic and varies depending on tasks, experiences of mastery, and successes or failures (DiBenedetto & Schunk, 2022).

The early years of schooling are therefore crucial for laying the foundations upon which self-efficacy beliefs develop (Usher et al., 2023). Furthermore, potential influences on students' academic beliefs are significant during lower secondary school years, as the transition from primary to lower secondary school often introduces a wider social peer group, a greater emphasis on grades and competition, and a larger, less personal environment (Harter, Whitesell, & Kowalski, 1992; Britner & Pajares, 2006).

In light of these considerations, academic self-efficacy emerges as a key variable in teaching-learning processes, capable of influencing not only students' performance but also their relationship with knowledge and with school experiences as a whole (DiBenedetto & Schunk, 2022).

3.3. Sources of self-efficacy

According to Bandura (1997), an individual develops their self-efficacy for a specific task through social and personal experiences that fall into four categories: mastery experiences, vicarious learning experiences, verbal persuasion, and an individual's physiological and emotional state (al state). These have been defined as 'sources' of self-efficacy, which are used to build an individual's self-efficacy (Usher & Pajares, 2008).

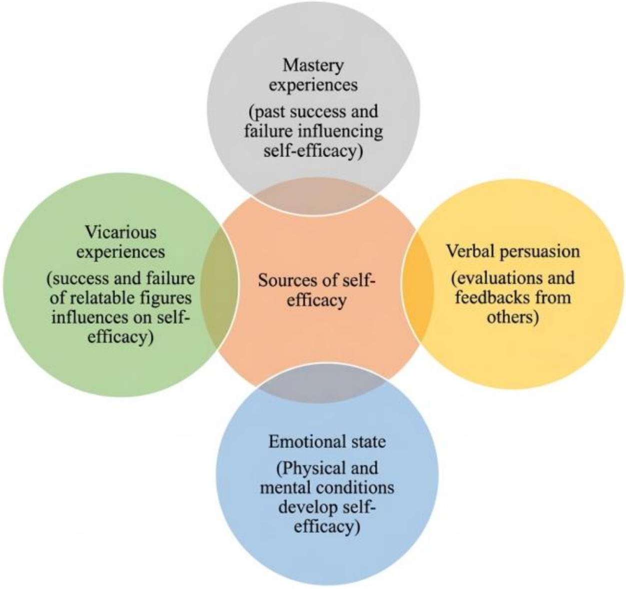
Mastery experiences
(past success and failure influencing self-efficacy)
Vicarious experiences
(success and failure of relatable figures influences on self-efficacy)
Sources of self-efficacy
Verbal persuasion
(evaluations and feedbacks from others)
Emotional state
(Physical and mental conditions develop self-efficacy)

Fig. 1 Sources of self-efficacy (Bandura, 1996)

The mastery experience refers to direct experiences of success or failure gained whilst performing specific tasks (Bandura, 1997). It represents the most influential source of information that students use to create and develop their beliefs about self-efficacy, as this experience provides the most authentic evidence of students' ability to master subsequent tasks in related domains (Usher & Pajares, 2008). However, the impact of direct experiences does not depend solely on the outcome of the performance, but on how it is interpreted by the individual. Self-efficacy judgements are, in fact, the result of a cognitive processing mechanism, through which experiences are evaluated and integrated with pre-existing beliefs (Bandura, 1986). Consequently, the same experience of success or failure can produce different effects on the sense of self-efficacy, depending on how it is interpreted.

In particular, this processing is influenced by various factors. Firstly, pre-existing self-efficacy beliefs tend to guide the interpretation of experiences: when performance is consistent with them, it is used as confirmation; conversely, when it is inconsistent, it may be downplayed or reinterpreted in order to maintain a certain sense of self-consistency (Alden, 1987). This process may be adaptive in the presence of high self-efficacy, but risks becoming dysfunctional when it contributes to maintaining beliefs of ineffectiveness.

Secondly, the interpretation of performance depends on the conditions under which the task was carried out. A failure occurring under particularly difficult conditions may be attributed to external factors and have a limited impact on self-efficacy; similarly, a success achieved with the support of others may be perceived as less indicative of one's own abilities (Bandura, 1986).

Finally, the level of effort expended plays a significant role. Performance is more informative when it results from a high level of effort and the overcoming of difficulties, contributing more significantly to the development of a sense of efficacy (Bandura, 1997). However, failure following intense effort can negatively affect beliefs in one's efficacy, just as success achieved with little involvement may be less significant (Usher & Pajares, 2008).

Overall, the development of a stable sense of self-efficacy does not depend on individual experiences, but on the integration of multiple performances over time, which enable the individual to build a more solid and consistent assessment of their own abilities (Bandura, 2000).

In the school context, these processes take on particular significance. After completing a task, students interpret and evaluate the results obtained and, based on these interpretations, build or modify their beliefs about their own effectiveness. When they believe their efforts have been successful, their confidence in completing similar or related tasks increases; when they believe their efforts have not produced the desired effect, their confidence in succeeding in similar endeavours decreases (Usher & Pajares, 2008).

Experiences of mastery in an educational setting can have lasting effects. For example, students who have achieved excellent grades in a particular subject during their school years will generally believe themselves capable in that field for years to come, and this can influence future choices and the way the student approaches new tasks in the same subject area. Beliefs in self-efficacy also tend to change as skills develop, when individuals face new tasks. Although failure may occur from time to time, when students notice a gradual improvement in their abilities over time, they generally experience an increase in their self-efficacy (Schunk, 1984; Zimmerman, 2000).

Vicarious experience, also known as ‘observational learning’, consists of an assessment of one’s own abilities and performance through comparison with those of others, that is, through the observation of others (Bandura, 1997). This comparison may take place either on the basis of normative parameters or through reference to specific individuals with whom one identifies, known as ‘role models’ (Bandura, 2000). Generally speaking, observing a role model’s success tends to increase self-efficacy, whilst observing a failure can contribute to reducing it (Schunk, 1987; Zimmerman, 2000).

In many academic contexts, there are no absolute standards of competence; consequently, vicarious experience frequently takes the form of comparison with peers, in an attempt to establish a benchmark. When a student receives an assessment, they tend to interpret it in relation to their peers’ results: if they perceive that they have performed better than the majority, their self-efficacy is likely to increase; conversely, if they rank below the group, their beliefs in their own efficacy may diminish. The use of such normative comparisons represents a common form of vicarious experience in the school setting (Usher & Pajares, 2008)

The effectiveness of this process depends largely on the characteristics of the observed model (Jourden et al., 1991; Wood, 1989). For vicarious information to be perceived as relevant, there must be a certain similarity between the individual and the model, both in terms of skills and abilities, and with regard to personal characteristics that may influence performance (Wood, 1989; Suls & Miller, 1977). The more the model is perceived as similar, the greater the impact of observation on self-efficacy beliefs; conversely, models perceived as too distant are unlikely to produce significant effects (Schunk, 1987). Role models can be identified not only on the basis of skill level, but also in relation to variables such as gender, ethnicity or access to resources (Usher & Pajares, 2008).

Students will seek a competent role model in the tasks they aspire to, particularly individuals who possess status, power and prestige (Bandura, 1997). Although vicarious experiences often occur through the observation of everyday acquaintances such as classmates or family members, the development of the media has greatly expanded the availability of symbolic role models, making them easily accessible (Bandura, 2000). Such role models can convey relevant information, both on a behavioural and attitudinal level , regarding how to approach schoolwork and social relationships.

As already highlighted, direct experience is the most influential source in the development of self-efficacy; however, in conditions of uncertainty or limited knowledge of one's own abilities, vicarious experience can play a particularly significant role. In such situations, social models become fundamental points of reference, especially when students have limited experience with the task at hand (Schunk, 1987; Bandura, 1997).

Social persuasion (verbal persuasion) consists of verbal encouragement or support provided by others and represents one of the sources through which beliefs in self-efficacy are formed (Bandura, 1997). It frequently takes the form of evaluative feedback regarding an individual's performance. Feedback that highlights abilities and skills, accompanied by suggestions for improvement and constructive criticism, tends to strengthen the sense of self-efficacy (Schunk, 1991). Conversely, feedback focused on shortcomings or phrased negatively can reduce beliefs in one's effectiveness and have a negative impact on motivation and commitment (Baron, 1988).

External evaluations may be more or less consistent with an individual's self-assessments. When the degree of discrepancy is high, such judgements tend to lose credibility, especially when referring to current or imminent performance (Bandura, 2000). In such cases, the individual may fail to integrate this information into their belief system, thereby limiting its impact on self-efficacy.

Considered in isolation, however, social persuasion has a relatively limited capacity to generate a stable and lasting sense of self-efficacy (Bandura, 2000). In fact, it is generally easier to undermine beliefs in efficacy through negative messages than to reinforce them through encouragement, particularly during developmental stages when individuals attach particular importance to judgements from significant others (Bandura, 1997). As Bandura himself points out (1997, p. 101), 'it is easier to maintain a sense of efficacy, especially in the face of difficulties, when significant others express confidence in one's abilities rather than when they convey doubts'.

The effectiveness of verbal persuasion also depends on the credibility of the source from which the feedback originates. Judgements are most influential when expressed by people perceived as competent and expert in the domain in question (Crundall & Foddy, 1981; Webster & Sobieszek, 1974). In the school context, teachers and significant peers play a particularly important role, as they are sources of feedback frequently used by students to assess their own abilities. In particular, when students are not yet able to self-assess accurately, they tend to rely on external judgements to interpret their own performance and build their beliefs about their own efficacy (Usher & Pajares, 2008).

Finally, emotional or physiological states refer to the inner emotions experienced in association with positive or negative events, such as joy, stress, frustration, satisfaction or fear (Bandura, 1997).

Individuals learn to interpret their physiological arousal as an indicator of personal competence, evaluating their performance under different conditions (Usher & Pajares, 2008). In this sense, emotional reactions associated with academic tasks can provide clues about expected success or failure. A high level of anxiety, for example, can be interpreted as a sign of inadequacy, contributing to a reduced sense of self-efficacy; students who experience tension, or apprehension in relation to a subject tend, in fact, to regard such states as evidence of poor competence in that area (Pekrun et al., 2002; Putwain & Daly, 2014).

Bandura (1997) suggests that people tend to function optimally when their physiological arousal is neither too high nor too low; that is, physiological arousal may be curvilinearly related to self-efficacy. In general, improving students' physical and emotional well-being and reducing negative emotional states strengthens self-efficacy.

Negative physiological arousal may become more prevalent as students progress through their studies, partly due to changes in school practices. The transition to higher levels of schooling involves increasingly standardised assessment procedures, an increase in homework, and a decrease in teacher-pupil interaction; all these factors can lead to higher levels of anxiety regarding schoolwork (Usher & Pajares, 2008).

It is important to highlight that pre-existing self-efficacy beliefs act as an interpretative filter through which emotional experiences are processed (Zimmerman, 2000; Efklides, 2011). Students with low self-efficacy tend to interpret anxiety as a sign of incompetence, fuelling expectations of failure that can result in actually poorer performance. Conversely, students with high self-efficacy beliefs are generally better able to manage normal fluctuations in physiological arousal without compromising their performance. The general emotional tone also influences these interpretations: a pessimistic outlook can lead to interpreting mistakes as proof of incompetence, further reducing self-efficacy, whilst positive emotional states foster confidence in one's abilities, motivation and success, triggering a virtuous circle (Seligman, 1991).

The same physiological state can produce different effects on self-efficacy depending on how it is interpreted: it may be experienced as a signal of activation that is functional to performance or as a debilitating factor. Furthermore, the way in which such states are attributed to internal or external causes helps to determine their impact on beliefs about efficacy (Bandura, 2000).

Finally, there is a bidirectional relationship between physiological states and self-efficacy (Bandura, 2000). On the one hand, emotional reactions influence the perceived sense of efficacy; on the other, a high level of self-efficacy allows for the regulation and containment of anxiety and stress, whilst low levels of self-efficacy can amplify these states, making them potentially debilitating (Bandura, 2000).

Students integrate information obtained from various sources to form judgements about their own academic abilities. The contribution of each source varies depending on the domain under consideration and the cognitive processing strategies adopted by the individual. The way in which different pieces of information are weighed up and combined influences the final level of self-efficacy (Britner & Pajares, 2006). However, the way in which this information is evaluated, interpreted and integrated is not an automatic process, but is influenced by multiple personal and contextual factors.

Some sources exert a direct and linear influence, as in the case of mastery experiences. Other factors, however, may have a curvilinear relationship with self-efficacy and performance: for example, moderate levels of physiological arousal may enhance performance, whilst levels that are too low or too high may hinder it (Britner & Pajares, 2006). Bandura (1997) hypothesised that the integration rules used by individuals to evaluate and interpret information relevant to self-efficacy may be additive (the greater the number of available sources, the greater the reinforcement of self-efficacy beliefs), relative (one source is stronger than another), multiplicative (two sources have an interactive effect) or configurative (the strength of a source' s on the presence of others), each of which depends to a large extent on personal and contextual factors.

As they grow up, young people develop cognitive skills that help them process information relevant to their beliefs in a more sophisticated way. Nevertheless, as argued by Bandura (1997), individuals often find it difficult to carry out multifactorial analyses and tend to follow heuristic processes, that is, simplified modes of processing that prioritise the most salient information or that which is easily accessible in memory (Nisbett and Ross, 1980).

3.4 The role of self-efficacy in learning processes

Beliefs in self-efficacy, formed through school experiences, in turn influence the way in which students approach new learning tasks. Numerous studies have shown that these beliefs are associated with academic success and are closely linked to other motivational constructs, such as self-regulation (Zimmerman, 2000), goal orientation (Urdan, 1997) and self-concept (Bong & Skaalvik, 2003). They influence cognitive, motivational, affective and decision-making processes, helping to determine the level of effort, persistence in the face of difficulties, the use of appropriate strategies and the willingness to tackle tasks perceived as complex (Bandura, 2000).

With regard to cognitive processes, self-efficacy affects the way in which students interpret the task, plan and organise their actions, and anticipate possible outcomes (Carroll & Bandura, 1990). In particular, students with high levels of self-efficacy tend to visualise successful outcomes, plan more effective strategies, and maintain greater control over the learning process. Conversely, low levels of self-efficacy are associated with the anticipation of failure or difficulty (Krueger & Dickson, 1994) and can reduce cognitive investment in the task and make it more difficult to employ effective strategies. Such mental representations can directly influence the quality of performance and the task, as positive or negative expectations guide behaviour and effort (Powell, 1973).

Self-efficacy also influences motivational processes, contributing to goal-setting, the level of effort and perseverance (Bandura, 2000). In this context, three main factors can be distinguished. Firstly, causal attributions regarding successes and failures: attributing a failure to a lack of effort can encourage greater subsequent involvement, whilst attributing it to a lack of ability can lead to avoidance of the task (Weiner, 1985). Secondly, outcome expectations influence the level of motivation during task performance: high self-efficacy promotes the anticipation of positive outcomes, which serve as guidance and support (Ajzen & Fishbein, 1980). Finally, the setting of conscious goals also plays a central role: setting challenging yet realistic goals is a powerful motivational factor, whilst the achievement of such goals helps to further reinforce beliefs in one’s own efficacy (Bandura, 1991, 2000).

On an emotional level, beliefs about self-efficacy influence the way in which students experience and regulate emotions such as anxiety, stress and frustration. A high sense of self-efficacy can foster a greater ability to tolerate uncertainty and to interpret emotional arousal as part of the learning process. Conversely, students with low self-efficacy may interpret anxiety as confirmation of their own inability, fuelling expectations of failure and further reducing confidence in their own capabilities. (Bandura, 1986). The relationship between self-efficacy and anxiety is, moreover, bidirectional: on the one hand, anxiety experienced during a performance can reduce the sense of efficacy; on the other, a high sense of self-efficacy enables the regulation and containment of such emotional states.

Finally, self-efficacy influences decision-making processes, guiding the activities and contexts in which students choose to engage. Individuals tend, in fact, to avoid areas where they perceive little chance of success and, conversely, to engage in activities for which they feel competent (Meyer, 1987). In an educational context, this aspect is particularly significant because underestimating one's own abilities can limit interest and opportunities for development in specific subjects where students do not perceive themselves as self-efficacious (Bandura, 2000).

Overall, students with high self-efficacy tend to engage more fully, seek out new learning opportunities, manage their studies more effectively, and interpret difficulties as surmountable challenges. Conversely, low levels of self-efficacy can lead to avoidance of demanding tasks, reduced confidence in one's abilities, and more dysfunctional attributions of failure (Bandura, 2005, 2006; Schunk & DiBenedetto, 2016; DiBenedetto & Schunk, 2022).

In summary, self-efficacy influences numerous aspects of behaviour, including the choice of activities and goals, levels of motivation and commitment, perseverance in the face of difficulties, resilience to failure, and the ability to manage stress and anxiety whilst performing a task (Bandura, 2000; Zimmerman, 2000; Bong & Skaalvik, 2003; Bernacki et al., 2015; Talsma et al., 2018). It helps to explain why, given the same level of ability, some students approach tasks with greater commitment and confidence, whilst others tend to avoid difficulties or interpret failures as proof of incompetence (DiBenedetto & Schunk, 2022). This regulatory function is particularly relevant in subjects perceived as complex, such as science, where beliefs about efficacy can influence students' engagement, persistence and relationship with the subject (Usher & Pajares, 2008).

3.5 Scientific Self-Efficacy

Science Self-Efficacy (SSE) can be described as a person's belief in their ability to successfully complete scientific tasks (Bandura, 1997; Tang & Zhang, 2020). In recent years, this construct has received greater attention in formal education due to its positive correlation with students' persistence in engaging with and achieving academic results in science subjects (Cassidy, 2015; Tang & Zhang, 2020).

Studies have shown that SSE has been associated with student behaviours relevant to learning in active environments, such as perseverance, motivation, interest and self-regulation (Trujillo & Tanner, 2014). It has proven to be a strong predictor of performance in science courses, resilience and career choices in STEM fields (Dalgety & Coll, 2006; Dweck, 2014). Furthermore, students' beliefs about their scientific self-efficacy influence their choices regarding scientific activities, the effort they devote to them, the perseverance they show in the face of difficulties and, ultimately, their success in science (Bandura, 1997; Britner & Pajares, 2001; Zeldin & Pajares, 2000; Britner & Pajares, 2005). This makes self-efficacy a central construct for science educators seeking to promote student success and engagement in scientific disciplines.

Bandura (1986) argued that students' beliefs about their self-efficacy are often more accurate predictors of their academic success than objective assessments of their abilities. This is because such beliefs mediate the effects of prior achievements, knowledge and skills on subsequent outcomes (Schunk, 1985). Research on motivation has also shown that perceived self-efficacy in one's academic abilities is associated with both motivation and learning outcomes across various subject areas, including science, mathematics and languages (Britner & Pajares, 2001; Lent, Brown, & Gore, 1997; Pajares & Valiante, 1999; Shell, Colvin, & Bruning, 1995; see Pajares, 1997, for a review). Beliefs in self-efficacy are also positively correlated with key motivational constructs such as self-regulation (Zimmerman, 2000; Zimmerman & Bandura, 1994), mastery goal orientation (Urdan, 1997), adaptive causal attributions (Stajkovic & Sommer, 2000) and self-concept (Bong & Skaalvik, 2003). Self-efficacy beliefs influence academic performance through various behavioural and psychological processes (Bandura, 1986, 1997). In the field of science, students who possess a strong belief that they can succeed in tasks and activities tend to select such activities, actively commit to completing them, persevere in the face of difficulties, and interpret physiological signals in a way that is conducive to performance. Conversely, students who do not believe they are capable of succeeding in scientific activities tend to avoid them where possible, or to invest minimal effort in them. When faced with the difficulties typical of scientific disciplines, they are also more likely to give up and experience high levels of stress and anxiety, which further undermine their performance (Britner & Pajares, 2005).

Numerous studies have shown that SSE is associated with both academic performance and academic and professional choices in science throughout the entire educational pathway. At university level, it predicts both academic performance (Andrew, 1998) and persistence in scientific study programmes and careers (Gwilliam & Betz, 2001; Lent, Brown, & Larkin, 1984; Luzzo et al., 1999). It has also been shown that self-efficacy tends to decrease in physics courses taught using traditional methods (lecture-based teaching) (Sawtelle et al., 2010; Dou et al., 2016); however, research has shown that even in physics courses using active teaching methods, self-efficacy either decreased (Dou et al., 2016) or remained unchanged (Sawtelle et al., 2010). In secondary school, scientific self-efficacy is correlated with science outcomes and emerges as a stronger predictor of performance and engagement than variables such as gender, ethnicity or family background (Kupermintz, 2002; Lau & Roeser, 2002).

Although a limited number of studies have focused on the early stages of education (Chen & Usher, 2013; Lin & Tsai, 2018), it is crucial to remember that self-efficacy develops from the very start of students' educational journey (Master, 2020). Pre-adolescence marks a crucial phase in which children form their attitudes and beliefs towards science (Archer et al., 2013) and in which self-efficacy beliefs are particularly malleable (Lazowski & Hulleman, 2016). It is also a period in which students' interest in scientific subjects frequently begins to wane (Sheldrake & Mujtaba, 2020).

In light of this evidence, it is clear that scientific self-efficacy represents a crucial variable in the learning processes of scientific disciplines. It not only affects performance but also significantly influences students' engagement, academic and career choices, and the way in which they tackle the difficulties typical of scientific learning (Shunk, 1991; Chen & Usher, 2013).

Promoting positive efficacy beliefs means fostering active participation, perseverance and the development of deeper and more lasting skills.

These aspects are particularly relevant in the early stages of schooling, when students' beliefs are still forming and most susceptible to change. Early intervention on this construct can therefore help counteract the decline in interest in scientific disciplines and support the development of a more positive and informed relationship with science (DiBenedetto & Schunk, 2022; Usher et al., 2023).

From this perspective, scientific self-efficacy stands as a central element for educational research and innovation, offering a useful interpretative framework for understanding learning processes and guiding the design of effective teaching interventions.

3.6 Gender differences in scientific self-efficacy

Gender differences between boys and girls in the school setting have long been documented. These tend to vary according to context, age and subject area (Webb-Williams, 2017). In particular, several studies have focused on differences in scientific subjects, but the debate on this issue remains open (Britner & Pajares, 2006; Chan, 2022; Whitcomb & Singh, 2020). Most studies have found that boys have higher levels of SSE than girls (Chan, 2022; Lofgran et al., 2015; Marriott et al., 2019; Usher et al., 2019) and that they tend to harbour aspirations related to scientific disciplines more frequently than their female peers (Archer et al., 2020; Sheldrake & Mujtaba, 2020).

In particular, Chan (2022) highlights that boys report higher levels of SSE, particularly in dimensions related to confidence in their ability to tackle scientific tasks and solve problems, emphasising that these differences are more closely linked to perceptions of competence than to actual differences in ability. Similarly, Marriott et al. (2019) show that higher levels of self-efficacy in boys are associated with a greater propensity towards STEM study programmes and careers, whilst in girls, lower SSE may contribute to reduced interest in these fields, even when academic performance is equal. Similarly, the study conducted by Lofgran et al. (2015) in primary and lower secondary schools analysed students' SSE and attitudes towards science. The results highlight that boys report greater scientific self-efficacy, particularly in practical and experimental activities, whilst girls show greater uncertainty, even when performance is similar.

Overall, gender differences in scientific disciplines emerge as early as primary school and primarily concern motivational and perceptual dimensions rather than actual performance (Murphy & Beggs; 2003; Lofgran et al. 2015; Carroll et al., 2024). Girls tend to report lower levels of self-efficacy, interest and confidence in their scientific abilities, even in the absence of significant differences in performance. These differences appear to be strongly influenced by socio-contextual factors, including the role of feedback, social comparison and the interpretation of learning experiences (Murphy & Beggs; 2003; Lofgran et al. 2015; Carroll et al., 2024).

A significant contribution is provided by Usher et al. (2019), who analysed the sources of scientific self-efficacy. The results indicate that boys report experiences of mastery more frequently and tend to perceive their confidence as less influenced by negative factors. Girls, on the other hand, are found to be more sensitive to emotional states, reporting higher levels of anxiety and insecurity in scientific activities.

A particularly widespread finding concerns female students' emotional perceptions of science. Most research highlights, in fact, that female students tend to experience greater anxiety and stress during science assignments or experiments (Whitcomb & Singh, 2020; Carroll et al., 2024), negatively affecting their interest and motivation towards these disciplines. According to some studies, women are susceptible to stress and anxiety arising from stereotype threat (i.e. the fear of confirming stereotypes about women in many STEM disciplines), a condition not experienced by their male peers (Johnson, 2012; Hilts et al., 2018). The stereotype threat that women experience in many STEM disciplines can increase anxiety in learning and assessment situations, leading to a decline in performance and generating stress and anxiety (Whitcomb & Singh, 2020). This ' ' process can negatively affect performance, grades achieved, scientific self-efficacy and the likelihood of persisting in a course of study (Bandura, 2005).

Even at university level, most studies show that, in physics courses, female students exhibit lower levels of SSE, even when their performance is similar to that of their male peers (Li et al., 2020; Whitcomb & Singh, 2020). These differences emerge from the very start of courses and tend to widen over time (Marshman et al., 2018). Furthermore, some studies have found that this gap is particularly pronounced in physics compared to other STEM disciplines (Nissen & Shemwell, 2016). This suggests that physics represents a particularly critical context for the development of female self-efficacy. At the same time, it is clear that the differences perceived by female students are not linked to actual performance, but are strongly influenced by perceptions and socio-cultural factors (Marshman et al., 2018).
Given that self-efficacy is one of the main predictors of success and persistence in physics courses (Sawtelle et al., 2012), these differences can negatively influence a vicious circle that undermines interest and motivation, ultimately leading to students dropping out—a phenomenon that is widespread in physics courses (Marshman et al., 2018; Whitcomb & Singh, 2020).

However, not all studies have yielded similar results.
According to some studies conducted with students aged 12–16, girls had stronger self-efficacy beliefs than boys in science (Britner & Pajares, 2001; Pajares, Britner, & Valiante, 2000). Similarly, large-scale analyses have shown a higher proportion of girls at the highest

levels of self-efficacy in science (Mashela, 2022), suggesting that, in certain contexts, female students may develop perceptions of competence comparable to or higher than those of their male peers.

Research conducted by Webb-Williams (2014) in the UK in a small-scale study found that primary school girls exhibited higher levels of SSE than boys. To explain this unexpected result, the author hypothesised that the small sample size or the teaching practices of the teachers involved might have influenced the findings (Webb-Williams, 2014). Indeed, in a subsequent mixed-methods study, Webb-Williams (2017) reported finding no statistically significant differences in SSE levels between boys and girls, in line with the findings of most studies conducted (Britner & Pajares, 2006; Huang, 2013; Kiran & Sungur, 2012; Marshman et al., 2018; Kirbulut & Kondacki-Uzuntiryaki, 2019; Sezgintürk & Sungur, 2020).

Finally, the results tend to vary by subject area; for example, the study by Britner and Pajares (2006) highlighted that, in biology, girls reported levels of self-efficacy equal to or higher than those of boys, suggesting that certain scientific disciplines may provide contexts more conducive to the development of female self-efficacy.

This overview highlights how gender differences in scientific self-efficacy represent a complex and multidimensional phenomenon, influenced by multiple factors, including age, socio-educational context, teaching practices and disciplinary domain. Although the literature shows a general trend towards lower levels of SSE among female students, this gap does not appear to be uniform or universally confirmed (Webb-Williams, 2017; Usher et al., 2019; Whitcomb & Singh, 2020). Generally, differences emerge as early as the first years of schooling and tend to become entrenched and, in some cases, widen in subsequent years (Lofgran et al., 2015; Webb-Williams, 2017; Carroll et al., 2024).

In light of this, scientific self-efficacy can be interpreted not only as an individual variable, but as the result of a dynamic interaction between cognitive, emotional and contextual factors, with important implications for female students' participation, success and retention in STEM pathways (Bandura, 2005; Usher & Pajares, 2009).

3.7 Conclusion

In summary, self-efficacy is a multidimensional and dynamic construct concerning an individual's beliefs about their ability to successfully tackle specific tasks and situations. It is not a general, stable personality trait, but varies according to the contexts of experience, the tasks required, and the interpretations the individual attributes to their own successes and failures.

In the school context, self-efficacy plays a central role in teaching and learning processes, as it helps to shape students’ motivation, interest, level of commitment, perseverance in the face of difficulties, and educational choices. Beliefs in personal efficacy develop from the earliest years of schooling and are progressively built up through experiences of mastery, interaction with peers, feedback received from teachers, and the emotional states associated with learning activities. From this perspective, the educational practices, assessment methods and methodological choices adopted by teachers take on particular significance, as they can either support or, conversely, hinder the development of positive self-efficacy beliefs.

Within this framework, scientific self-efficacy represents a particularly significant dimension. Scientific subjects, in fact, are often perceived by students as complex and difficult, and this perception can contribute to reducing confidence in one’s own abilities, fuelling a negative cycle of low self-efficacy, lack of interest, anxiety and a gradual drift away from scientific pathways. The literature also highlights the presence of gender differences in scientific self-efficacy, often to the detriment of female students, who tend to perceive themselves as less competent than their male peers and to experience higher levels of anxiety and stress in STEM subjects. This trend appears particularly relevant in fields such as physics, where a lower perception of competence can negatively impact engagement, persistence and subsequent educational choices.

In light of these considerations, it is clear that it is important to promote the development of scientific self-efficacy from the earliest years of schooling, when pupils’ beliefs are still particularly malleable. Primary school provides an opportunity to build positive and meaningful experiences before any perceptions of incompetence become entrenched, and this can support pupils in their transition to subsequent school levels, which are often perceived as challenging.

Active teaching methods, collaborative activities, constructive feedback and opportunities for incremental success can help to strengthen students’ belief in their own ability, fostering a more positive, informed and lasting relationship with the sciences.

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CHAPTER 4

ENERGY

To promote meaningful and sustainable scientific learning, fundamental disciplinary ideas and cross-curricular concepts are widely regarded as important content for science teaching at primary and lower secondary school level (National Research Council, 2007).

The development of sound scientific knowledge on energy-related topics is recognised as one of the main learning objectives in schools, as these topics are considered cornerstones for students' understanding of other concepts and phenomena in the science curriculum. Energy conservation is a fundamental principle in physics that governs how real-world systems can evolve (National Research Council, 2012; Quinn, 2014). Consequently, many primary school curricula, or framework documents for such curricula, already include energy as a teaching topic for young learners (AAAS, American Association for the Advancement of Science, 2009; Ministry of Education, 2018). In Italy, the Guidelines for the National Curriculum for pre-school and the first cycle of education highlight energy as one of the four main cognitive organisers, of great conceptual and cultural importance in the first cycle of schooling (Ministry of Education, 2018). Furthermore, the development of energy literacy for all citizens is crucial now that we are facing global climate change and the rapid depletion of existing energy resources (Merritt et al., 2019).

However, the concept of energy is not easily understood by students, and methods for teaching it have been the subject of much research in the field of education. Energy, in fact, involves abstract concepts (Duit & Haeussler, 1994; Yuenyong & Yuenyong, 2007) and its meaning in everyday language contributes to the spread of misconceptions (Millar, 2005; Dekten, 2023). Students often struggle to distinguish energy from other physical quantities such as force or power (Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994; Mann & Treagust, 2010) and fail to develop a scientific understanding of energy and everyday expressions such as energy dissipation, energy waste and energy storage (Duit & Haeussler, 1994; Leggett 2003; Melzer 2004; HirËa & Akdeniz, 2008). Many studies in the literature have focused on energy and the difficulties associated with teaching this concept (Chen et al., 2014), highlighting that students are often unable to apply the principle of conservation—which is central to the productive use of the concept of energy—to everyday phenomena (Nordine et al., 2011; Duit, 2014).

For the purposes of this research, this chapter will focus primarily on the teaching and learning of energy in primary school, examining the scientific concept of energy, its use in everyday contexts, and discussing some of the main issues raised regarding its teaching.

4.1 What is energy?

Understanding and explaining what energy is from a physical perspective is certainly not straightforward. Indeed, from the perspective of physics itself, this question has no exhaustive answer, or indeed no answer at all, as Feynman himself argues (1992, vol. 1, par. 4.1).

It is important to bear in mind that in modern physics, we have no knowledge of what energy is. We do not have a model that expresses energy as the sum of defined terms. It is not like that, full stop. However, there are formulas for calculating certain numerical quantities; and if we add them all up, we will always get the same number.

In the scientific context, energy represents an abstract concept that is mathematically formalised; for this reason, it is difficult to provide a complete and unambiguous definition (Millar, 2005).

The question ‘What is energy?’ can be interpreted in two distinct ways: on the one hand as a question about the essence and meaning of energy, and on the other as a request for an operational and quantitative definition of a physical quantity.

In the first case, one might argue that such a question does not strictly fall within the domain of physics, a science that does not concern itself with essences. However, it is legitimate to question the ontological status of energy, asking whether it should be considered an abstract construct devised by scientists to describe and predict phenomena, or a physical reality comparable to a substance. The substantialisation of physical quantities is a spontaneous tendency in common thought and is also present in the thinking of scientists. Energy lends itself particularly well to this, as it is an extensive quantity and subject to conservation, characteristics that evoke the idea of a substance. However, the fact that its value depends on the reference frame makes such a substantialist interpretation problematic (Besson, 2015).

Significant difficulties also arise regarding the second meaning of the question ‘What is energy?’.

Whilst it is relatively straightforward to define kinetic energy or potential energy associated with a specific force, it is, on the other hand, complex, if not impossible, to formulate a general definition of energy without further specification. Many texts define energy as the capacity to perform work, a definition also found in Maxwell (1871, p.90): ‘the energy of a body may be defined as the capacity which the body has to perform work, and is measured by the amount of work it can perform’. However, it was subsequently considered that this definition conflicts with the second law of thermodynamics and the theory of thermal mechanics (Besson, 2015). Some authors have proposed defining energy as the capacity to produce changes, but this reformulation has also been subject to similar objections (Besson, 2015).

An important complementary perspective concerns the operational and experimental foundations of the energy concept. Historically, Joule’s classical investigations of the mechanical equivalent of heat showed that a measured amount of mechanical work could be related quantitatively to the thermal change produced in a specified system, such as a known quantity of water. The significance of these experiments was not that they revealed an absolute amount of energy contained in an isolated object, but that they established a reproducible quantitative relationship between changes produced in different physical systems and thus contributed to the empirical basis of energy conservation (Young, 2015; Newburgh & Leff, 2011).

Building on this operational logic, Karplus (1981) proposed that energy could be introduced through comparison with standard systems. In particular, he suggested using an ice–water mixture as a reference system: when a system is brought into thermal equilibrium with this mixture, the mass of ice melted, or of water frozen, provides a measurable indication of the energy transferred. In this approach, energy is not directly observed as an intrinsic substance or independently measurable quantity; rather, it is inferred from the changes produced in a specified reference system during an interaction.

More generally, calorimetric approaches make energy changes experimentally accessible by relating energy transfers to measurable variables, such as mass, temperature variation and heat capacity. They therefore highlight the importance of defining the system, its boundaries, the initial and final states, and the quantities whose changes are measured. Research on the learning of calorimetry has also shown that these approaches require students to coordinate several conceptual elements, including heat transfer, temperature change, system–surroundings relations and conservation principles (Greenbowe & Meltzer, 2003; Christensen et al., 2011).

Energy is not what makes things go or what sets phenomena in motion. The possession of energy is not what drives, explains or justifies change. Energy is what participates in change. Free energy is what determines whether change can take place.

Many favour a general definition of energy as a scalar quantity that is conserved in every physical process and transformation. The Nobel Prize-winning physicist, Richard Feynman, begins his discussion of the scientific concept of energy as follows (Feynman, 1963, p. 4-1):

> There is a fact, or if you prefer a law, which governs all natural phenomena known to date. There is no exception to this law – it is exact as far as we know. The law is called the conservation of energy. It states that there is a certain quantity, which we call energy, that remains unchanged amidst the various changes that nature undergoes. This is a very abstract idea, because it is a mathematical principle; it states that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, nor of anything concrete; it is simply a strange fact that we can calculate a certain number, and when we finish watching nature perform its tricks and calculate the number again, it is the same.

Feynman describes energy as ‘a numerical quantity that does not change when something happens’ (Feynman, 1963). From his definition, it is possible to highlight several fundamental aspects of energy. First of all, energy is an abstract and mathematical quantity, not something tangible; it is a property of an object or a system that can have a numerical value. (Millar, 2005). Furthermore, the most important idea about energy emerges, namely that it is conserved in every event and process and that, in the end, there is the same total quantity as there was at the beginning (Millar, 2005).

In this thesis, the expression “energy of a system” is therefore used in a modelling sense. It does not refer to energy as a material entity contained in objects, nor to an absolute amount possessed by a system independently of the theoretical model, the reference frame, the state variables and the system boundaries chosen for the analysis. Rather, energy is treated as an abstract quantitative property that can be associated with the state of a specified and modelled system. However, in physical reasoning, the most productive use of this quantity often concerns changes between states: whether the energy associated with the selected system increases, decreases or remains constant, and how these changes are constrained by the principle of conservation (Bächtold, 2018; Seeley et al., 2019).

From this perspective, the focus is not on determining an absolute “amount of energy” of an object or system, but on comparing an initial and a final state and accounting for the changes that occur. These changes may be described in terms of energy transfers across the boundaries of the system, or in terms of changes in the way energy is stored, distributed or represented within the system. Thus, the language of energy as a property of a system and the language of energy changes and transfers should not be seen as contradictory, provided that energy is understood as a model-dependent quantity whose use requires the explicit specification of the system and of the states being compared Seeley et al., 2019).

A definition in terms of property is therefore proposed—neither constructive nor operational—according to which the principle of conservation becomes the assumption that this quantity exists, a type of existential assertion that is very common in mathematics but rarer in the experimental sciences (Besson, 2012).

4.2 Energy in science education: an educational challenge

Energy is considered to be one of the key concepts in science education (National Research Council, 2007), cutting across all fields of science and engineering, and a solid basic understanding is essential for informed citizenship (Duit, 2014; Jin & Anderson, 2012; National Research Council, 2012). The conservation of energy is a fundamental principle in physics that governs how real-world systems can evolve (National Research Council, 2012; Quinn, 2014). Furthermore, the historical period we are facing requires the development of energy literacy for all citizens, to address global climate change and the rapid depletion of existing energy resources in an informed manner.

Very often, students perceive the concept of energy as very difficult (Nordine et al., 2011; Duit, 2014; Millar, 2014). They highlight various difficulties in understanding energy conservation, energy conversion, energy transmission and energy sources, often demonstrating purely rote learning (Ellse, 1988; Ogborn, 1990; Solomon, 1982; Toman, Karatas and Cimer, 2016; Trumper, 1998). They generally lack the integrated understanding required to apply energy concepts meaningfully in scientific or practical contexts (Duit, 2014; Herrmann-Abell & DeBoer, 2017; Liu & McKeough, 2005; Neumann et al., 2013).

This is essentially true for two reasons (Warren, 1991; Millar, 2005): a) it is an abstract, mathematical quantity for which we seek to provide a definition; b) unlike many other areas of physics, the word ‘energy’ is used daily in everyday language and consequently carries with it a range of meanings that actively influence subsequent scientific learning.

A vast body of literature documents this problem, cataloguing students’ difficulties, criticising existing curricular approaches and suggesting alternatives (Brook & Wells, 1988; Hecht, 2019; Millar, 2005; Solomon, 1985, 1992; J. W. Warren, 1983; Watts, 1983). The Framework for K-12 Science Education (National Research Council, 2012) promotes science learning as a developmental progression, ‘so that students continually build upon and revise their knowledge and skills over several years’ (p. 2), starting from primary school. This implies a basic conceptual understanding of the behaviour of energy, including energy transfers, by the end of primary school.

This requirement poses a significant pedagogical challenge (Lacy et al., 2014). Energy is an abstract concept: young children are asked to reason about something they cannot see, touch or measure directly.

4.3 Key aspects in the teaching of energy

As energy is a complex concept, several key aspects have been identified in the literature to guide the teaching-learning process (Duit, 1986, 2014; Herrmann-Abell & DeBoer, 2018; Liu & McKeough, 2005; Neumann et al., 2013; Nordine, 2016; Tobin et al., 2018).

4.3.1 The role of system specification in energy analysis

The defining characteristic of energy is its conservation, even though energy can be transferred and transformed. This statement already implies the need to specify a system, since energy transfer can only be meaningfully described with reference to the boundary across which energy enters or leaves that system (Seeley et al., 2019). In the canonical approach adopted in physics, “we will often consider a particular system, by which we mean a particular object or set of objects; everything else in the universe is called the ‘environment’” (Giancoli, 2000). Similarly, according to the NGSS 5th-grade Earth Systems Standards, “a system can be described in terms of its components and their interactions” (5-ESS2-1). The emphasis, therefore, is on identifying the relevant objects, their interactions, and the boundary that separates the system from its environment.

Energy is always conserved, regardless of the system chosen. However, in physics we often choose systems whose total energy is not constant. The system selected for analysis influences the way in which energy conservation is accounted for (Jewett, 2008). In situations in which there is no net transfer of energy into or out of a specified system, energy conservation implies that the total energy of that system remains constant. Conversely, when energy is transferred into or out of a system, the change in the total energy of the system is exactly equal to the net energy transfer across its boundaries. In this sense, energy is always a conserved quantity, but the energy of a specified system is constant if and only if there is no net transfer of energy into or out of that system; it is non-constant when there is a net energy transfer (Close, 2005; Etkina et al., 2019).

A productive approach to applying the principle of energy conservation therefore involves the following steps: precisely and strategically specifying the system of interest; identifying its components, boundaries and environment; analysing energy transfers into or out of the system; and determining whether the total energy of the system increases, decreases or remains constant. Recognising the universality of energy conservation, even in specific situations in which the energy of the selected system is not constant, is a subtle but crucial step in developing scientific reasoning about energy (Seeley et al., 2019).

Energy should always be analys with respect to a system of interest, its boundaries, its environment, and the initial and final states being compared. From this perspective, the distinction between transfer and transformation becomes clearer: energy transfer refers to energy crossing the boundary between systems or subsystems, whereas energy transformation refers to changes in the way energy is stored, distributed or manifested within the system under analysis. If the system is not explicitly defined, expressions such as "energy is transferred", "energy changes form" or "energy is conserved" may remain ambiguous and may reinforce a quasi-material view of energy as something that simply flows, changes form or disappears. By contrast, specifying the system allows students trace how the energy associated with the selected system or subsystems changes, whether energy is transferred across the system boundary, and how observable indicators change during the process. In this sense, system specification provides the conceptual frame within which forms, transfer, transformation, dissipation and conservation can be meaningfully coordinated.

From an educational perspective, especially in primary school, this implies that energy teaching should promote activities in which the system of reference is made explicit from the beginning. Pupils should be guided to identify the objects or components involved, distinguish the system from its environment, compare the initial and final states of the phenomenon, and describe whether the observed changes involve energy transfers across the system boundary, transformations within the system, or both. Such an approach allows the metaphor of energy as something that can be stored, transferred or transformed to remain pedagogically useful, while preventing it from becoming an vague or misleading representation of energy as a magical substance.

4.3.2 Forms, transfer, transformation, dissipation and conservation

Within this system-oriented framework, the fundamental aspects of energy are illustrated in Figure 4.1 and summarised below:

- Manifestations/forms of energy. This first aspect revisits the debate on forms of energy discussed in the previous section. In this context, a teaching approach is adopted that emphasises the unified nature of energy, using forms of energy as different indicators of its presence (Papadouris & Constantinou, 2016). Energy is not directly observable, but changes in the energy associated with a system can be inferred from observable indicators (Nordine et al., 2011) associated with an element of a system, for example an object (moving objects are said to have kinetic energy). From this perspective, the focus is on the transfer of energy between systems; in this sense, the 'language of forms' is used as an interpretative tool to describe the changes occurring within systems.

- Transformation. When the elements of the system interact, there may be corresponding gains and losses of different forms of energy. A falling ball, for example, gains speed whilst losing height. This is represented in modelling terms by the transformation of one form of energy into another (in this example, gravitational potential energy into kinetic energy). The initial and final states of the systems must be clearly identified to focus students' attention on the types of energy involved in the physical situation being analysed (Carr & Kirkwood, 1988; Millar, 2005). Furthermore, energy concepts should be introduced in situations characterised by observable changes (Brook & Wells, 1988; Carr & Kirkwood, 1998; Colonnese et al., 2012).

- Transfer. During interactions, there may be corresponding gains and losses of quantities associated with different elements of the system. A moving ball striking a stationary ball, for example, slows down whilst the other accelerates. This phenomenon is modelled as the transfer of energy between the two elements of the system (in this case, kinetic energy).

- Dissipation and degradation. Due to friction and other ‘loss’ mechanisms, real-world processes tend to run down. This is represented by the transformation of energy into less ‘useful’ forms (degradation, for example, into thermal energy) and/or by the transfer of energy to the environment (dissipation).
- Conservation. In a closed system, the total energy remains constant.

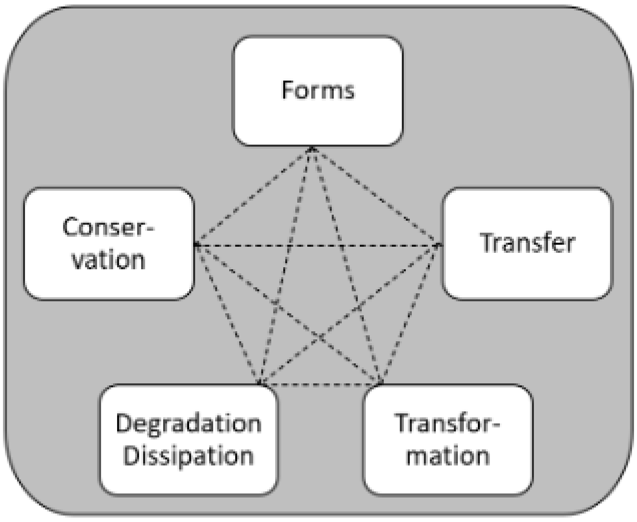

Fig. 4.1 Schematic representation of the fundamental aspects of energy (based on Duit, 1986 and Dekter, 2023).

These fundamental aspects are closely interlinked: for example, to understand that all energy is fundamentally the same (central aspect: forms), the fundamental aspects of transfer and transformation are necessary. Understanding transformation, in turn, requires knowledge of the different forms of energy (Nordine, 2016). Understanding the principle of conservation is only possible if one recognises the form of thermal energy and the transfer of energy to the environment (degradation, dissipation) (Dekten, 2023). These ideas cannot be learnt sequentially nor in isolation from one another (Duit, 2014; Goldring & Osborne, 1994; Herrmann-Abell & DeBoer, 2017; Lacy et al., 2014; Neumann et al., 2013; Papadouris & Constantinou, 2016; Yao et al., 2017).

Learning progressions relating to energy, therefore, do not proceed sequentially from one topic to the next, but start from the common knowledge that students already possess — for example, that batteries ‘contain’ energy and the willingness to accept that moving objects have energy (Lacy et al., 2014) — and systematically develop an integrated understanding of all topics, accompanied by a growing ability to coordinate them and successfully apply them to phenomena of increasing complexity (Jin & Anderson, 2012; Lacy et al., 2014; Neumann et al., 2013; Nordine et al., 2011).

Learning the scientific concept of energy, therefore, means progressively developing a conceptual model that enables one to interpret observable phenomena in terms of energy and to understand how energy manifests itself, is transferred and is conserved within and between systems (Duit, 1986; Lacy et al., 2014; Tobin et al., 2018).

From this perspective, learning about energy does not involve acquiring a formal definition, but rather developing a network of meanings that links empirical observations, representations and scientific language (Neumann et al., 2013; Herrmann-Abell & DeBoer, 2018).

More specifically, students should learn to infer the presence of energy from real-world observations based on specific indicators, to trace the related increases and decreases in these indicators within the system of interest, and to describe these observations in terms of energy transfer, transformation, dissipation, degradation and conservation (Nordine et al., 2011; Tobin et al., 2018; Dekten, 2023).

From an educational perspective, this implies that energy education should promote activities in which students are guided to identify the systems involved, to recognise where energy is initially present, how it is transferred between systems, and how it is distributed in its various forms during the process (Millar, 2005; Papadouris & Constantinou, 2016; Fortus et al., 2015). Consequently, the aim of teaching energy in schools is to support the development of increasingly sophisticated conceptual models that progressively incorporate all five fundamental, interconnected aspects of energy — forms, transfer, transformation, dissipation/degradation and conservation — integrating them into a coherent view of physical processes (Fig. 1; Lacy et al., 2014, 2022; Tobin et al., 2018; Herrmann-Abell & DeBoer, 2018).

4.4 Issues and debates regarding the teaching of energy

There is a lively debate regarding the most appropriate and effective ways to present energy-related content in schools (Warren, 1991; Solomon, 1992; Millar, 2005; Nordine, 2016). In the following sections, we explore the main points of discussion regarding the teaching of energy.

4.4.1 Energy as a quasi-material substance

In the context of primary school, to which we refer in this work, it is strongly recommended to promote the teaching and learning of energy at a qualitative level (Millar, 2005; Colonnese et al., 2012; Opitz et al., 2015; Delegkos & Koliopoulos, 2020; Dekter, 2023).
According to Warren (1991), the fundamental flaw in a qualitative approach to energy is that it makes energy appear as a ‘magical substance’, invisible and intangible, yet capable of flowing from one place to another, changing form as it goes, whilst remaining constant in quantity. Others (Duit, 1987; Millar 2005; Nordine et al., 2011; Dekter, 2023), however, consider this an acceptable, indeed useful, way of simplifying a difficult concept. As Papadouris and Constaninou (2016) argue, this approach can lead to ‘coherent qualitative understandings that can provide a solid foundation for a meaningful quantitative understanding of the concept of energy.
It is very difficult, especially for children, not to think of energy as ‘something’ that flows, or is somehow transferred, from one place to another (Millar, 2005). If this tendency typical of children is encouraged, a model of energy develops as a sort of intangible substance that flows from one place to another. Although we know that this model is not in line with the scientific idea of energy, it nevertheless represents a useful and effective tool for promoting an understanding of energy conservation (Millar, 2005; Nordine et al., 2018). Since energy is entirely abstract, there is no single ‘scientifically correct’ conceptualisation, but different conceptualisations can highlight different fundamental aspects of energy and obscure others (Dekter, 2023). The substance metaphor, therefore, may support students in reasoning as if energy were something that can be conserved, transferred, stored, transformed or made to flow from one object or system to another. In this sense, its educational value lies not in providing an ontology of energy, but in offering a coherent model for following energy through physical processes. The metaphor of substance, therefore, is considered to aid understanding of the transfer and conservation of energy (Nordine, 2016).

This perspective has been further developed in the Energy Project by Scherr et al. (2012). In this line of research, the substance metaphor is not treated as a misconception, but as a productive conceptual resource for learning about energy. Energy is represented as something that can be tracked as it moves from object to object and changes form, while remaining conserved. Such a representation helps students reason about complex energy dynamics, especially when they need to identify where energy is located, how it is

transferred, and how it is transformed during a process (Scherr et al., 2012a; Scherr et al., 2012b; Scherr et al., 2013; Daane et al., 2015).
A similar contribution is offered by the Forces of Nature approach developed by Fuchs and Corni (2023). In this framework, physical processes are introduced through the interaction of different "forces of nature", such as water, wind, heat, electricity and motion. Energy is not presented as an isolated entity or as a substance existing by itself, but as something that is carried, exchanged or made available through the interaction between these agents. The metaphorical language of flow, transfer and exchange is therefore used to make visible the role of energy in physical processes and to support children in constructing qualitative explanations of phenomena. This approach is particularly relevant in primary education, because it acknowledges the embodied and imaginative ways in which children make sense of natural processes, while gradually preparing them for more formal scientific conceptualisations (Fuchs & Corni, 2023; Fuchs, Corni, & Pahl, 2021).

This view is shared by Brewe (2011), Duit (1987) and Falk et al. (1983), who emphasise the pedagogical value of presenting energy as a quasi-material substance that is transferred, arguing that this metaphor has more educational advantages than disadvantages, particularly in introductory energy teaching. Overall, the quasi-material substance metaphor can therefore be considered a useful bridge between pupils' spontaneous reasoning and a more structured understanding of conservation, transfer and transformation of energy (Scherr et al., 2012; Fuchs & Corni, 2023).

4.4.2 The role of forms of energy in teaching

When using a model of energy as a quantity that can be stored in different places (and ways) and that can flow from one place to another, the need arises to label the different 'forms' that energy can take. Traditional teaching has made extensive use of this approach, tending to present categories such as kinetic, potential, chemical, electrical and light energy (Millar, 2014; Nordine, 2016).
The 'forms of energy' approach is not scientifically accurate and has therefore been the subject of heated debate (Millar, 2005; Nordine, 2016). Despite this, numerous teaching approaches in the literature continue to incorporate the idea of forms of energy, albeit with varying degrees of explicitness (Fortus et al., 2015; Nordine, 2016; Papadouris & Constantinou, 2016; Krajcik et al., 2017). For example, some explicitly include the idea that

energy exists in distinct forms, whilst others seek to present energy as a single quantity whilst continuing to use the language of forms primarily as linguistic and communicative tools.
One criticism levelled is that students simply learn a set of labels, which adds little to their understanding (Millar, 2005). Furthermore, school textbooks frequently use expressions that describe energy as if it were transferred 'from one form to another' (for example, 'transferred from chemical energy in a person's muscles to the kinetic energy of something moving'), a formulation that can be conceptually ambiguous, as it tends to confuse processes of transformation with those of transfer.

This ambiguity can be reduced by explicitly referring to the system under analysis. From a system-oriented perspective, it is not sufficient to state that one form of energy is transformed into another in a general sense. Rather, it is necessary to ask which system is being considered, which components are involved, and whether energy remains within the system or crosses its boundary (Seeley et al., 2019). For example, instead of simply saying that chemical energy is transformed into kinetic energy, it may be more productive to describe how, within the selected system, some observable indicators decrease while others increase, or how energy is transferred from one system to another and then becomes associated with different indicators in the receiving system (Papadouris & Constantinou, 2016; Lehavi & Eylon, 2018).
In this sense, the language of forms should not be interpreted as suggesting that energy is composed of separate entities that change their nature. Rather, forms of energy can be understood as functional descriptions of where and how energy is stored, distributed or made observable within a system (Millar, 2005; Papadouris & Constantinou, 2016). This interpretation allows the pedagogical usefulness of the language of forms to be maintained, while reducing the risk of confusing transfer with transformation or of reinforcing a quasi-material view of energy as something that simply turns into another substance (Millar, 2005; Nordine, 2016; Lehavi & Eylon, 2018).

Another criticism of the 'forms of energy' approach is that it focuses attention in the wrong place, on the 'form' of energy at different points, rather than on the processes through which energy is transferred from one object or system to another (Millar, 2005). Ellse (1988) argues that a perspective based on forms and transformations of energy is misleading and introduces unnecessary complications into teaching. He proposes not using labels for forms of energy and simply speaking of 'energy' that is 'transferred' from one place to another, rather than ‘transformed’ or ‘converted’ from one form to another. Similarly, Swackhamer (2005) argues that speaking of transformations of forms improperly suggests that energy changes its nature, diverting attention from the physical changes in the systems involved.

Many authors (Optiz, 2015; Fortus et al., 2015; Papadouris & Constantinou, 2016; Krajcik et al., 2017) acknowledge the limitations associated with the language of forms; however, they argue that the benefits of using such language outweigh the risks associated with its use, particularly in the early stages of learning. In particular, it allows qualitative aspects of energy phenomena to be made visible and enables the gradual introduction of the concept of transformation, which represents a key step towards the development of more complex models (Fortus et al., 2015; Papadouris & Constantinou, 2016).

Millar (2005, 2014a) suggests distinguishing between ‘reservoirs’ of energy, understood as ways in which energy can be stored in objects or systems, and ‘pathways’, that is, the mechanisms by which energy is transferred between systems. Millar argues that it may be useful to speak of forms of energy as a way in which it can be transferred rather than as a ‘form’ in which it can be stored. Whilst acknowledging, therefore, the usefulness of labels such as ‘kinetic’, ‘chemical’ or ‘gravitational’, Millar emphasises the need to interpret them as functional descriptions of the ways in which energy is conserved or transferred, rather than as separate entities.

The approach described by Papadouris and Constantinou (2016) assigns a central role to the transfer of energy between systems, whilst still making extensive use of the idea that energy manifests itself in different forms. Their approach seeks to establish the necessity of the conceptual framework of energy for interpreting the changes that occur in systems. A central feature of this approach is the construction of ‘energy chains’. Such representations enable students to identify the systems involved in phenomena, the ways in which energy manifests itself at different times, and the processes of energy exchange (for example, via heat).

An alternative approach is proposed by Lehavi and Eylon (2018), who emphasise the unified nature of energy and its variation within systems. Their approach focuses on the increase or decrease in energy (energy change) as a way of explaining the processes occurring within and between systems. This ‘energy change’ approach focuses on variables that characterise changes in specific phenomena (distances between objects in a system, speed, size, etc.) and emphasises the unified nature of energy. However, Lehavi and Eylon recognise the usefulness of forms for teachers and do not recommend completely abandoning such concepts. Rather, they suggest considering the language of forms and transfer as useful rhetorical devices for describing different situations in which energy increases or decreases. Overall, the literature highlights that the use of forms of energy has conceptual limitations, but also significant educational potential, particularly when integrated with an explicit focus on transfer processes between systems. In primary education, an approach that combines reference to forms of energy with the description of energy flows between systems can foster a qualitative understanding of phenomena and provide a conceptual foundation for the gradual introduction of more abstract and formal models. Such integration makes it possible to make energy observable through its effects, to link it to changes in systems, and to guide students towards a more coherent and productive understanding of the scientific concept of energy (Millar, 2005; Fortus et al., 2015; Papadouris & Constantinou, 2016; Krajcik et al., 2017; Lehavi & Eylon, 2018).

4.5 Common-sense knowledge

Based on everyday experiences, individuals develop conceptions that function as mental models of reality and enable them to navigate everyday life; however, these are often inconsistent, unstable and highly context-dependent (Greca & Moreira, 2000; Johnson-Laird, 2013).

Even in the early years of life, children develop conceptions about the world in which we live (Smith & Wiser, 2013; Wilkening & Cacchione, 2010). Based on everyday experiences, these conceptions are highly plausible in specific situations or contexts but cannot be generalised and are often far removed from the scientific view. Students' conceptions are made up of a variety of elements drawn from different contexts, such as life experiences, everyday language and social interactions (Amin et al., 2014). These elements are integrated to varying degrees to form conceptual models as mental representations of reality (Dekten, 2023). According to theories of conceptual change, meaningful learning occurs when children actively alter their previous representational models to gradually form increasingly abstract and complex conceptual models. Ideally, they thus progressively approach the scientific concept (Amin et al., 2014; Duit & Treagust, 2003). There is a reciprocal relationship between the scientific concept and the everyday concept in this learning process: the scientific concept facilitates the integration of everyday experiences into a framework of scientific ideas, whilst everyday ideas, being linked to concrete situations, can bring the abstract scientific concept to life and thus prevent the learning of ‘empty words’ (Fleer, 2015; Halldén et al., 2013).

Learning can therefore be understood as a cognitive process in which learners actively modify their own conceptions, gradually approaching the scientific concept (Detken, 2023).

4.5.1 Common-sense knowledge about energy

In everyday language, energy is something we ‘use’ and ‘consume’. Expressions such as ‘I’ve used up a lot of energy’ and ‘I’ve used a lot of energy’ are common. We often say we ‘buy energy’ when we purchase gas or electricity for use in our homes. On television or social media, we hear explanations on how to reduce energy consumption by insulating homes or switching to more efficient appliances, such as more modern central heating boilers, energy-saving light bulbs or solar panels. Government statistics published annually tell us about ‘energy consumption’ in various sectors of the economy, such as industry, transport, the domestic sector and so on. It is said that certain foods provide a lot of energy, or that they give a quick boost when you need it.

In this way of speaking – which is not scientific even though it is influenced by scientific ideas – energy is a commodity or a resource (Millar, 2005), something to be bought and used. It comes in various forms, such as petrol, oil, gas and coal, or we can obtain energy through food. This way of speaking, however, can blur the distinction between the scientific and everyday meanings of energy. We all get used to talking about energy in ways that are not entirely scientific – and, as a result, we may come to think of energy in ways that are not in line with the scientific concept.

Initial or everyday conceptions, therefore, constitute important resources and a key factor for effective teaching and learning (Duit & Treagust, 2003; Amin et al., 2014; Vosniadou, 2019).

Many studies in the literature have investigated the most common understandings of energy (Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Millar, 2005; Yuenyong & Yuenyong, 2007; Nordine et al., 2011; Colonnese et al., 2012; Opitz et al., 2015; Nordine, 2016; Bezen et al., 2016; Detken & Brückmann, 2021; Detken, 2023).

The studies agree that students hold anthropocentric and vitalistic conceptions of energy (Besson, 2015; Nordine et al., 2011), that is, they tend to associate energy with living beings and movement. Millar (2005) argues that pupils spontaneously associate food and fossil fuels (such as gas and methane) with energy. Furthermore, energy is often viewed as a quasi-material substance that can flow from one object to another (Solomon, 1992; Colonnese et al., 2012). Secondary school students are found to have partial, unintegrated understandings of the concept of energy, with disconnected ideas (Nordine et al., 2011). Recent research on learning progressions indicates that students are often unable to apply the principle of conservation—which is central to a productive use of the concept of energy—to everyday phenomena (Herrmann-Abell & DeBoer, 2018). Duit (2014) describes students' prior knowledge as fragmented; they recognise certain energy-related phenomena but do not link the fundamental ideas together.

Fewer studies, however, have focused on children's conceptions of energy in nursery and primary school (Yuenyong & Yuenyong, 2007; Colonnese et al., 2012; Chen et al., 2014; Optiz et al., 2015; Nordine, 2016; Delegkos & Koliopoulos, 2020; Detken & Brückmann, 2021).

Yuenyong and Yuenyong (2007) examined the ideas about energy held by Thai pupils in Years 1 to 6 of primary school, all of whom had already been introduced to the concept of energy in a school setting. Most pupils in Years 1 and 2 referred primarily to technological objects and movement, without linking energy to humans or food. The authors highlight that the pupils implicitly referred to various forms of energy and their transformations but did not make a clear distinction between forms and sources and did not refer to the concepts of energy conservation and degradation.

Colonnese et al. (2012) developed a vertical teaching programme to introduce the concept of energy in primary school and administered a pre-test and a post-test. Analysis of the pre-test revealed that many pupils described energy as an almost material substance, in terms of consumption and electricity; furthermore, they spontaneously associated energy with phenomena or sources such as water, wind, the sun or turbines, but not always in terms of energy transformations.

Two studies conducted in English-speaking contexts, one in nursery school (Hook et al., 2008) and one in a third-grade pupils (Lacy et al., 2014), show that energy is predominantly associated with living beings (especially humans), movement and activities such as running or playing, and only to a lesser extent with batteries and electrical devices.

According to Lacy et al. (2014), third-grade pupils interviewed interpreted energy as an intrinsic, dichotomous property ('present or absent') of living beings or certain technical objects capable of moving autonomously. This view falls within the so-called 'human-centred framework’ (Watts, 1983), whilst no other types of alternative interpretative framework emerged.

Detken and Brückmann (2021) propose a classification of children’s ideas about energy based on the degree of connection with the central aspects of the scientific concept (forms, transfer and transformation of energy), distinguishing between substantialist conceptions, references to forms of energy, and descriptions of transfer and transformation processes. The participants (aged 6–8 years) spontaneously used the term ‘energy’ to describe phenomena and objects during the interviews. Most of them linked energy to physical activity or the state of living beings, particularly humans. In some cases, the children demonstrated ideas of transfer, describing energy as if it were moving from one object to another.

This brief analysis highlights the main common conceptions that pupils hold about energy, which reflect typical spontaneous intuitive models based on everyday observations and common language. These conceptions fully influence subsequent school learning, as they shape the way students interpret energy and attribute meaning to the content presented in formal teaching (Duit & Treagust, 2003; Vosniadou, 2019). For this reason, they should be considered an essential starting point for designing educational interventions that are effective and consistent with students’ conceptual development (Herrmann-Abell & DeBoer, 2018; Detken & Brückmann, 2021).

4.6 Examples of teaching programmes in primary school

It has been demonstrated that young learners are capable of learning about energy sources, energy transfer and storage possibilities through practical, inquiry-based activities (Van Hook & Huziak-Clark, 2008). The benefits of an early start to learning about the concept of energy were highlighted by Novak (2005), who, in a long-term longitudinal study, showed that early learning about energy has positive effects on pupils’ understanding of energy concepts in science lessons in subsequent school years.

The literature documents various teaching approaches to energy in primary school, with the aim of moving beyond a purely terminological approach and fostering a concept-building process grounded in experience. A prime example is the study by Colonnese et al. (2012), which proposes a teaching sequence based on exploratory and laboratory activities, in which pupils are enabled to directly observe phenomena of energy transformation and transfer (for example, through simple devices such as dynamos, turbines or moving objects). The course design favours an inquiry-based approach (Bybee, 2015): pupils are guided to formulate hypotheses, collectively discuss their observations and progressively attribute meaning to the phenomena observed, even before formal terminology is introduced. The results show that, even in the absence of early formalisation, children are able to construct coherent representations of energy processes, suggesting that concrete experience provides an effective basis for the emergence of abstract concepts such as energy transformation and transfer.

A complementary contribution is provided by Opitz (2015), who analyses the development of understanding of the concept of energy over an extended period, from primary school through to higher levels. His work does not merely describe individual teaching activities, but highlights the need for a coherent conceptual progression, in which the concept of energy is revisited in different contexts (physical, biological and technological) and gradually refined. According to the author, learning is more robust when energy is not presented as an isolated entity, but as a quantity that allows different phenomena to be interpreted through a single explanatory framework. From this perspective, primary school plays a crucial role, as it provides the context in which the foundations of a unifying concept of energy can be laid, preventing it from being learned as a mere linguistic label devoid of conceptual reference.

A further example of a structured approach is provided by Sissamperi and Koliopoulos (2015; 2021), who propose a teaching module centred on energy systems (such as the operation of a power station) as a prime context for introducing the concept of energy in primary school. In this case, energy is treated not merely as an abstract quantity, but as a key element of a technical and social system, in which concrete transformations, transfers and uses are intertwined. The authors demonstrate that the analysis of complex systems, suitably simplified, enables pupils to link observable phenomena (motion, heat, electricity generation) to more general scientific explanations. This approach fosters a systemic understanding of energy, reducing the risk of conceptual fragmentation and promoting an integrated view of physical processes.

Crissman, Lacy, Nordine and Tobin (2015) describe an approach to teaching energy that introduces the concept of a system as early as the final years of primary school. In this approach, students learn to ask themselves a series of questions when considering phenomena from an energy perspective, including: ‘What is the system of interest?’, ‘Where does the energy come from?’ and ‘Where does the energy go?’. In a study of this approach, Tobin, Lacy, Crissman and Haddad (2018) found that fourth-grade pupils were able to identify appropriate systems for energy analysis and to pinpoint the relevant components (i.e. subsystems) of the systems under consideration. Although the students' energy analysis was relatively simple, it demonstrates that education can help students connect the ideas of energy and systems.

A particularly significant contribution in this regard is the study by Lacy et al. (2022), which analyses the introduction of the concept of energy in primary school through an approach based on the idea of a system. The authors propose a teaching model in which pupils are guided to interpret physical phenomena by asking key questions such as: 'What is the system of interest?', 'Where does the energy come from?', 'Where does the energy go?'. In this framework, energy is not presented as a vague property or as a mere 'resource', but as a quantity that allows us to describe changes in systems and the interactions between them. The results show that primary school pupils are able to identify systems relevant to energy analysis and to recognise their relevant components (subsystems), even if their descriptions remain qualitative and simplified. However, these findings highlight that explicit systems-oriented teaching can foster an initial conceptual link between energy and the structure of physical phenomena, moving beyond a purely anthropocentric or vitalistic view of energy.

Overall, these studies converge in suggesting that the teaching of energy in primary school can be conceptually meaningful if based on concrete experiences, an intentional progression of content, and rich interpretative contexts capable of giving meaning to the observed phenomena. They also show that the early introduction of the concept of energy is not only possible but is potentially beneficial for building more stable cognitive foundations for subsequent learning (Novak, 2005; Colonnese et al., 2012; Optiz et al., 2015; Nordine, 2016; Lacy et al., 2022).

4.7 Teaching guidelines for primary schools

Based on the above considerations, it can be argued that in primary school it is more appropriate to offer teaching programmes that approach energy from a qualitative perspective; this will subsequently enable better understanding and meaningful learning (Duit, 2014; Papadouris & Constaninou, 2016).

It is useful to employ a model of energy as a quasi-material substance that can be stored in different places (and in different ways) and can be transferred from one object or system to another (Kaper and Goedhart, 2002; Millar, 2005; 2014). However, it is important to pay attention to exactly how this is done and to the terms that are introduced and used.

A good starting point for teaching energy is to build on students' prior knowledge (Millar, 2005; Colonnese et al., 2012), particularly in relation to energy resources (including food). Most students associate energy with food (Millar, 2005; Colonnese et al., 2012; Nordine, 2016; Detken & Brückmann, 2021), identifying the latter as fuel for humans. It may therefore be useful to propose activities involving food and different types of packaging to discuss energy quantities.

Millar (2005) recommends using the word 'fuel' instead of 'energy' to avoid expressions such as 'energy consumption', which could cause problems with the concept of conservation. Conversely, it is not incorrect to speak of 'fuel consumption'.

This could naturally lead to a discussion of renewable energy sources, such as wind, sunlight and waves. It does not seem very natural to call wind, sunlight and waves 'fuels', or 'energy resources'. Calling them 'energy sources', or simply talking about 'wind energy' and 'solar energy', seems more natural – and is unlikely to cause many comprehension problems (Millar, 2005).

Colonnese et al. (2012) recommend initially capitalising on children's natural tendency to identify an (internal) energy within the human body; this constitutes a very natural approach for pupils (Watts, 1983; Solomon, 1992; Trumper, 1993; Duit & Haeussler, 1994; Goldring & Osborne, 1994; Driver & Warrington, 1995; Mann & Treagust, 2010).

Another recommendation to follow is to focus on energy concepts in situations where observable changes occur (Carr & Kirkwood, 1998; Colonnese et al., 2012): wheels spinning faster, objects falling from higher to lower positions, temperatures rising, etc. Furthermore, the initial and final states of the systems must be clearly identified to focus pupils' attention on the types of energy involved in the physical situation being analysed (Carr & Kirkwood, 1998; Millar, 2005; Colonnese et al., 2012).

It is generally not recommended to introduce the concept of work in primary school (Colonnese et al., 2012), due to its relationship with the concept of force: it would be difficult for pupils to distinguish the scientific concept of work from the everyday meaning of the word. Another topic that is generally not covered with pupils aged 6–10 is long-distance interaction in terms of energy transfer between systems. Many researchers have reported that older students struggle with the concept of a field in physics education (Guisasola et al., 2004; Saarelainen, Laaksonen et al., 2007).

The US Framework for K-12 Science Education recommends that the teaching of energy explicitly link the concepts of energy and fields for students aged 11 and above (National Research Council, 2012).

An alternative way of introducing energy is to start from measurable energy changes. In this approach, energy is not treated as something that an object or a system "has" in an absolute sense, but as a quantity whose changes can be inferred from changes in measurable variables within a modelled system (Lehavi & Eylon, 2018; Bächtold, 2018). Simple calorimetric activities provide a clear example of this approach: a process such as combustion, heating or cooling is analysed by measuring the temperature change of a known quantity of water or another material, and the energy transfer is then inferred from this change. In this perspective, the focus is not on determining the absolute energy of a battery, a fuel or a food item, but on modelling a process and estimating the increase or decrease in the energy of selected subsystems (Lehavi & Eylon, 2018; Seeley et al., 2019).

Such an operational approach has clear conceptual advantages, because it makes explicit the link between energy, measurement, system boundaries and changes between states. It also avoids treating energy as a material entity contained in objects. For this reason, approaches based on measurable energy changes, including calorimetric experiments and simple energy balances, are particularly useful in later stages of schooling, when students can work with quantitative measurements, proportional reasoning and more formal models of systems and interactions (Linn & Songer, 1991; Colonnese et al., 2012; Bächtold, 2018).

However, the aim of the present research is different. Since it is addressed to primary school pupils, the objective is not to provide an operational or quantitative definition of energy, but to support the construction of an initial qualitative model that enables pupils to interpret familiar phenomena in terms of systems, changes, transfers and transformations (Millar, 2005; Colonnese et al., 2012; Papadouris & Constantinou, 2016; Lacy et al., 2022). Everyday contexts such as food, human effort, batteries and fuels were therefore selected not because they allow pupils to determine an absolute "energy of the system", but because they are cognitively accessible and strongly connected with children's prior knowledge and everyday language (Millar, 2005; Colonnese et al., 2012; Nordine, 2016; Detken & Brückmann, 2021).

In this sense, the context-based qualitative approach adopted in this work should be understood as a preparatory and educationally appropriate step. It allows pupils to begin reasoning about energy through observable changes — for example, movement, heating, light emission or the functioning of devices — while progressively learning to identify the system of interest, its components, its interactions with the environment, and the initial and final states being compared. This approach does not aim to replace later operational and quantitative treatments of energy. Rather, it provides a conceptual foundation on which such treatments can be built, helping pupils move from everyday meanings of energy towards a more coherent scientific understanding of energy conservation, transfer and transformation (Duit, 1987; Millar, 2005; Papadouris & Constantinou, 2016; Lacy et al., 2022).

4.8 Conclusions

Energy is considered a central idea and a cross-cutting concept in science education (National Research Council, 2012; Duit, 2014). However, it is often considered a difficult concept for students, and its teaching is the subject of considerable debate (Lacy et al., 2014; Nordine, 2016). This complexity stems from the abstract nature of energy and its frequent use in everyday language, which easily conveys meanings far removed from its physical definitions (Millar, 2005).

Numerous studies have highlighted the value of introducing educational programmes as early as primary school, using practical and concrete approaches (Novak, 2005; Dekter, 2023). At this level of education, it is possible—and desirable—to develop programmes that focus primarily on the qualitative aspects of energy, with reference to its nature, processes of transformation and transfer, and the role of systems (Fortus et al., 2015; Papadouris & Constaninou, 2016). Studies indicate that such early approaches subsequently foster more meaningful learning of the concept of energy (Colonnese et al., 2012; National Research Council, 2012; Herrmann-Abell & DeBoer, 2018).

The teaching and learning of energy should promote the progressive development of a conceptual model that integrates the aspects considered fundamental in the literature (Herrmann-Abell & DeBoer, 2017; Lacy et al., 2014; Neumann et al., 2013; Dekten, 2023): manifestations/forms of energy, transformation, transfer, dissipation, conservation. These aspects are closely interlinked and cannot be learnt sequentially or in isolation; consequently, the teaching of energy in primary school should foster an integrated understanding of these elements, supporting the construction of a unified interpretative framework of physical phenomena (Lucy et al., 2014; Nordine, 2016).

Furthermore, it is essential to develop learning pathways that build on students’ prior knowledge: students frequently use the term ‘energy’ in ways that often differ significantly from its scientific meaning (Chen, 2014; Dekten, 2023). Studies have extensively documented such knowledge, highlighting how energy is often confused with force and electricity, and interpreted as a characteristic specific to living beings (Nordine, 2016; Dekten, 2023). An educational programme on energy in primary school should therefore initially capitalise on children’s natural tendency to conceive of energy as an almost material substance and to associate it with the human body and food, before gradually guiding them towards moving beyond a predominantly vitalistic and anthropocentric view (Duit, 2014; Millar, 2014).

In light of these theoretical considerations, the following chapters (Chapter 7 and Chapter 8) present the teaching programmes designed to promote the acquisition of scientific knowledge about energy among primary school pupils.

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CHAPTER 5

RESEARCH DESIGN

The research carried out over recent years as part of the PhD programme (2023–2026) involved various phases of study, monitoring, planning and practical fieldwork.

The initial phase was devoted to theoretical reflection and an in-depth study of the literature on self-efficacy, physics teaching, gender differences and active methodologies. This enabled the precise and accurate definition of the theoretical constructs of this research and the precise delineation of the studies carried out in these areas. Theoretical knowledge is the essential foundation that precedes and accompanies the drafting of any research project, enabling aims and objectives to be defined coherently.

Therefore, the work carried out focused on gender differences in the perception of scientific self-efficacy among primary school boys and girls. As described in the previous chapters, this issue is receiving significant attention both nationally and internationally, demonstrating the social importance it holds today.

We are increasingly aware that, to promote a more equitable society, it is necessary to discuss and work actively towards achieving the much-vaunted gender equality that we have been striving for for over 80 years. The process of gender segregation begins in the early years of human life and is due to a set of socio-cultural factors that are difficult to eradicate, often unspoken but absorbed passively (Master, 2021; Schmader, 2023). Gender stereotypes become increasingly entrenched throughout the school years, contributing to the creation of a distorted self-image, including perceptions of one's own abilities and aptitudes, and effectively influencing educational and career choices (Hill et al., 2010; Master, 2021). The belief that women are not suited to science and mathematics undermines not only interest in these subjects but also motivation and a sense of self-efficacy (Toma et al., 2018; Whitcomb & Singh, 2020). The latter is one of the factors that most strongly influences students' educational and career choices (Master, 2021; OECD, 2023). Schools, whose primary task is to educate the citizens of tomorrow, have a duty to play an active and concrete role in the fight for gender equality, through the use of targeted methodologies and inclusive learning pathways (Furtak et al., 2012; UNESCO, 2017).

The following sections describe the stages of the research carried out, which will be explored in greater depth in the subsequent chapters.

5.1 Research objectives

The research was guided by several objectives.

Firstly, the general objective concerns the analysis of gender differences in scientific self-efficacy among primary school pupils, through the development and validation of a questionnaire, named Self-efficacy In Science (SE-IS). This was developed to investigate whether such differences already emerge in the early stages of schooling, as indicated in some studies (OECD, 2023). In parallel, the research focused on the use of the ISLE (Investigative Science Learning Environment) methodology, analysing its role both in the development of scientific self-efficacy and in the learning of subject content.

Overall, the research objectives are: 1) to construct and validate a measure of scientific self-efficacy (SE-IS) in primary school; 2) to investigate gender and al differences in scientific self-efficacy; 3) to evaluate the effectiveness of the IBSE methodology in promoting conceptual change and the development of scientific self-efficacy.

5.2 Structure of the research

This research, therefore, is structured around two complementary and interrelated strands.

The first concerns the construction and validation of a scientific self-efficacy (SE-IS) measurement tool, developed through a series of progressive studies (Studies 1–4).

The second line of research aims to investigate students' conceptions of energy and to evaluate the effectiveness of an intervention based on the ISLE (Investigative Science Learning Environment) methodology, both in terms of conceptual learning and scientific self-efficacy. This line of research utilises two instruments: the questionnaire on conceptions of energy (Colonnese et al., 2012) and the SE-IS questionnaire.

The research questions are therefore tailored to the specific objectives of the various studies, whilst maintaining overall consistency within the research design.

From a methodological perspective, the research process was developed sequentially and iteratively, integrating quantitative and qualitative approaches within a mixed-methods framework.

In an initial phase, the SE-IS questionnaire was designed and a pilot study (Study 1) was conducted, which served a dual purpose: on the one hand, to test the instrument in a real educational context and provide preliminary guidance for revising the items; on the other, to analyse the effects of an ISLE-based intervention. The pilot study did not serve solely an exploratory function, but represented an initial application of the research design, allowing for the simultaneous analysis of students' conceptual change and the development of their scientific self-efficacy, thanks to the administration of the SE-IS questionnaire and the energy questionnaire. An initial TLS was designed and implemented, which will be described in detail in Chapter 6.

Subsequently, two studies were conducted on independent samples (Studies 2 and 3), aimed at exploratory factor analysis and the progressive refinement of the questionnaire's structure. The version of the SE-IS questionnaire obtained at the end of Study 3 was used in a quasi-experimental trial with a control group and an experimental group, together with a questionnaire on conceptions of energy (Colonnese et al., 2012). This experiment aimed to evaluate the effectiveness of the ISLE methodology compared to traditional teaching, both in promoting scientific self-efficacy and in conceptual learning. To this end, the TLS was revised and refined, as described in Chapters 8 and 9.

Finally, in a subsequent phase, a confirmatory factor analysis (Study 4) was carried out with a sample different from those used in the previous studies, including in terms of geographical location, in order to verify the soundness of the theoretical model and consolidate the evidence of the instrument's validity. The entire process of constructing and validating the SE-IS questionnaire (Studies 1 to 4) is described in Chapter 7.

Table 1 provides a summary description of the research carried out.

Table 1. Summary of the research design

Study	Objective
Study 1: pilot study	Preliminary testing of the SE-IS questionnaire and the TLS conducted with ISLE; analysis of initial conceptions and conceptual change regarding the concept of energy; initial assessment of the development of scientific self-efficacy
Study 2	Exploration of the factor structure of the SE-IS questionnaire through exploratory factor analysis (EFA)
Study 3	Refinement and revision of the factor structure of the SE-IS questionnaire using EFA
Experiment	TLS with GC/EG to assess the effectiveness of the ISLE methodology compared to traditional teaching on conceptual change and scientific self-efficacy
Study 4	Validation of the factor structure of the SE-IS questionnaire through confirmatory factor analysis (CFA)

The studies form part of a progressive and interdependent research design: Study 1 represented a preliminary phase of fine-tuning and initial application of the design; Studies

2 and 3 allowed for the review and modification of the instrument; the experimental phase enabled its application to be tested in a school context using a quasi-experimental design; finally, Study 4 consolidated the theoretical model through confirmatory validation.

5.3 Conclusion

In summary, the research design outlined here takes the form of a structured, progressive and methodologically integrated approach, aimed at systematically investigating both the development and validation of the SE-IS instrument and the effectiveness of an ISLE-based teaching intervention on students’ scientific self-efficacy and conceptual change.

The following chapters will examine the individual phases of the research in detail, with particular attention to the methodological procedures adopted and the results obtained.

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CHAPTER 6

THE PILOT STUDY

Based on the discussions in the previous chapters, we developed a Teaching Learning Sequence (TLS) on energy with 75 primary school pupils.

This is a preliminary phase of the research aimed at testing the feasibility, design, procedures, and data collection tools before conducting the experimental study (Thabane et al., 2010). It therefore serves to identify and correct any methodological or logistical issues, reducing the risk of failures or inefficiencies in the main research.

The pilot study allows for the testing and, where necessary, modification of measurement and data collection tools, such as questionnaires, assessment tests or interviews (Van Teijlingen & Hundley, 2001). Furthermore, it helps to determine whether the teaching activities have been structured appropriately to achieve the intended research objectives (Thabane et al., 2010).

The pilot study was conducted with fifth-grade pupils (10-11 years old) from the town of Bagheria, near Palermo.

6.1 Research aims and pilot study design

The TLS was implemented using a quasi-experimental group design involving a single group of participants, to whom an experimental factor (Fe) was applied.

The experimental design adopted is defined as quasi-experimental because the sample involved is not representative of the entire target population (Benevento, 2015). Consequently, it is not possible to determine with certainty to what extent the variations observed in the dependent variable are actually attributable to the manipulation of the independent variable, or whether these changes were influenced by extraneous variables or confounding factors, such as the maturation of the subjects, concurrent historical events or the very effect of administering the tests.

Quasi-experimental designs are widely used in educational research (Benevento, 2015), due to the fact that it is more complex to randomise participants in schools.

The operational framework of the single-group quasi-experimental design involves administering an pre-instruction, an experimental treatment or intervention (ET), and administering a post- instruction. The main objective of this design is to observe whether the TLS produces a change in participants by comparing the data collected before and after its application (Campbell & Stanley, 1963). If the results of the post- instruction differ from those of the pre- instruction, this could indicate an improvement due to the effect of the Fe.

The choice of this specific experimental design is motivated by a number of methodological considerations.

Firstly, the main aim of the pilot study is to test the overall feasibility of the project: the TLS, the data collection tools and the research questions (Van Teijlingen & Hundley, 2001). In this preliminary phase, it is not essential to include a control group, as the primary objective is to verify whether the TLS is capable of generating a change, observable through a comparison of the data collected before and after the TLS.

Secondly, it is envisaged that the subsequent experimental study (see Chapter 8) will adopt a different design, including both an experimental group and a control group, in order to allow for a more rigorous comparison between different conditions.

In this pilot study, the five classes involved in the research were treated as a single group, and all followed the same TLS on the topic of energy. All activities were conducted by the external researcher, in each class.

The hypothesis underlying this pilot study is that the use of an active methodology such as ISLE (Investigative Science Learning Environment) can promote the acquisition of knowledge and skills regarding the concept of energy in primary school pupils and, at the same time, contribute to the development of scientific self-efficacy (SSE).

6.2 Research questions and methodological approach

Based on theoretical considerations and the literature, we designed a TLS on the topic of energy for Italian fifth-grade pupils (aged 10–11). The main objectives of the planned methodological activities were to help pupils become aware of the concept of energy and to promote their Scientific Self-Efficacy (SSE). The sequence was implemented using the ISLE methodology (Bybee, 2015), consistent with the constructivist approach (Dui & Treagust, 1998).

The classes were from a single school and had voluntarily chosen to participate in the project. The implementation was carried out by one of the researchers, who delivered the TLS in all participating classes. The activities were conducted following the same timetable and using the same procedures in all classes, and the participants were therefore considered a single study group.

The following three research questions (RQs) were posed in the study:

RQ1. What common-sense conceptions about energy emerge among primary school pupils in the present study?

RQ2. To what extent does the planned TLS using the ISLE facilitate the transition from everyday knowledge to scientific knowledge regarding the concept of energy among fifth-grade pupils?

RQ3. To what extent does the planned TLS using ISLE promote an improvement of science self-efficacy in male and female pupils?

6.3 Research context and participants

The pilot study involved 75 pupils (M=40, F=35) aged between 9 and 11 from the 'Giovanni e Falcone' State Comprehensive School in Bagheria. All pupils underwent the experimental treatment.

The school serves a diverse catchment area, covering the territory of Bagheria and the hamlet of Aspra, though there are few cases of irregular attendance. The school was formed by the merger of two schools located in these two areas, which have different socio-economic profiles. The population of Bagheria is largely employed in the secondary and tertiary sectors (crafts, manual labour, construction, commerce, the liberal professions and the public sector). The population of Aspra is particularly involved in fishing and the production, preservation and marketing of fish products.

The socio-economic and cultural background of the students is predominantly lower-middle class. However, in both areas covered by the Institute's campuses, there are students with relational and behavioural issues stemming from a particularly disadvantaged and deprived family environment. There are voluntary associations in the area that contribute in various ways to addressing the various school-related issues.

All the fifth-year classes at the school took part in the pilot study.

The group consists of five classes, located at the school complex in Bagheria; they have the same science teacher and follow an similar curriculum. The students mostly come from families with a middle-class socio-economic and cultural background.

The classes include:

- 6 pupils with SLDs who took part in the activities with the support of the support teacher.

- 1 pupil with an Autism Spectrum Disorder. They benefit from Law 104/92, Article 3, paragraph 3, and receive support from the support teacher for 22 hours per week. They took part in the activities with the support of the support teacher.

- 1 pupil with an autism spectrum disorder. They benefit from Law 104/92, Article 3, paragraph 3, and a support teacher for 22 hours per week. They did not take part in the planned activities.

- 1 pupil with spastic quadriplegia. The pupil benefits from Law 104/92, Article 3, paragraph 3, and a support teacher for 22 hours per week. The pupil did not take part in the planned activities.

6.4 Designing the Teaching and Learning Sequence (TLS)

The TLS has a dual purpose: whilst on the one hand it aims to foster the development of pupils' scientific self-efficacy, on the other it seeks to promote the acquisition of scientific knowledge and skills relating to energy through practical and engaging teaching activities.
The implementation was carried out by one of the researchers who developed the TLS in all participating classes. The activities were conducted following the same timetable and using the same procedures in all classes, and the participants were therefore considered a single working group.
The learning objectives and a description of the activities carried out are set out in the following sections.

6.4.1 Learning outcomes and objectives

The content and learning objectives were selected and organised pedagogically, partly through careful consultation with the teachers of each primary school class involved in the trial, in collaboration with experts and researchers.
The learning objectives relating to the core areas 'Objects, materials and transformations' and 'Observing and experimenting in the field' were defined, with reference to the National Guidelines (2012, 2018) for the curriculum of nursery and primary schools, in a manner consistent with the chosen subject content.

Goals for the development of skills by the end of primary school

- The pupil develops a curious attitude and ways of looking at the world that encourage them to seek explanations for what they see happening
- They explore phenomena using a scientific approach with the help of teachers and classmates, independently observing and describing the unfolding of events, formulating questions based on hypotheses, and proposing and carrying out simple experiments.
- They identify similarities and parallels in phenomena, take measurements, record significant data, and identify spatial and temporal relationships.

Learning objectives by the end of fifth-grade

Objects, materials and transformations

- Through the observation of concrete experiences, identifies scientific concepts such as: spatial dimensions, weight, specific gravity, force, motion, pressure, temperature, heat, etc.
- Begins to recognise patterns in phenomena and to construct, at a basic level, the concept of energy

Field observation and experimentation

- Continue to make frequent and regular observations, with the naked eye or using appropriate instruments, with classmates and independently, of a section of the local environment; identify the elements that characterise it and their changes over time.

6.4.2 Learning content

Given the students' age, we have focused primarily on the qualitative aspects of energy. Following previous studies (Colonnese et al., 2012; Mariani et al., 2012; Delegkos, 2020), we focused on the following three aspects of energy: 1) energy as a property of a system in a particular state (a state property, described in everyday terms); 2) the manifestations of energy in different forms and sources (kinetic energy, potential energy, internal energy), associated with internal structure and temperature, and energy associated with light; 3) energy transfers and conversion. We decided not to focus on the fourth fundamental aspect of energy – 4) the degradation and dissipation of energy – because, based on previous studies (Millar, 2005; Mariani et al., 2012; Colonnese et al., 2012), we consider this content unsuitable for primary school pupils.

In developing the TLS, we followed the recommendations found in the existing literature to promote more effective student learning.

The principle of conservation of energy was not addressed explicitly, but rather introduced implicitly, allowing it to emerge as a natural extension in subsequent learning experiences (Millar, 2025; Colonnese et al., 2012). Following Driver's (2004) suggestions, we proposed a TLS that 'initially capitalises on pupils' tendency to feel energetic and then extends that sense of energy to other living beings and then to inanimate objects'. The sequence begins with the notion of 'human energy', emphasising the food-energy relationship—which is easily accessible and familiar to children—thus providing a meaningful starting point (Nordine et al., 2011; Millar, 2005; Liu, 2008). The concept of energy was consistently embedded in contexts involving observable changes—such as wheels spinning at increasing speeds, objects falling from higher to lower positions, or rising temperatures—so that students could directly link abstract concepts to empirical evidence (Colonnese et al., 2012; Carr & Kirkwood, 1988). Furthermore, the initial and final states of the systems were systematically highlighted to ensure that students' attention was focused on the specific changes under consideration, thereby reducing potential conceptual distractions (Brook & Wells, 1988). In addition, we proposed some simple activities to highlight the most important differences between renewable and non-renewable energy sources.

6.4.3 Methodological choices: ISLE and the promotion of Science Self-Efficacy

TLS is implemented using an active learning methodology, based on constructivist theories which assert that individuals actively construct their own understanding and knowledge of the world through experiences and reflections on those experiences (Duit & Treagust, 1998; Fauth et al., 2014). In our research, the approach adopted is ISLE (Investigative Science Learning Environment), which represents a teaching framework oriented towards inquiry and the progressive construction of scientific meaning (Etkina, 2015).

ISLE fosters curiosity and motivation by starting with authentic problem-based situations and engaging students in scientific practices such as observation, hypothesis formulation, investigation design, data interpretation and argumentative discussion (Buggé & Etkina, 2020; Brookes et al., 2020). The literature highlights how this approach fosters the development of critical thinking, creativity, problem-solving skills, and communication and collaboration skills, even in primary school (Etkina et al., 2019).

In this study, these elements are integrated into the instructional design: the energy-related learning pathways guide the structure of the TLS, the ISLE informs the teaching methods, and Bandura's sources of self-efficacy guide the design of activities, with the aim of developing both conceptual understanding and scientific self-efficacy.

Pupils are actively engaged through observation, hypothesis-forming, experimentation and group discussion. The teaching activities were designed to build on pupils' prior knowledge, making this explicit through guided discussion and brainstorming sessions, eliciting initial preconceptions and fostering a supportive emotional climate. Group discussions following the activities allowed observations to be formalised and scientific language to be gradually introduced, facilitating the transition from naive conceptions to models more consistent with disciplinary knowledge. Practical investigative activities were carried out in small groups, in which students formulated and tested hypotheses in a non-assessment context. These support a qualitative understanding of the content, whilst promoting the experience of mastery and vicarious experiences, two key sources of self-efficacy. In the group discussions, the students articulated their observations and the teacher progressively introduced scientific terminology, supporting conceptual reorganisation and verbal persuasion.

In addition, provision was made for applying these concepts in new contexts, thereby promoting the transfer of knowledge, consolidating understanding, and strengthening students' conceptual integration and sense of competence. Finally, assessment has been integrated throughout the programme, through the monitoring of discussions and activities, using both structured tools (pre- and post- instruction), in order to identify changes in conceptual understanding and levels of scientific self-efficacy.

This process promotes conceptual reorganisation and, at the same time, activates the main sources of self-efficacy, in particular the experience of mastery (linked to success in activities), vicarious experience (through comparison with peers) and verbal persuasion (mediated by the role of the teacher and the class group) (Etkina et al., 2019; Brookes et al., 2020). Finally, the active involvement of students in authentic scientific practices, the cyclical nature of the inquiry process and the collaborative dimension of learning help to foster students' emotional engagement and promote positive emotions related to science (Etkina et al., 2019).

Overall, the use of ISLE has enabled the learning of energy concepts and the development of Science Self-Efficacy to be addressed as closely interlinked dimensions within the same TLS.

6.5 Data collection and analysis methodology

The data collection tools used in this first phase are varied and include both quantitative and qualitative instruments. The decision to adopt such diverse methodologies responds to the need to ensure greater richness and variety in the data collected, thus offering a broader range of information and nuances regarding the observed phenomena. The approach adopted in the research is, therefore, a mixed-methods approach, aimed at leveraging the strengths of both quantitative and qualitative methodologies within educational research (Creswell and Garrett, 2008).

Among the quantitative data collection tools, a Likert-scale questionnaire, entitled Self-Efficacy in Science (see Chapter 7), and a test of scientific knowledge (Colonnese et al. 2012) were used. Both were administered at the start and end of the programme, representing the pre- instruction and the post- instruction.

Among the less structured tools, documents produced by the pupils themselves were used, such as parts of their exercise books and diagrams, as well as observations and recordings made during classroom activities.

6.5.1 The knowledge questionnaire

The knowledge test is based on the research conducted by Colonnese et al. (2012), carried out in a primary school with pupils aged between 10 and 11.

The responses to the questionnaire enable the collection of significant data on the representations and conceptions that pupils hold regarding the concept of energy. These responses provide a valuable basis for identifying the main conceptual 'sticking points', i.e. the difficulties that children might encounter in constructing a scientifically sound understanding of the topic.

The questions in the questionnaire are as follows:

- Question 1. What do you know about energy?
- Question 2. As far as you know, are there things that provide energy?
- Question 3. As far as you know, are there things that have or possess energy?
- Question 4. Can energy be conserved? In your answer, explain what you mean by 'conserved'.
- Question 5. Can energy be transformed? Explain, giving some examples.
- Question 6. Is it possible to lose energy? Explain, giving some examples.
- Question 7. What 'types' of energy do you know?

To adapt the questionnaire to the specific content covered during the TLS, an additional question has been included. In particular, opportunities for reflection on energy sources have been provided, distinguishing between renewable and non-renewable sources.

- Question 8. What is the difference between renewable and non-renewable energy sources?

The questions developed in the study by Colonnese et al. (2012) were administered in a school setting similar to that of the present research. In both cases, the sample consists of Italian primary school pupils aged between 10 and 11.

We subjected the test to face validity (Jensen, 2003) and content validity (Haynes et al., 1995) assessments.

For the first validation, we presented the questions to 10 pupils in a fifth-grade class at the same school. The pupils had no difficulty in understanding the questions. The very broad nature of the questions meant that the answers obtained varied considerably, as each pupil interpreted the meaning of ‘producing energy’, ‘losing energy’ and ‘having energy’ in their own way.

The responses from this initial validation can be grouped into three categories. In the first, a view of energy linked to electricity is evident:

“Things that have energy are phones, the TV, power banks...”
“Energy is wasted if we leave the light on”
“Energy is stored in batteries”

In the second group, a vitalistic view of energy emerges:

“We need energy to move”
“Food gives us energy”
“We lose energy when we move”
“We conserve energy when we sleep”

Finally, the last group of responses links the concept of energy to wind, water, the sun, solar panels and/or wind turbines:

“The sun gives us energy”
“Energy is stored in solar panels”
“The sun’s energy is transformed into light”

These types of responses are in line with what we had hypothesised and with the findings of the study by Colonnese et al. (2012).

Finally, we carried out content validation by submitting the test to an expert in the field, namely a researcher from the research group. The comments received were positive and concluded the validation process.

The open-ended responses to the knowledge questionnaire were classified as common-sense knowledge, partially scientific knowledge and scientific knowledge, using a phenomenographic analysis (Marton, 1981). This classification allows us to assess not only the correctness of the answers, but also the quality and level of scientific rigour in the students' thinking.

In educational research, this type of distinction enables the monitoring of learning processes and student progress (Duit & Treagust, 2003).

We have identified a classification rubric (Driver et al., 1985; Duit & Treagust, 2003; Krippendorff, 2013) to classify the responses obtained. All these instruments allowed us to build different databases, which will be analyzed in Chapter 7, by means of different methodologies. In general, from each database collected with a specific methodology/tool, it is possible to extract information on some of the dimensions of learning that we have chosen to study. However, as we will see in the next chapter, some databases are more suitable than others for investigating a given dimension/variable related to learning. All the instruments used to collect the data are well-known in the literature and commonly used in research in education.

In the following sections, we give a brief description of each data collection instrument and of the variables it can help to study.

Table 1 Classification levels and criteria

Level	**Criteria**	**Example of a response**
Common knowledge	References to everyday experiences; intuitive explanations; conceptual errors	"Energy is needed to move" "Energy is the spark we need to live" "Energy is stored in the power lines"
Partially scientific knowledge	Presence of scientific terms without correct or complete connections; partially scientific language; declarative answers that state concepts without context; examples explored during the course reported incompletely and/or partially correctly	"Wind turbines have energy" "Energy is neither created nor destroyed" "The bike transferred some of its energy to the light bulb and it became light energy"
Scientific knowledge	Correct and consistent use of scientific language; identification of cause-and-effect relationships	"If we take a whisk and a bowl full of water and start stirring the whisk inside the bowl, the water will heat up, because the kinetic energy of the

	whisk has been converted into thermal energy”

The responses classified as common knowledge include all those statements in which students do not use scientific language, refer to everyday experiences, and in which conceptual errors and misconceptions are evident. In the case of energy, these responses often reflect a view linked to electricity, the use of household appliances, movement and food.

Responses classified as partially scientific included statements that used partially scientific language, were incomplete, and were not entirely accurate. Furthermore, we included those responses that provided standard definitions of energy but were not sufficiently substantiated; these are defined as declarative and decontextualised, as they merely restate what had been learnt previously without any attempt to establish a cause-and-effect relationship. This was confirmed by asking these students to explain the meaning of the statements verbally, and they demonstrated that they had not understood their meaning.

The responses classified as scientific knowledge included all statements that demonstrated correct use of scientific language and a clear grasp of the concepts. In particular, this category included all responses that precisely and accurately described the experiments conducted during the TLS. In these cases, the students answered the questions correctly and provided a comprehensive explanation of the observed phenomenon.

Furthermore, the responses were analysed at various levels and in different stages: by identifying and counting the occurrences of concepts and terms used, and by determining the frequencies of these occurrences as revealed by the data. The categorisation of responses was carried out in light of the main misconceptions regarding the concept of energy documented in the literature (Millar, 2005; Nordine et al., 2011; Colonnese et al., 2012; Opitz et al., 2015; Bezen et al., 2016). In some cases, statements falling into two categories were provided by a single student. For the purposes of frequency counting, however, each student was assigned to a particular category based on their predominant view.

The responses were analysed separately by three researchers. Each categorised the responses into three categories, and the results were compared during a series of meetings. The results were compared and discussed to reach a shared agreement. The initial inter-rater agreement was 90% between researcher 1 and researcher 2, 93% between researcher 1 and researcher 3, and 89% between researcher 2 and researcher 3. Disagreements were resolved through iterative discussions among the researchers, leading to full consensus on the final coding and analysis.

6.5.2 The Self-Efficacy in Science Questionnaire

We developed a self-efficacy questionnaire (SSE – Self-Efficacy in Science) aimed at primary school pupils, drawing inspiration from previous studies conducted at various educational levels. In particular, items from the PISA questionnaire (OECD, 2019) and the IS-SEC-Q (Carroll et al., 2013) were examined and adapted. The PISA questionnaire was originally designed for Italian upper secondary school students, whilst the IS-SEC-Q was created for Irish primary school students.

In our study, the items from the PISA questionnaire were adapted to account for the age difference between our sample and the 15-year-old students for whom the PISA questionnaire is intended. The items from the IS-SEC-Q questionnaire were translated using the TRAPD method (Harkness et al., 2010). Two psychometric experts, native Italian speakers with excellent knowledge of English, carried out the translation from English into Italian.

The construction of the questionnaire was followed by a preliminary validation phase. Firstly, an ‘a priori’ analysis of students’ possible responses to the questionnaire items was conducted (Brousseau, 1997). To further strengthen the validity of the instrument, this analysis was carried out independently by two researchers. Subsequently, a consensus was reached through comparison and discussion, leading to the definition of a shared final version, optimised in line with the research objectives.

To further test the validity of the questionnaire and identify any issues related to the items, such as the use of ambiguous or unclear terms, a pilot study (Jensen, 2003) was conducted involving a fifth-grade class from the same school. Following this validation, two items that appeared unclear were removed.

Further information on the initial development of the SE-IS and the validations carried out is provided in Chapter 7.

The questionnaire consists of 53 items and is divided into five sections (A-B-C-D-E), each comprising several items: the first four consist of 5-point Likert scales and the final section

(E) consists of an 11-point Likert scale (from 0 to 10). The version of the SE-IS questionnaire used can be found in the Appendix (Annex A).

The questionnaire was specifically designed to assess the intensity of students' scientific self-efficacy (SSE) beliefs and their perception of exposure to the four sources of SSE (Bandura, 1997; Usher & Pajares, 2008). In its construction, the recommendations of Bandura (1997, 2006) were followed, according to which a measure of self-efficacy is effective only if it is appropriately contextualised with respect to the task, the domain and the specific context.

Based on the literature (Bandura, 1997; Bandura, 2006; Usher & Pajares, 2008; Carroll, 2024), we identified 11 factors or variables in our questionnaire (see Table 2), closely linked to the subdimensions of learning we intend to investigate. To calculate the score for each variable, the scores for the responses to the items comprising it were summed and then divided by the total number of items, thus yielding an average score for each participant.

Table 2. Variables in the questionnaire

	Variables
F1	Desire to learn and expand
F2	Growth mindset
F3	General academic self-efficacy
F4	Self-efficacy in specific knowledge – Life sciences
F5	Self-efficacy in specific knowledge – physics and chemistry
F6	Attitude towards science
F7	Experience of mastery
F8	Vicarious experience
F9	Verbal Persuasion
F10	Emotional State
F11	Specific Science Skills

For each of the variables, the mean scores, standard deviation and standard error were calculated and analysed. The mean scores of the pre- instruction and post- instruction of the self-efficacy questionnaire were also analysed for both males and females. Subsequently, a comparison was made between the data of the two gender groups. The final section (E) corresponds to variable 11 and was analysed separately from the previous variables. A t-test was also conducted, and Cohen's d was calculated.

This analysis made it possible to observe any statistically significant changes in the variables identified in the questionnaire between the first and second administrations.

6.6. Classroom teaching activities

The TLS, lasting a total of 12 hours, was divided into 7 sessions. During the first and last sessions, each lasting one hour, the self-efficacy questionnaire and the knowledge test were administered. The remaining 5 sessions lasted 2 hours each, during which the scientific content was presented and the experiments were carried out.
Table 3 briefly summarises the main activities.

Table 3. Teaching activities

Lesson	*Activity*	*Description*
1st	Introduction to the concept of energy	Brainstorming on energy. Activity carried out during circle time.
	Introduction to the difference between renewable and non-renewable energy.	The pupils look at pictures of various renewable energy sources and have to sort them into two separate groups. Activity carried out on the interactive whiteboard during circle time and led by the teacher.
	Viewing and discussion of the characteristics of renewable and non-renewable energy.	Viewing of a video on renewable and non-renewable energy. Guided discussion during circle time.
	Creation of a concept map on renewable and non-renewable energy.	Working in pairs, pupils create a mind map in their workbooks summarising the main characteristics of renewable and non-renewable energy sources.
	Reading and analysing food labels.	Analysis of nutritional values on food products and discussion of the meaning of the energy values shown. The activity is carried out in small groups using products brought in by the pupils.
	Verbal and written summary of the activities carried out.	During circle time, the pupils describe the activities carried out during the lesson and then write them down in their notebooks.
	Summary of the previous lesson.	The teacher asks the pupils to summarise the activities carried out in the previous lesson.
	Teacher-led discussion	During circle time, the teacher asks open-ended questions to encourage reflection on ‘human energy’.

2nd	Practical activity on kinetic energy: *The bicycle and the dynamo*	Experiment carried out in pairs. The pupils will try to understand how to power the dynamo using the bicycle. Each pair tests their hypotheses until one pupil spins the bicycle with their hands and the other places the light bulb on the wheel. The teacher asks the pupils to describe the phenomenon they have observed and to analyse its consequences.
	Verbal and graphical documentation of the activities carried out	During circle time, the pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Joint discussion to agree on a definition of kinetic energy.
3rd	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Practical activity on kinetic energy	The pupils are divided into small groups and each is given a small generator connected to an LED. They come up with different ways to light up the LED.
	Experiment: building *a water turbine*	Working in small groups, the pupils build a small, rudimentary water turbine, to which the LED used previously is connected.
	Practical activity on kinetic and potential energy: *the water turbine*	Working in groups, the students try to light the bulb by pouring water from different heights. The students note down what happens to the bulb depending on the height from which the water is poured.
	Guided discussion	During circle time, the teacher asks open-ended questions about the activity and highlights various concepts: obtaining energy from non-living sources (water and wind), the transformation of energy (from kinetic to light), and the concept of height.
	Verbal and written expression	During circle time, the pupils verbally describe the activities carried out during the lesson and then write them down in their exercise books.
	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Practical activity on kinetic energy	The teacher shows a toy turbine to demonstrate the fall of objects (sand, stones, balls) and introduce the concept of potential energy.

4th	Practical activity on potential energy: *sand and balls*	The pupils are divided into small groups. Each group is given a container with sand, several balls and a ruler. They have no instructions on how to use the tools. They write down their observations in their notebooks.
	Practical activity on potential energy: *toy cars*	The pupils are divided into small groups. Each group is given wooden boards of different lengths and two or more toy cars. They are not given any instructions on how to use the tools. They write down their observations in their notebooks.
	Guided discussion	The teacher asks the various groups to present their observations on the experiments carried out. The focus is on the different effects observed in the sand and the distance travelled by the toy car.
	Verbal and written expression	During circle time, the pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. The class agrees on a definition of potential energy.
5th	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Guided discussion on the concept of transformation and energy transformation	During circle time, the teacher asks open-ended questions that refer back to the experiments already carried out to focus attention on the concept of energy transformation.
	Practical activity on thermal energy: *The whisk and water*	Each pair is given a container of water and a whisk (non-electric). The pupils rotate the whisk in the water and reflect on the concept of kinetic energy.
	Practical activity on thermal energy: *the eraser and the desk*	The pupils rub a section of the desk with an eraser and use the thermal camera to observe the rise in temperature.
	Verbal and written expression	During circle time, the pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Group discussion to agree on a definition of thermal energy.

6.6.1 DAY 1

After an initial phase dedicated to getting to know the different classes, the teacher led a brainstorming session to initiate an initial guided discussion on energy. The activity allowed the topic to be introduced in a simple way, building on the pupils' existing knowledge and what they had often heard said about energy in various contexts (Nordine et al., 2011).

Common themes emerged across all classes: the pupils mentioned technological devices (such as phones, computers, televisions, fridges and tablets), as well as wind and solar energy. The latter are, in fact, examples well known to the pupils thanks to the common sight of solar panels and wind turbines.

Conversely, few children mentioned heat or fire. In one specific case, a pupil, at the end of the brainstorming session, stated that "In my opinion, all the words fit well, except for fire. I would take that one out".

In four out of five classes, concepts related to movement, the human body and sport emerged. In just one class, the word 'food' emerged; in two classes, the word 'sport' was linked solely to human movement. In no class did words emerge that linked energy to inanimate objects, except in the case of electrical objects or those explicitly manufactured to store and supply energy, such as batteries and fuels, but not electronic devices.

The data collected confirm what is found in the literature: particularly among younger students, anthropocentric and vitalistic conceptions prevail: energy is linked to life and movement, to the ability to perform work (Chen et al., 2014; Opitiz et al., 2015; Bezen et al., 2016).

In the second activity, the students were divided into small groups and observed a series of images projected onto the interactive whiteboard showing different energy sources. The groups worked independently to categorise the energy sources into two distinct groups.

Although many pupils stated that they had never heard of renewable and non-renewable energy, all were able to correctly categorise the images presented initially, placing power stations, oil and petrol in one group and solar panels and wind turbines in the other. Most pupils justified this choice by arguing that 'Renewable energies produce energy from natural sources. Non-renewable energy is man-made". However, the widespread use of the term 'produce' is evident. Indeed, the pupils repeatedly state that 'Energy is produced in all the images'.

Two short videos on renewable and non-renewable energy were then shown, which sparked a discussion on the environmental impact of these energy sources, their lifespan, and how readily available they are.

The final part of the lesson was devoted to exploring the link between food and energy (Millar, 2005; Nordine et al., 2011).

The pupils brought some food packets to the classroom, such as pasta, milk, biscuits, almonds and chocolate. Everyone readily linked ‘human energy’ with food: it seems clear to them that to have energy, one must eat.

The teacher asked thought-provoking questions, such as “Which do you think gives us more energy: 100g of pasta or 100g of milk?”, “If you and your teacher ate 100g of pasta, who would have more energy in the end?”.

Initially, almost all the pupils agreed that the ‘most energy-giving’ food was pasta or ‘energy drinks’. Furthermore, many stated that if a child and an adult ate the same amount of the same food, the child would get ‘more energy’.

A simple example is given to make the concept clearer: “If a child and a lion eat 100g of almonds, who will have more energy?”. The pupils immediately realise that the subject’s digestion is the key process. It is explained to them that the digestive process influences the transfer of energy from food to the body and therefore people can eat the same amount of food but have different body shapes due to differences in metabolism.

The students were divided into pairs and studied the nutritional labels on food products, discussing the meaning of the energy values shown. They found the activity interesting and were able to link it to the information they had studied on digestion.

6.6.2 DAY 2

The second session began by linking back to the previous activity on reading food labels. The teacher asked how we use the energy we get from food, sparking a discussion during circle time. Initially, the pupils’ answers were vague and general, such as “it helps us live”, “to do everything”, “to move”, and gradually became more specific, referring to examples from everyday life: walking, running, jumping, getting dressed, cycling, swimming, playing football, pushing, lifting things, etc.

The pupils were then asked to try and give a name to this form of energy. Among the most frequently suggested terms were: kinetic energy, bodily energy, human energy, sporting energy, vital energy, muscular energy. The explanations were as follows: “Vital because we need it to live”, “Muscular because we need muscles”, “Human because all humans have it”, “Movement because we are always moving”. The common thread of movement was ultimately found in all classes but was linked solely to humans and animals.

The transition from kinetic energy, which is unique to living beings, to inanimate objects was achieved through the bicycle experiment, carried out in small groups.

To carry out the activity, it was necessary to bring in a (children's) bicycle and a dynamo. The teacher turned the bicycle upside down in the centre of the classroom and explained how the light bulb works. The various groups were asked to try to hypothesise how to light the bulb using the bicycle. The pupils approach and try out various hypotheses, which initially fail. The pupils were, in fact, free to propose even 'unconventional' ideas and hypotheses, without any judgement or assessment of their scientific accuracy (Etkina et al., 2019). After several attempts, and with the help of the teacher's prompting questions, the pupils notice that the end of the dynamo consists of a small circular wheel. Realising this, many groups understood that it was necessary to rotate the wheel through the circular movement of the bicycle's wheels.

By dividing up the various tasks, all the students tried out the experiment: one pupil was tasked with holding the bicycle steady, another with turning the pedals, and the last with keeping the dynamo firmly pressed against the wheel.

The students discussed the activity at length, prompted by the teacher's guiding questions. They hypothesise that:

"My energy has passed into the wheel and now it's moving"
"I gave my energy to the bike and the dynamo"
"The dynamo lights up because the little wheel is turning"
"Some of the wheel's energy goes to the light bulb and becomes light energy"
"My energy hasn't been lost; it's gone into the bike and the bulb"
"The bike gets its energy from the child. The light bulb gets its energy from the bike"

The teacher assists the pupils and encourages the use of scientifically accurate terminology that focuses on the concept of energy transformation, thereby emphasising that the children's energy has not been lost but has simply changed form.

The pupils demonstrate that they have understood the experiment and the concept of energy transformation. They complete the lesson by writing down the activities carried out in their notebooks.

6.6.3 DAY 3

The third session begins with a brief summary of the previous lesson. The pupils describe the bicycle experiment and the dynamo: it is possible to note a more frequent use of terms such as 'transform' or 'transfer' by the students.

The teacher then shows a new dynamo, in this case a smaller one with a small LED attached to one end. The electric generator was originally designed as a teaching aid for generating wind energy, but during the activity it was also used to create a scientific model for generating hydroelectric energy. The small wind turbines, initially connected to one end, were removed to allow the pupils to reflect independently on the different ways in which light energy can be obtained.

The pupils put forward various hypotheses, many of which relate to the wind. They discuss wind energy and look at images on the interactive whiteboard of various wind turbines in Sicily.

Subsequently, the teacher asks them to suggest another way to light up the LED. After a few unsuccessful suggestions, the pupils propose water.

Working in cooperative learning groups, the pupils build a small, rudimentary water turbine. Small wooden sticks are glued into a plastic bottle cap, with small plastic caps attached to their ends. The LED used previously is connected behind the central cap.

The experiment is then carried out in pairs: one pupil holds the small water turbine whilst another pours water over the cap to set it in motion and thus generate light. Initially, however, the LED does not light up. The pupils discuss and reflect.

"Maybe it only lights up with the wind"

"Maybe we need more water"

"We need to pour the water harder"

The pupils try pouring the water in a steady stream, then create a lighter stream interspersed with short pauses. Finally, in the various classes, the pupils begin to understand that the water stream becomes stronger and stronger as the height from which the water is poured increases. In this way, they manage to light up the LED.

The pupils discuss the experiment they have just carried out, focusing their attention mainly on the height and the 'force' of the water. They say:

"The energy of the water is transferred to the blades and from there to the light bulb"

"The energy of the water becomes kinetic energy and then light energy",

"The bulb only lights up if the jet is strong enough and if I pour the water from a height."

The teacher invites the pupils to reflect on the transformation of energy and suggests scientific terms to use. Furthermore, the pupils argue that "As you go lower and lower, the energy decreases". The teacher asks them to reflect on this statement, trying to imagine what will happen as the height is reduced further and further. The pupils conclude the lesson by stating that "Energy also depends on height" and that "This energy becomes 0 when h=0". Finally, the pupils write down the activities they have carried out in their notebooks.

6.6.4 DAY 4

The teacher asks the pupils to summarise the experiments carried out, focusing particularly on the transformation of energy. In particular, they are asked to describe the relationship between height and energy that they observed in the water turbine experiment.

It is clear to all pupils that height is a determining factor and strongly linked to energy: the greater the height, the greater the energy. On this basis, two experiments focusing on potential energy are carried out.

To confirm this, the teacher shows a toy turbine and some sand. He asks the pupils to try pouring the sand onto the turbine, as they did with the water in the previous experiment. Initially, the children pour the sand from a lower height and subsequently from a greater height. In this way, they were able to visually observe how the speed of the falling sand and the speed at which the small turbine rotated varied.

Next, the pupils are divided into small groups. Each group must carry out two different experiments, divided between two stations. In the first experiment, they are given a container with sand and small balls. They are not given any instructions on how to use the materials. They carry out several trials and note down their observations. When the time is up, each group moves to the second station, where they find wooden boards of different lengths and two or more toy cars. They are not given any instructions on how to use the equipment. They carry out several trials and note down their observations. At the end of the time, each group presents their notes and hypotheses to the whole class.

In the first experiment, involving sand and balls, the pupils achieved some interesting results. Most of them quickly grasped how to use the materials provided, demonstrating manual dexterity and creativity. The pupils dropped the balls from different heights, noting the holes they made in the sand. The hole left by these objects in the container was associated with their energy; consequently, greater depth indicated greater energy (Colonnese et al., 2012). Almost all the groups spontaneously stated that this type of energy is strongly linked to the height from which the objects are dropped.

The second experiment, involving toy cars, proved more complicated. Many students did not understand how to use the materials provided: some groups laid the wooden boards horizontally on the floor, others placed them between two tables to create a U-shaped ramp (half-pipe), and others placed them side by side against the classroom wall. Only a few pupils observed the different distances travelled by the toy cars depending on the point from which they were set in motion.

In this second experiment, the teacher had to intervene; through prompting questions and observations, they helped the pupils to focus on the crucial aspects.

In the final discussion, the pupils discussed and formulated hypotheses about the energy associated with falling objects, which they initially referred to as 'falling energy' or 'gravitational energy'. Everyone agreed that it depends on one main factor: height.

The session concluded with the scientific term (potential energy) and with the students recording the activities carried out in their notebooks.

6.6.5 DAY 5

The lesson begins with a summary of the experiments carried out. In particular, the teacher draws attention to the different forms of energy transformation, asking questions such as: "Where did the energy from the bicycle go?" or "Is the energy we obtain from food lost?".

The pupils answered in the affirmative, demonstrating that they had understood that, in the examples explored, energy is not lost but transformed. For example, they stated: "The energy from the bicycle's wheels became light energy" or "The energy from the water was not lost; it went into the light bulb".

The teacher asks the same questions after showing a container of water and a hand-held whisk, used to stir the water. The pupils discuss actively and exchange ideas to hypothesise what happens to what they call the 'kinetic energy of the whisk'. The most common hypothesis in the classes is that it simply disappears or 'dissolves' into the water. Subsequently, attention turns to the temperature of the water and how it might change during the experiment. Most students argue that it will remain unchanged, whilst some suggest that it will increase.

The teacher demonstrates and explains how a thermal imaging camera works – provided by the University of Palermo – which allows the temperature of living beings, objects and liquids to be measured. The pupils are immediately fascinated by the instrument and are given the chance to use it in pairs. One of the two children uses the whisk to stir the water in the container, whilst their partner measures the water's temperature before, during and after. In this way, they can observe the change in the water's temperature, which rises slightly.

The pupils explain this phenomenon with various hypotheses:
“It’s gone up because of the whisk”
“It’s gone up because the whisk makes the water move”
“The kinetic energy of the whisk went into the water.”

This last statement (and others like it) were used by the teacher as a starting point to explain the energy transformation the pupils had witnessed and to discuss thermal energy.

A further small experiment (the eraser and the desk) is carried out to further reinforce the concept of the conversion of kinetic energy into thermal energy. The pupils must use the thermal imaging camera to measure the change in the desk’s temperature after rubbing an eraser on it. Unlike the previous experiment (carried out with a liquid), in this case the measurement is taken on a solid object, so the temperature change is greater and easily perceptible even just by touching it with the hands. This immediacy was very useful for the pupils, who were able to observe the transformation taking place more easily.

After recording the activities carried out, the teacher asked the pupils to describe what they had learnt about energy during the lessons: most of their comments focused on transformation and the different states of energy, demonstrating a clear and solid understanding of the fundamental concepts.

6.7 Results

We administered the knowledge questionnaire and the first version of the SE-IS questionnaire (Appendix A) to the students as pre- instruction and post- instruction. In this first phase, we present the results obtained through the phenomenographic analysis of the knowledge questionnaire. The aim is to assess the level of prior knowledge about energy and how this has changed at the end of the TLS.

6.7.1 Results of the knowledge questionnaire

We summarise here the data obtained from the pre- instruction on knowledge administered to the 75 students who attended the TLS described above.

In the pre- instruction, the vast majority of responses were classified as common knowledge. There were few unanswered questions, with the exception of questions 4, 6 and 8, where the percentage of unanswered responses was higher. No responses were classified as scientific knowledge, with the exception of a small percentage of responses to question 7 (see Figure 1).

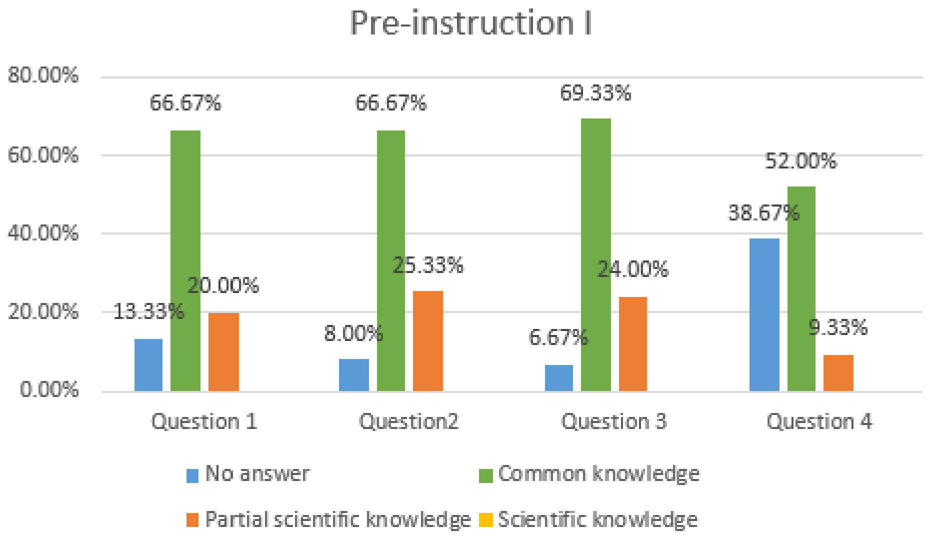

Fig. 1 Pre-instruction results I

Question 1. What do you know about energy? In the pre- instruction, almost 70% of the answers were classified as common knowledge. Energy was, in fact, described using definitions linked to: everyday life (15 answers) such as ‘it allows us to live’, ‘it is a force within us’, ‘it is indispensable’; to technological objects/electricity (25 responses) such as “we need it to provide light”, “it is a source of electricity”, “it enables cars to run”; to movement (10 responses), such as “it is needed to make the body move”. The answers classified as partially scientific knowledge refer to the different forms of energy (9 responses), such as “I know there are many types of energy”, and to certain definitions of energy (6 responses) that were not sufficiently substantiated, such as “it is the ability of a body to perform work” and “energy is neither created nor destroyed”. Ten pupils did not answer question 1.

Question 2. As far as you know, are there things that produce energy? In the pre-instruction, among the answers categorised as common knowledge, pupils referred largely to food (29 answers), followed by technological devices/electricity (16 answers) such as ‘Wi-Fi’, ‘the telephone’, ‘electricity’, natural elements (4 responses), such as water, wind and the sun, and, finally, combustible materials (4 responses) such as wood and oil. In the responses categorised as partially scientific knowledge (around 25%), pupils mentioned devices and infrastructure for energy production (19 responses), such as solar panels/wind turbines and various types of power stations. Six pupils did not answer question 2.

Question 3. As far as you know, are there things that have or possess energy? In the pre-instruction, in the answers classified as common knowledge (around 70%), pupils stated that things that have energy are mostly technological objects/electricity (32 answers), such as “PlayStation”, “the phone”, ‘the tablet’, followed by natural elements (10 responses), such as ‘sunlight’, ‘lightning’, food (8 responses), understood as ‘nutrients that give us energy to do things’, and finally living beings (5 responses). In the responses classified as partially scientific knowledge (24%), pupils mentioned devices and infrastructure for energy production (14 responses), such as solar panels, wind turbines and various types of power stations, as well as certain ‘types’ of energy (5 responses), such as ‘solar energy’ or ‘wind energy’. Five pupils did not answer question 3.

Question 4. Can energy be conserved? In the pre-instruction, in the answers classified as common knowledge (around 52%), pupils responded by referring to the literal meaning of conservation, i.e. setting aside for future use (30 answers), such as “Conserving energy means you don’t use energy for a while so you can use it later” and “in my opinion, conserving means it shouldn’t be wasted”; they also frequently referred to the storage of energy in technological devices (9 responses), such as “it means we put it in batteries and use it later” and “for example, when you charge your phone”. In the responses classified as partially scientific knowledge, pupils spoke of devices and infrastructure for energy production (7 responses), such as “energy is stored in solar panels and then used when we need it”. Twenty-nine pupils (approximately 39%) did not answer the question.

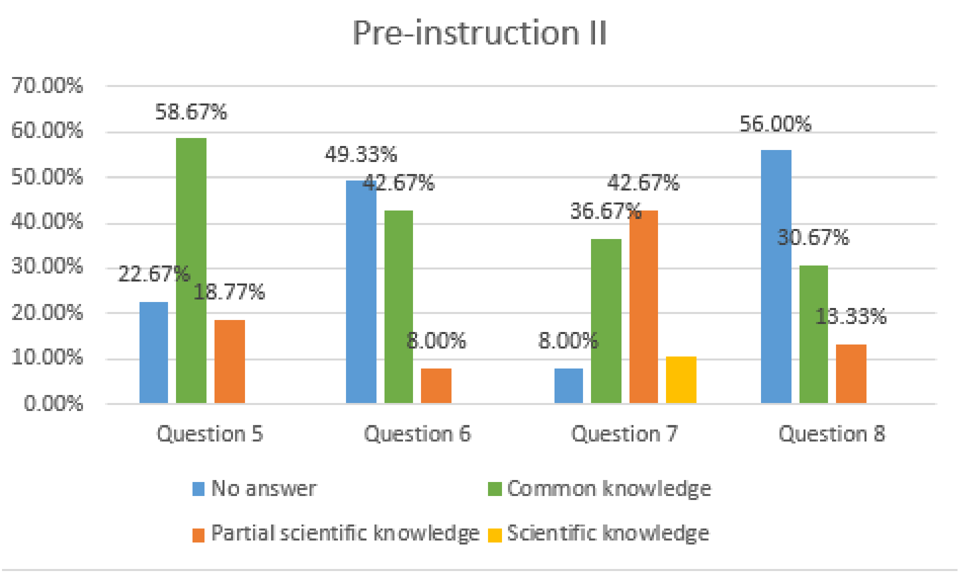

Fig. 2. Pre-instruction II results

Question 5. Can energy be transformed? Explain, giving some examples. In the pre-instruction, among the answers classified as common knowledge, pupils referred to food (25 answers), such as “Food is transformed into energy”, to technological objects (13 answers), such as “Energy can be transformed into light”, “it is transformed via a battery charger”, to natural elements (6 responses), such as “The sun or wind become energy”, and to examples from everyday life (6 responses), such as “it can be transformed into mental energy” or “when we sleep we can transform our energy”. Answers classified as partially scientific knowledge account for around 19% and refer to devices and infrastructure for energy production (14 responses), such as “energy from solar panels is transformed into light” or “energy is transformed in power stations”. Seventeen students answered question 5.

Question 6. Is it possible to lose energy? Explain, giving some examples. In the pre-instruction, in the answers classified as common knowledge, pupils linked the concept of ‘losing energy’ to the waste and consumption of electricity (16 responses), such as ‘energy is lost if we leave the lights on for too long’, and to the body and movement (16 responses), such as ‘if I get very tired, it means I’ve lost energy’ and ‘for example, when I play five-a-side football, I lose energy’. In the answers classified as partially scientific knowledge, the students answered the first part of the question in the affirmative but did not provide any reasoning (6 answers), such as “energy is never lost”. Around half of the students did not answer.

Question 7. What ‘types’ of energy do you know? In the pre- instruction, in the answers classified as common knowledge, pupils cited examples of forms of electrical energy (14 answers), such as “technological energy”, “gas energy”, “telephone energy”, human energy (12 answers), such as “body energy”, and energy associated with natural elements (6 answers), such as “energy from the sun/water/wind”. In the answers classified as partially scientific knowledge, the pupils listed various forms of energy: static energy (9 answers), electrical energy (9 answers), hydroelectric energy (8 answers), solar energy (8 answers), wind energy (7 answers). In the answers classified as scientific knowledge, all pupils mentioned kinetic energy (8 answers). Six pupils did not answer.

Question 8. What is the difference between renewable and non-renewable energy sources? In the pre- instruction, most of the responses (42 answers) were either not provided or stated “I don’t know”. In the answers classified as common knowledge, pupils referred to the literal meaning (22 answers) of the two terms, for example, “renewable ones can be replenished and non-renewable ones cannot” and “renewable energy can be renewed and non-renewable energy cannot". Among the answers classified as partially scientific knowledge, pupils responded by citing examples of different energy sources (10 answers), such as "The sun is renewable energy, oil is non-renewable energy", and by discussing the use or non-use of sources (7 answers), such as "non-renewable energy sources cannot be reused".

In the post-instruction, most answers were classified as partially scientific knowledge and scientific knowledge. There were few unanswered questions.

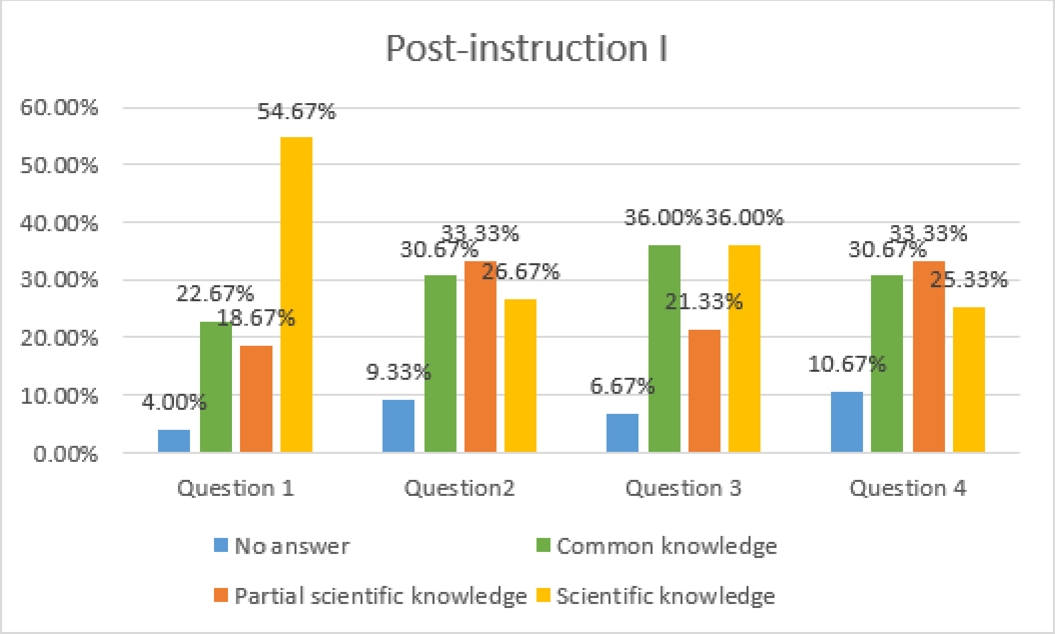

Fig. 3 Post- instruction results on knowledge I

Question 1. What do you know about energy? In the post- instruction, among the answers classified as common knowledge, energy was described using definitions related to: everyday life (10 answers), movement (4 answers), such as "energy allows us to move", and technological objects/electricity (3 answers). The answers classified as partially scientific knowledge refer to the difference between renewable and non-renewable energy sources (12 answers) and the existence of nuclear power stations (2 answers). Answers classified as scientific knowledge account for just over half, and in these energy was described as a quantity that transforms (21 answers), as "energy cannot be seen or touched, but it is everywhere and can be perceived through a transformation", and as a quantity that takes different forms (20 answers), such as "I know that energy can be kinetic, wind, potential, etc.". Three pupils did not answer the first question.

Question 2. As far as you know, are there things that produce energy? In the post- instruction, in the answers classified as common knowledge, pupils referred to food (15 responses), natural elements (6 responses), such as the sun, wind, water and fossil fuels (4 responses), and technological objects/electricity (2 responses). In the answers categorised as partially scientific knowledge, the pupils mentioned devices and infrastructure for energy production (27 answers), such as “wind turbines produce energy thanks to the wind”. In the answers classified as scientific knowledge, all pupils gave examples explored during the course (20 answers), such as falling objects, movement and heat. Seven pupils did not answer the question.

Question 3. As far as you know, are there things that have or possess energy? In the post-instruction, in the answers classified as common knowledge, pupils stated that things that have energy are living beings (5 answers), such as people or animals, food (10 answers), such as “if you eat a plate of pasta, you have lots of energy to move around and do things”, technological objects/electricity (5 responses) and natural elements (7 responses), such as the sun, wind and water, as in “the sun produces energy for homes”. In the responses categorised as partially scientific knowledge, pupils spoke of devices and infrastructure for energy production (18 responses), such as wind turbines, solar panels and power stations/thermoelectric plants. In the responses classified as scientific knowledge, the pupils described the examples covered during the course (20 responses), such as falling objects, height, the windmill and the bicycle, and attributed energy to all systems and all bodies (7 responses), for example, “everything has energy because energy can be transferred”. Five pupils did not respond.

Question 4. Can energy be conserved? In the post- instruction, in the answers classified as common knowledge, pupils responded by referring to the literal meaning of the term ‘conserve’, talking about setting aside for future use (6 answers), storing energy in one’s own body (10 answers), as an energy reserve, for example ‘our body sets aside a bit of energy’, and the prevention of electrical dissipation (6 answers). In the answers classified as partially scientific knowledge (around 33%), pupils stated that energy can be conserved but did not provide any further reasoning (4 answers), spoke of transmission (4 answers), through the use of devices and infrastructure for energy production (5 answers), and described examples explored in the course (15 answers). The latter were categorised as such because the language used is often unclear and imprecise, for example, “if we hit a slab with a hammer, the energy remains in the slab”. In the responses categorised as scientific knowledge, the pupils defined the conservation of energy as transformation (7) and through examples explored in the course (15), such as “in the bicycle experiment we saw that the energy of the wheels is conserved and transformed into light energy". Eight pupils did not respond.

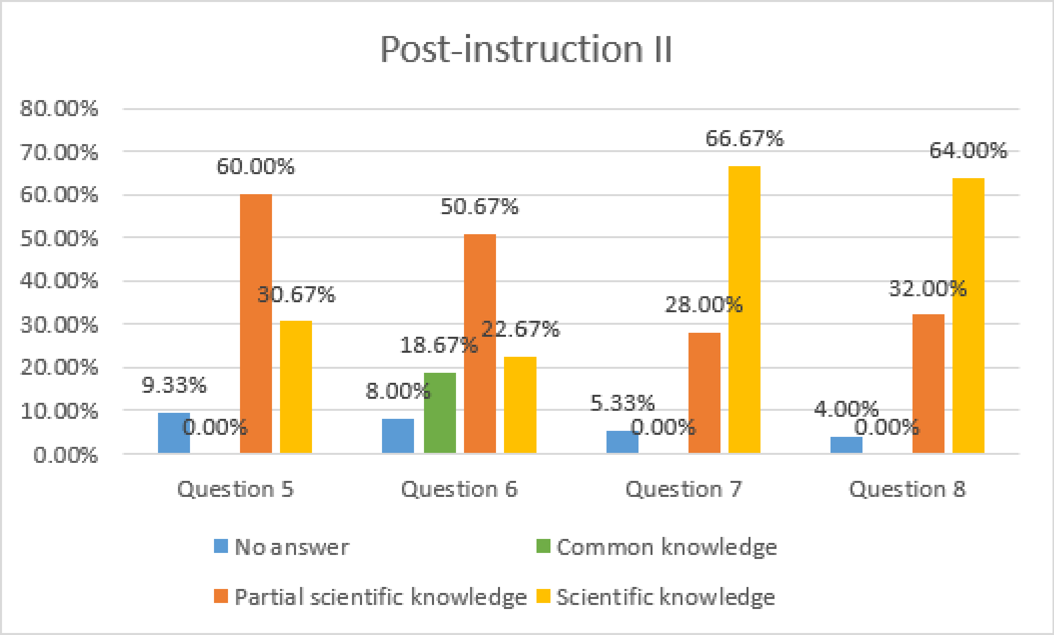

Fig. 4 Post- instruction results on knowledge II

Question 5. Can energy be transformed? Explain, giving some examples. In the post instruction, 7 pupils did not answer the question. The remaining pupils stated that energy can be transformed and justified their answers by referring to the experiments conducted in class. In particular, 45 responses (60%) were classified as partially scientific knowledge and the remaining 22 as scientific knowledge. The criteria used for this classification are a) the use of scientific language and b) precision and accuracy in the description of the phenomenon(s). In the first group, we find answers such as "If we turn the wheel with our hands, we transfer our energy into kinetic energy"; in the second group, we find answers such as "For example, the bicycle experiment, which involved turning the bike's wheel by pushing it with our arms, and in doing so our kinetic energy was transformed into rotational kinetic energy. We then also tried placing a dynamo torch on the wheel, and realised that our kinetic energy was converted into the rotational kinetic energy of the bicycle, which in turn was converted into the light energy of the dynamo torch".

Question 6. Is it possible to lose energy? Explain, giving some examples. In the post-instruction, among the answers classified as common knowledge, four pupils answered in the negative and the rest stated that energy can be lost due to movement (12 answers). Among the answers classified as partially scientific knowledge, pupils answered in the affirmative without providing explanations (4 answers) and referred to experiments carried out during the course (32 answers). In the answers classified as scientific knowledge, pupils responded by discussing energy transformation (7 answers) and citing the experiments carried out during the course (11 answers). The criteria for classifying the answers are the same as those used previously. Six pupils did not answer.

Question 7. What ‘types’ of energy do you know? In the post- instruction, there were no answers classified as common knowledge. All students, with the exception of the four who did not answer the question, cited types of energy discussed during the course (kinetic, potential, thermal, light, solar and wind energy). Among the answers classified as partially scientific knowledge, in addition to the examples mentioned above, there are also types such as static energy (8 answers), electrical energy (7 answers) and dynamic energy (4 answers).

Question 8. What is the difference between renewable and non-renewable energy sources? In the post- instruction, there are no answers classified as common knowledge. Among the answers classified as partially scientific knowledge, pupils described various examples of energy sources (8 answers), such as “Renewable energy is, for example, wind or solar energy; non-renewable energy uses oil and coal”, and referred to the possibility of using or not reusing them (16 answers), such as “non-renewable energy can run out” or “Renewable energy can be reused”. Finally, among the answers classified as scientific knowledge (64%), pupils explained the difference between renewable and non-renewable sources by focusing on the limitations of the sources (19 answers), in particular highlighting the dangers associated with pollution, and on the advantages of the sources (17 answers), and on the contrast between natural and artificial sources (10).

6.7.2 Results of the Self-Efficacy in Science (SE-IS) questionnaire

We present the pre-instruction and post-instruction data for female and male pupils in the self-efficacy questionnaire, comparing the data between the two genders, analysed using descriptive statistics.

Table 4 shows the mean, standard deviation, p-value and Cohen’s d resulting from the comparison between the responses of female and male students in the pre-instruction.

Table 4. Pre- instruction: comparison between boys (ma) and girls (fe)

	Pre- instruction mean ma	Std. dev. pre ma	Mean PRE fe	Standard deviation pre fe	p-value	Cohen's d
F1	3.940	0.447	4.006	0.480	0.544	0.142
F2	3.825	0.510	3.410	0.671	**0.003**	**0.697
F3	3.913	0.447	3.650	0.648	**0.049**	*0.471
F4	4.169	0.469	4.043	0.583	0.311	*0.238
F5	3.731	0.458	3.295	0.632	**0.001**	**0.788
F6	4.061	0.548	3.861	0.678	0.163	*0.324
F7	3,771	0.608	3.457	0.671	**0.037**	**0.500
F8	4,200	0.806	4,200	0.714	1,000	0.000
F9	3,738	0.608	3,386	0.686	**0.021**	**0.543
F10	2,150	0.900	3,200	0.566	**0.000**	**1,397**
F11	7,425	0.0471	7,544	1,050	0.646	0.106

Notes: Significant p-values (p ≤ 0.05) are shown in bold.

_***d_ 0.80–1.19 _large_; _**d 0._50–0.79 medium, _*d_ 0.20–0.49 small, _d very small_

From the independent t-test analysis, statistically significant differences emerged between males and females in the pre-instruction phase (see Table 4). In particular, prior to the TLS, boys showed significantly higher mean scores in F2 (Growth Mindset), F3 (General Academic Self-Efficacy), F5 (Knowledge-specific SSE: Physical/Chemical Sciences), F7 (Mastery Experience) and F9 (Verbal Persuasion) compared to girls. Conversely, girls reported higher levels in F10 (Emotional State) than their male peers, demonstrating greater anxiety towards science than boys, as also reported in the literature (Toma et al, 2019; Master, 2021).

We found p-values lower than 5% for F2, F3, F5, F7, and F9, and a p-value lower than 1% for V10. A very strong Cohen's d effect size was found in V10.

No significant differences were observed between boys and girls for F1 (Desire to Learn), F4 (Knowledge-specific SSE: Life Sciences), F6 (Attitude towards Science) and F8 (Vicarious Experience).

Table 5. Male pupils: comparison between pre- and post-instruction

	Mean PRE ma	Std. dev. Pre mean	Mean POST ma	Standard deviation Post ma	p-value	Cohen's d
F1	3.940	0.447	3.920	0.480	0.857	*0.043
F2	3.825	0.510	3.800	0.600	0.851	*0.045
F3	3,913	0.447	3.850	0.500	0.568	0.132
F4	4,169	0.469	4,113	0.520	0.600	0.114
F5	3.731	0.458	3,889	0.316	0.071	*0.402
F6	4.061	0.548	4.189	0.387	0.177	*0.271

F7	3.771	0.608	3.886	0.316	0.303	*0.236
F8	4,200	0.806	4,300	0.648	0.472	0.137
F9	3,738	0.608	3,650	0.608	0.480	0.144
F10	2,150	0.900	2,100	0.714	0.790	0.062
F11	7,425	0.0471	7,861	0.687	**0.007**	*0.451

Notes: Significant p-values (p ≤ 0.05) are shown in bold.

***d 0.80–1.19 *large*; **d 0.50–0.79 medium, *d 0.20–0.49 small, *d very small*

Through the dependent t-test analysis, statistically significant variations between the pre- and post-evaluations of male pupils (see Table 5) were found only in F11 (Skills-related school SSE). In the other 10 variables, male pupils maintained an equivalent average score in both evaluations. In general, both before and after instruction, males reported satisfactory levels in all variables, with the exception of F10 (Emotional State), where a lower score was observed, indicating lower anxiety and stress related to science.

Table 6. Female pupils: comparison between pre- and post-instruction

	Pre-instruction mean fe	Std. dev. Pre fe	Mean POST fe	Post-fe standard deviation	p-value	Cohen's d
F1	4.006	0.480	4.200	0.480	0.097	*0.405
F2	3,410	0.671	3,562	0.748	0.274	*0.214
F3	3.650	0.648	3.843	0.520	0.187	*0.328
F4	4.043	0.583	4.107	0.548	0.658	0.114
F5	3.295	0.632	3,756	0.469	**0.001**	***0.827
F6	3.861	0.678	4.188	0.566	**0.010**	**0.523
F7	3.457	0.671	3.792	0.616	**0.008**	**0.520
F8	4,200	0.714	4.429	0.600	0.118	*0.347
F9	3,386	0.686	3.586	0.781	0.213	*0.272
F10	3,200	0.566	2,586	0.894	**0.001**	***0.821
F11	7,544	1.050	7.857	1,182	0.208	*0.280

Notes: Significant p-values (p ≤ 0.05) are shown in bold.

***d 0.80–1.19 *large*; **d 0.50–0.79 medium, *d 0.20–0.49 small, *d very small*

For the female pupils, the dependent t-test revealed statistically significant differences between pre- and post-instruction (see Table 6) in F5 (Knowledge-specific SSE: physics and chemistry), V6 (Attitudes towards science), F7 (Mastery Experience) and F10 (Emotional State). According to Cohen's d, the most pronounced variations among these are F5 and F10. In both the pre- and post- instruction, female students reported high average scores in V1 (Desire to Learn and Extend), F4 (Knowledge-specific SSE: Life Sciences), and F8

(Vicarious Experience). In the pre-instruction phase, they demonstrated higher levels of self-efficacy in life sciences compared to physics/chemistry. In the post-instruction phase, the differences between F4 (Knowledge-specific SSE: Life Sciences) and F5 (Knowledge-specific SSE: Physics/Chemistry) have decreased.

Table 7. Post-instruction: comparison between boys (ma) and girls (fe)

	POST mean ma	Post-instruction standard deviation for ma	POST mean fe	Post-fe standard deviation	p-value	Cohen's d
F1	3.920	0.480	4.200	0.480	**0.014**	**0.584
F2	3,800	0.600	3.562	0.748	0.132	*0.351
F3	3.850	0.500	3.843	0.520	0.952	0.014
F4	4,113	0.520	4.107	0.548	0.965	0.010
F5	3.889	0.316	3,756	0.469	0.154	*0.333
F6	4.189	0.387	4.188	0.566	0.989	0.003
F7	3.886	0.316	3,792	0.616	0.407	0.192
F8	4,300	0.648	4,429	0.600	0.381	*0.206
F9	3,650	0.608	3.586	0.781	0.691	0.092
F10	2,100	0.714	2,586	0.894	**0.011**	**0.600
F11	7,861	0.687	7,857	1,182	0.929	0.020

Notes: Significant p-values ($p \leq 0.05$) are shown in bold.

****d* 0.80–1.19 *large*; ***d 0.*50–0.79 medium, **d* 0.20–0.49 small, *d very small*

From a comparison between the post-instruction scores of males and females (see Table 6), we found a p-value lower than 5% in V1 and a p-value lower than 1% in V10. The effect size of Cohen's d is medium in both variables. There are no longer significant differences between males and females in F2 (Growth Mindset), F5 (Knowledge-specific SSE), F7 (Mastery Experience) and F9 (Verbal Persuasion). Moreover, whilst in the pre-evaluation the scores of boys and girls in F1 (Desire to learn and extend) were similar, in the post-evaluation, girls reported a higher level than their male peers. As indicated by the p-value (<0.011) and Cohen's d (0.600), significant differences between boys and girls remain in the post-instruction phase in F10 (Emotional State); however, examination of the data reveals a reduction in the gap between the two groups. Additionally, female students showed a greater decrease in anxiety and stress towards science compared to their male peers.

With regard to F10 (Emotional State), gender differences persist in the post-instruction phase, albeit with a reduced gap compared to the initial situation. In other words, girls continue to display higher levels of anxiety than boys, but to a lesser extent than before the TLS.

Thus, by the end of the TLS, girls reported significant improvements in all these variables. Conversely, for F10 (Emotional State), a lower average score was observed in the post-instruction, indicating that the girls' levels of anxiety had decreased.

6.8 Discussion of results: knowledge questionnaire

One of the main objectives of this pilot study was to analyse what common knowledge primary school pupils demonstrate regarding energy (RQ1).

Most of the answers given before the TLS were classified as common knowledge, as they are based on everyday life experiences and on what children have the opportunity to observe. The data collected confirm the findings reported in the literature (Brook & Wells, 1988; Boyes & Stanisstreet, 1990; Millar, 2005; Nordine et al., 2011; Chen et al., 2014).

Analysis of the students' responses indicates that energy is conceptualised as something — an almost material substance — that can be possessed exclusively by living beings and is therefore closely associated with life and movement (Nordine et al., 2011; Millar, 2005). Furthermore, significant confusion with electricity emerged (Chen et al., 2014). On the one hand, students' responses highlighted the idea that energy can only be possessed by living beings and is therefore inextricably linked to food (which provides energy) and movement (as evidence that someone 'possesses or produces' energy). On the other hand, energy was often confused with electricity (Millar, 2005). Thus, smartphones, tablets, computers and technological devices were regarded as objects capable of producing, storing or transforming energy. Energy was seen as 'something that gives life or strength', a quality rather than a quantity (Trumper, 1990).

Based on their everyday experiences, some students referred to solar, wind and hydroelectric power as sources that provide energy. As previously noted in the literature (Shepardson et al., Zyadin et al., 2012), students possess basic but fragmented and incomplete knowledge of renewable and non-renewable energy. In particular, they distinguished 'clean and natural sources that regenerate' from those that 'pollute and do not regenerate'. According to some studies, this information comes from the media, advertising and cartoons, which are often rich in references to new energy sources (Evans et al., 2007).

Among the most difficult concepts for students were energy saving and energy loss. In particular, it emerged that most of them interpreted energy conservation as energy saving, contrary to the physical principle (Boyes & Stanisstreet, 1990). Students imagined energy as a substance that ‘is consumed’ and can be ‘put aside’ (Trumper, 1990). Similarly, the concept of ‘energy loss’ was often understood in an everyday or bodily sense, rather than a physical one. Students tended to conceive of energy as something that ‘is used and lost’ and can therefore disappear after use (Duit & Treagust, 1998).

With regard to RQ2, we analysed students’ responses following the TLS to understand how it altered students’ common conceptions and supported the development of the concept of energy. Whilst in the pre- instruction most responses were classified as common knowledge or not given, in the post- instruction most were classified as partially scientific or scientific knowledge.

A significant change is evident; in particular, students’ ideas became more clearly defined, thanks to the greater richness of responses in the post- instruction compared to the pre-instruction. The results, therefore, showed a significant improvement in students’ understanding of the concept of energy.

By the end of the TLS, around 70% of students described energy in a manner consistent with the scientific perspective, no longer relying exclusively on examples from everyday life. Operational definitions of energy emerged, primarily linked to its properties (transformation, conservation, abstract nature) and to the various forms of energy explored during the course. The pupils distinguished energy more clearly from electricity; technological devices such as smartphones and computers were no longer considered ‘energy producers’. Above all, the students argued that all systems possess energy—not just living beings—and also cited examples involving inanimate objects such as bicycles, stones and balls.

Some students, even in the post- instruction, described energy in terms of ‘production’ and emphasised the movement-energy association, but the number of such responses had fallen sharply.

The students consistently explained the concept of energy transformation, making particular reference to the activities carried out and describing the experiments in detail. Not all pupils, however, managed to correctly link energy transformation to the concept of energy conservation. This finding is not surprising, as reported in Colonnese (2012), since the idea of energy conservation was mentioned but not explored in depth. It is, however, interesting to note a shift in the pupils’ ideas towards the notion of the transformation and transfer of constant (non-dispersed) and indefinite properties. The understanding that energy cannot be lost, but only transformed and transferred, was another important perspective competently expressed by 60% of pupils in the post- instruction, compared to 80% who were confused or held the opposite view prior to the TLS, as noted, for example, in Colonnese (2012).

In the pre-instruction, answers classified as scientific knowledge were almost entirely absent, with the exception of question 7 ('What "types" of energy do you know?'), where a small percentage of students answered correctly by mentioning solar, wind and hydroelectric energy. It is worth noting, however, that although correct, the answers refer only to certain types of energy, completely excluding others, such as kinetic, thermal and potential energy. These terms appear to be unfamiliar to the students. In the post- instruction, all students correctly listed the types of energy explored in class. Some, in addition to these, mentioned types of energy not covered in the course (static energy, kinetic energy, etc.).

We can therefore conclude that the pre- instruction analysis of knowledge revealed a homogeneous group of students with a prevalence of common ideas and theories about energy, linked to everyday life, the human body and electricity. The results obtained are consistent with those found in the literature, as the responses referred to the students' daily lives, highlighting aspects characteristic of common knowledge about energy. In contrast, the post- instruction responses are mostly classified as scientific or partially scientific knowledge. The pupils provided detailed descriptions of the experiments carried out in class, demonstrating that they had understood the meaning and not merely memorised the content. The designed TLS facilitated the transition from common knowledge to scientific knowledge of the concept of energy for the majority of the students involved, highlighting the effectiveness of the methodology used.

6.9 Discussion of results: Science Self-Efficacy (SE-IS) questionnaire

The analysis and comparison of the pre- instruction and post-instruction data from the pupils in the SSE questionnaire enabled us to answer the third research question (RQ3).

The data from both administrations allow us to outline a sufficiently positive picture of the level of perceived scientific self-efficacy: the highest scores among students were obtained in specific scientific self-efficacy – life sciences, attitude towards science, vicarious experience and specific science skills.

Analysis of these results allows us to conclude that a short-term learning support programme (TLS) delivered using an active teaching-learning methodology did not produce a significant change in the SSE of the male students in our sample. Both before and after the TLS, the boys had already demonstrated satisfactory levels in key areas such as the desire to learn, a growth mindset and positive attitudes towards science. This high initial performance likely limited the potential for further growth, a phenomenon commonly known as the ceiling effect, in which individuals who start with high scores have less scope to show measurable improvements (Cotter, 2001). Therefore, we expected to obtain similar data.

Following the TLS, the female students achieved higher average scores across several variables: a significant improvement was reported in F5 (Self-efficacy in specific knowledge: physics/chemistry), F6 (Attitude towards science) and F7 (Mastery Experience). With regard to F10 (Emotional State), the average score obtained in the post- instruction decreased, confirming that the girls experience less anxiety and stress regarding science at the end of the TLS.

The activities proposed during the programme therefore fostered a positive approach to the subject, promoting confidence in their scientific abilities and leading to an improvement in scientific self-efficacy among primary school pupils.

This suggests that the short-term TLS, conducted using an active methodology, had a positive emotional effect, contributing to the creation of a more reassuring and inclusive learning environment for the female pupils, even if it did not completely eliminate the gap in perceived self-efficacy between the two groups. Unlike boys, girls, who start with lower scores in various areas, may have been more open or receptive to change.

When comparing the results obtained in the SE-IS questionnaire, statistically significant differences emerged between male and female students in various variables in the pre-instruction; in the post- instruction, no statistically significant differences were found between males and females in variables F2 (Growth Mindset), F5 (Self-efficacy in specific knowledge: physics/chemistry), F7 (Mastery Experience) and F9 (Verbal Persuasion). Statistically significant differences remain in V1 (Desire to learn and expand) and F10 (Emotional State).

The most striking results were found in the pre- instruction and post- instruction comparison of female students; the latter achieved higher average scores comparable to those of their male peers, and although statistically significant differences persist in F10 (Emotional State), we can nevertheless observe a narrowing of the gap between the two values. In other words, girls continue to show higher levels of anxiety than boys, but to a lesser extent than before the TLS.

6.10 Conclusion

The pilot study played a key role in the preliminary evaluation of the designed TLS, providing important insights both in terms of educational effectiveness and regarding the validity and functionality of the assessment tools used.

The data collected via the scientific self-efficacy questionnaire and the knowledge questionnaire enabled us to paint a clear picture of the students' initial conceptions, their beliefs regarding efficacy, and the changes that had taken place by the end of the course.

Prior to the TLS, students predominantly held common-sense knowledge about energy: their initial responses were linked to bodily perception and consequently described energy as a material substance, associated with movement, food and living beings (Millar, 2005). Furthermore, there was clear confusion regarding the concept of electricity: various technological objects were identified as capable of producing or losing energy. Finally, the language used was not scientifically accurate: students spoke of kinetic energy, wind energy, energy production and energy waste.

At the end of the TLS, the results show an improvement in students' understanding of energy: they demonstrated a greater grasp of the most significant aspects and a good ability to use scientifically appropriate language. Most of them had abandoned their initial ideas and typical misconceptions (Optiz et al., 2015; Ölçer, 2025), and described energy coherently, drawing primarily on the experiments conducted. The students thus improved their scientific language and revised many of the most common misconceptions on the subject. The TLS, planned and developed using the ISLE methodology, promoted the acquisition of certain fundamental qualitative aspects of energy and facilitated the transition from everyday knowledge to scientific knowledge in most students.

The results obtained via the SE-IS questionnaire confirm that there are some gender differences in SSE compared to primary school, although the gap between the two genders is not particularly wide. Our results are consistent with studies that have highlighted gender differences in the components of SSE (Bian et al., 2017; Toma et al., 2019; Carroll et al., 2024). We found statistically significant differences prior to the TLS, although not particularly pronounced, in Mastery Experience, Verbal Persuasion and Emotional State. Boys displayed a more positive attitude towards science and, in particular, less anxiety than girls. The latter reported feeling more anxiety towards science than boys, as observed in the literature (Hill et al., 2010; Toma et al., 2019; Whitcomb, 2020). At the end of the TLS, we observed an improvement in several factors of scientific self-efficacy, particularly among female students. These results are consistent with studies suggesting that SSE can be actively modified at this age through the use of appropriate pedagogical methodologies, as indicated in the literature. (Nordine et al., 2011; Fauth et al., 2014; Pajares & Schunk, 2002).

Overall, the pilot study confirmed the validity of the TLS and the suitability of the assessment tools used. The results are encouraging and indicate positive correlations between the use of the ISLE approach and the promotion of scientific knowledge, as well as improvements in students' scientific self-efficacy, particularly among girls. However, the absence of a control group and the relatively small sample size do not allow for the generalisation of the results. For this reason, the conclusions drawn from this study must be confirmed through future research. Based on these results, to better assess the effects of active learning methodologies on the understanding of the concept of energy and the development of SSE, we plan to design a revised version of the TLS on the concept of energy and to test it with an experimental group and a control group in fifth-grade primary school classes. Furthermore, the first phase of validation of the SE-IS has yielded encouraging results, as the instrument proved useful for measuring the scientific self-efficacy of primary school pupils. For this reason, we plan to conduct a factor analysis (Leandre & Duane, 2019) with a larger sample of pupils in the future.

The second version of the TLS, with the relevant modifications implemented, will be presented and discussed in the following chapter, which is dedicated to the actual trial.

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CHAPTER 7

QUESTIONNAIRE SELF-EFFICACY IN SCIENCE

Measuring self-efficacy is complex because it is a latent construct that cannot be directly observed; it is generally measured using self-assessment instruments structured into items that serve as indirect indicators of the construct (Scherbaum et al., 2006). Furthermore, variations in responses to the items reflect changes in perceived levels of self-efficacy (Lamb et al., 2014).

The development of valid and reliable instruments is a fundamental step in educational research, as it allows for the accurate measurement of latent psychological constructs such as self-efficacy (Bandura, 2006; DeVellis, 2017).

The construction and validation of a questionnaire are methodologically complex and iterative processes, marked by successive phases of analysis, revision and refinement, aimed at the progressive consolidation of the instrument's psychometric properties (DeVellis, 2017). From this perspective, construct validity is of crucial importance, as it relates to the extent to which the instrument is actually capable of measuring the theoretical construct it is intended to assess. Its verification is frequently conducted through exploratory and confirmatory factor analyses, which allow, respectively, the identification and corroboration of the latent structure of the measurement instrument (Tabachnick & Fidell, 2019; Brown, 2015), as well as the assessment of its consistency with the theoretical reference model.

Psychometric analyses provide information on the properties of the items and enable well-founded modifications to be made to the measurement instrument, thereby improving its precision and effectiveness in measuring the construct of interest (Lamb et al., 2014).

It is worth bearing in mind that questionnaires with a large number of items can lead to survey fatigue, causing participants to fail to complete the instrument or to provide inaccurate responses. Reducing the number of items can therefore help to improve the quality of the data collected and increase the likelihood of the questionnaire being completed accurately (Porter et al., 2004; Savage & Waldman, 2008).

7.1 Measuring sources of self-efficacy

Many instruments have been developed to measure self-efficacy in an educational context, some taking a general approach, others more specific to particular subjects or tasks. The latter have focused, in particular, on the analysis of Bandura's (1997) sources of self-efficacy.

Mastery experience has been assessed in various ways. Some researchers have asked students to evaluate their past and current performance in the academic subject of interest (Britner & Pajares, 2006; Lent et al., 1991). However, it is very difficult to use students' assessments and performance as objective indicators (Usher & Pajares, 2009). This source of self-efficacy can be better measured using self-report items that ask students to assess the extent to which they have experienced success (Usher & Pajares, 2009).

Vicarious experience is typically measured through items relating to how students perceive the academic abilities of career role models, friends, peers, parents or teachers. The literature recommends using items that capture both peer and adult modelling to assess vicarious experience (Lent et al., 1991; Lent, Lopez, Brown, & Gore, 1996; Lopez & Lent, 1992), as peers and adults exert very different influences on students at different stages of development (Harris, 1995).

Social persuasion (Verbal persuasions) is assessed using items that ask students to indicate whether they receive encouraging messages about their academic abilities from significant others, such as peers, parents, teachers and other adults (Lent et al., 1991; Matsui et al., 1990).

Emotional states are often analysed through items relating to the assessment of anxiety towards a specific subject. Students are asked how much they like a subject (Matsui et al., 1990), how thinking about a subject makes them feel (Klassen, 2004) or how school affects their physiological functioning (Hampton, 1998). The use of items focused on this emotion has shown high reliability coefficients (Usher & Pajares, 2009).

Several studies have sought to verify the construct validity of scales measuring the sources of self-efficacy, primarily using exploratory and confirmatory factor analyses. For example, Matsui et al. (1990) applied a factor analysis identifying a three-factor structure (vicarious experience, social persuasions and emotional state), but without adequately including the experience of mastery. Subsequently, Lent et al. (1996) used confirmatory factor analysis to test various structural models, finding that the four-factor model proposed by Bandura (1997) generally represented the best fit.

Subsequent research conducted with younger students employed exploratory factor analysis, sometimes identifying a five-factor structure in which vicarious experience was distinguished between peer- d models and adult models, although the peer-related items often showed low reliability (Usher & Pajares, 2006b). Other studies have highlighted further methodological problems, such as possible bias due to the negative wording of some items or multidimensionality not being adequately accounted for in the analyses (Bandalos, 2002; Marsh, 1996).

Subsequently, Usher and Pajares (2009) developed and validated a scale for measuring the sources of self-efficacy in students, identifying, through factor and confirmatory factor analyses, a four-factor structure fully consistent with Bandura's (1997) theoretical model, comprising mastery experiences, vicarious experiences, social persuasions and physiological/affective states.

7.2 Instruments for measuring scientific self-efficacy

Subject-specific measurement tools that investigate the sources of self-efficacy have been developed and used across a variety of disciplines and types of institutions. Recently, several studies in the literature have analysed students' self-efficacy in science subjects at various educational levels (Britner & Pajares, 2006; Webb-William, 2018; Carroll et al., 2023), creating science-specific instruments. This interest stems from evidence demonstrating the strong link between SSE and improved academic performance, motivation and interest in science (Britner & Pajares, 2006; Lamb et al., 2014; Webb-Williams, 2018). Furthermore, science is often perceived as more difficult than other subjects (Dweck, 2007), and when students lose the desire to engage with science-related subjects, they often highlight their perception that they lack the ability to do science (National Academies of Science, 2011)

However, despite the fact that self-efficacy beliefs appear to be more malleable in the early stages of learning (Master, 2021), most existing studies have focused on later school years (Chen & Usher, 2013; Webb-Williams, 2018). In contrast, only a small number have been designed to investigate scientific self-efficacy in primary school (Webb-Williams, 2018; Carroll et al., 2023).

One of the most widely used instruments for analysing self-efficacy in physics in university courses is the Sources of Self-Efficacy Science Courses–Physics (SOSESC-P), which examines self-efficacy through the lens of the four proposed sources: mastery experience, vicarious learning, emotional/physiological states, and social persuasion (Trujillo & Tanner, 2014).

For upper secondary school, several instruments for assessing scientific self-efficacy have been developed. A prime example is the PISA questionnaire (OECD, 2019), which, in addition to assessing the learning levels of 15-year-old students in Italian, mathematics and science, includes a section designed to analyse affective variables such as interest, motivation and self-efficacy.
Another tool developed for upper secondary school students is the Science Self-Efficacy Scale proposed by Hu, Jiang and Bi (2022). The scale was constructed using a mixed-methods approach and validated using the Rasch model (Bond et al., 2020). Unlike tools that analyse the sources of self-efficacy separately, it focuses primarily on the dimension of perceived competence in science and measures self-efficacy as a largely unidimensional construct, relating to the ability to tackle scientific tasks of varying complexity.

For lower secondary school, one of the most useful and statistically significant instruments for investigating self-efficacy in science is the questionnaire developed by Usher and Pajares (2009). This study represents one of the most robust empirical validations of the four sources of self-efficacy, as the items clustered clearly, the scales demonstrated high internal reliability, and the factor structure was consistent with the theoretical framework of self-efficacy (Usher and Pajares, 2009). The instrument has a multidimensional structure and has been widely used to analyse the factors contributing to the development of scientific self-efficacy, but it is less suitable for students under the age of 12.

For primary school pupils, Webb-Williams (2018) developed a quantitative questionnaire based on a seven-point Likert scale. In addition to investigating self-efficacy in the domains identified by Bandura (1996), scales were developed relating to general performance, specific subject areas, and scientific inquiry tasks. The items were primarily phrased as "How well can you…", in line with Bandura's (1996) methodological recommendations.

The scale relating to general performance in science is based on the levels of the UK National Curriculum. The domain-specific self-efficacy scale, on the other hand, includes items referring to fundamental topics of the science curriculum. Finally, the task-specific self-efficacy scale for science includes specific items relating to scientific inquiry, for example: "How well can you write the conclusion of a scientific inquiry?" (Webb-Williams, 2018). This latter scale measures how capable students feel of carrying out specific scientific activities, such as experiments, data interpretation or investigations. According to Bandura's (1996) self-efficacy theory, task-specific self-efficacy assessments are often the most predictive of behaviour.

A similar instrument was developed by Carroll et al. (2020) to measure scientific self-efficacy among primary school pupils in Ireland. The questionnaire comprises five scales, each of which focuses on a specific aspect of self-efficacy. The first analyses pupils' general self-efficacy across different school subjects; the second concerns self-efficacy relating to academic performance in science; the third measures specific self-efficacy in relation to specific scientific content; the fourth includes items relating to Bandura's (1996) four sources of self-efficacy; finally, the fifth scale focuses on self-efficacy relating to specific science tasks (Carroll et al., 2020). In this study too, the authors decided to focus on different aspects of scientific self-efficacy, in order to analyse the various dimensions of this construct in greater depth

In light of the literature reviewed, it is evident that instruments for measuring scientific self-efficacy may adopt different approaches. Some questionnaires focus exclusively on the sources of self-efficacy, in line with the theoretical model proposed by Bandura, as in the case of the scale developed by Usher and Pajares (2009). Other instruments, however, also include different levels of self-efficacy, distinguishing between general perceptions of competence, self-efficacy relating to specific disciplinary domains, and self-efficacy regarding specific scientific tasks, as in the study by Webb-Williams (2018).

This distinction reflects the theoretical conception of self-efficacy proposed by Bandura (1996, 2006), according to which efficacy beliefs can be formulated at different levels of specificity, ranging from more general perceptions of competence to very specific assessments relating to individual tasks or activities. In an educational context, more specific measures are often more effective in predicting students' behaviour and performance (Bandura, 1996, 2006).

7.3 The research

The aim of this research is to develop and validate an instrument for measuring science self-efficacy (SSE) in primary school pupils aged between 8 and 11.

Based on the studies discussed above, an integrated approach to measuring scientific self-efficacy was adopted. In an initial phase, the instrument was designed to include, in addition to the dimensions of self-efficacy, related variables such as attitude towards science, general self-efficacy in the main school subjects, the desire to learn and expand knowledge, and aspects related to a growth mindset.

During the validation process, these dimensions were progressively revised and reduced in order to limit the instrument to the components most closely related to science self-efficacy. This approach allowed for the progressive refinement of the construct under study and the development of an instrument that is more consistent from a theoretical and psychometric perspective.

Building on questionnaires already validated in the literature, in particular those by Carroll et al. (2023) and OECD/PISA (2019), the SE-IS (Self-Efficacy in Science) questionnaire was developed and adapted to the Italian primary school science curriculum.

The research question guiding the study is as follows:

1. What factor structure emerges from the measurement of scientific self-efficacy in primary school pupils, and to what extent does the SE-IS questionnaire provide evidence of validity for its measurement?

7.4 Research design and phases

The Self-Efficacy in Science (SE-IS) questionnaire was developed on the basis of questionnaires already validated in the literature (OECD, 2019; Carroll et al., 2023). Its development and validation took place across four studies (see Fig. 1 for an outline of the development strategy) over a two-year period (from March 2024 to February 2026).

The development strategy addresses five key steps in the construction of a questionnaire: (a) initial design/adaptation of items, (b) expert review of items, followed by content validation (Polit et al., 2006), (c) pre-testing of items on a small sample of the target audience, carrying out face validity testing (Jensen, 2003), (d) pilot testing of items, (e) assessment of the validity and internal reliability of the scales as a whole (DeVellis & Thorpe, 2021). The purpose of the final step is to ensure that the questionnaire 'works' as intended, i.e. that it accurately and reliably measures the construct(s) of interest. Therefore, the last two steps (pilot testing and evaluation) may be iterative, with each test of the questionnaire informing further changes to improve its psychometric properties. This process continues until the validity of the questionnaire is satisfactory.

Table 1. Phases of development and validation of Questionnaire

A: Initial construction of the questionnaire	**B: Study 1**	**C: Study 2**	**D: Study 3**	**E: Study 4**
1. Translation of questionnaire items already validated in the literature 2. Linguistic adaptation to the age of the sample (8–11 years)	**Quantitative analysis**: N=75 pupils (aged 10–11) completed the SE-IS	**Quantitative analysis**: N=320 pupils (aged 8–11) completed the SE-IS	**Quantitative analysis**: N=266 pupils (aged 8–11) completed the SE-IS	**Quantitative analysis**: N=246 pupils (aged 8–11) completed the SE-IS
3. Adaptation of items to the Italian science curriculum 4. Review by a group of experts (content validation) 5. Testing with 22 Year 6 pupils (face validity)	1. variables identified in the literature 2. Descriptive statistical analysis 3. Interpretation (interviews) 4. New face validity	1. Construct validation (n Exploratory Factor Analysis). 2. Internal consistency (Cronbach's alpha, McDonald's omega)	1. Construct validation (n Exploratory Factor Analysis). 2. Internal consistency (Cronbach's alpha, McDonald's omega) 3. Discriminant and convergent validity (bivariate Pearson correlation between scales)	1. Construct validation (r Confirmatory Factor Analysis). 2. Convergent validity (Average Variance Extracted – AVE) 3. Discriminant validity (Heterotrait-Monotrait Ratio – HTMT)
	Qualitative analysis: semi-structured interviews (N=6 pupils)			
Revision of the questionnaire	Revision of the questionnaire	Revision of the questionnaire	Revision of the questionnaire	

The development of the questionnaire followed the fundamental steps recommended for scale construction by Bandura (2006) and DeVellis (2017). The validation of the SE-IS was carried out using three independent datasets across four separate studies.

Following the initial construction of the questionnaire (phase A in Tab. 1), Study 1 was conducted with 75 children (B in Fig. 1), referred to as the Pilot Study.
Study 1 examined the comprehensibility of the questionnaire and its suitability for the target population. The main objective was to verify the clarity of the items and conduct an initial descriptive exploration of the data. Based on the literature (Usher & Pajares, 2009; Webb-

Williams, 2018; Carroll et al., 2023), 11 theoretical variables were identified and a descriptive statistical analysis was conducted on the collected data.

In parallel, semi-structured interviews were conducted with a subgroup of pupils to deepen the understanding and interpretation of the items, contributing to the assessment of the instrument's face validity. Furthermore, any gender differences in the perception of scientific self-efficacy following a TLS on energy were explored.

The results of Study 1 (see Chapter 6) highlighted some differences in the perception of scientific self-efficacy and confirmed the need to develop a valid and reliable measurement tool for the primary school context. Based on these results, the questionnaire was revised, leading to the second version of the SE-IS (Figure S2), which was subsequently tested in Study 2 on a larger sample of 320 pupils (phase C in Fig. 1).

Study 2 examined the construct validity of the questionnaire using exploratory factor analysis, with the aim of investigating the latent structure of the instrument and identifying the underlying factors. The results showed good sample adequacy and the suitability of the correlation matrix for factor analysis, whilst highlighting some critical issues in the interpretation of the factors. The questionnaire was therefore further modified at the end of Study 2.

Exploratory factor analysis was then replicated in Study 3 (phase D in Fig. 1) on an independent sample (N = 266), in order to verify the stability of the factor structure before proceeding to validation via confirmatory factor analysis. In both studies (Study 2 and Study 3), the internal reliability of the scales was also assessed using Cronbach's alpha.

In Study 4 (phase E in Fig. 1), the questionnaire was administered to an independent sample of 246 primary school pupils (aged 8–11), in order to confirm the factor structure that had emerged during the previous analysis.

The total number of items was progressively modified during the various validation phases. In the initial version, the questionnaire contained 51 items; by the end of Study 4, 31 items organised into 8 factors had been selected.

Data were collected in primary schools located in Sicily and the province of Pisa, selected via convenience sampling. Pupils in Years 4 and 5 (aged 8–11) took part, subject to informed consent from parents and the children's own consent. All studies were approved by the Research Ethics Committee of the University of Palermo. This choice represents a limitation of the study, since the sample, although adequate for the exploratory and psychometric aims of the research, cannot be considered fully representative of the national population of primary school pupils. Consequently, the results must be interpreted with caution regarding their generalisability and will need to be confirmed in future studies conducted on larger, balanced samples from different geographical and socio-cultural contexts.

7.4.1 Analysis methodology

In Study 1, the questionnaire responses were analysed using quantitative and qualitative methods. In particular, the semi-structured interviews conducted with a selected group of pupils (N=6) were analysed, and a descriptive statistical analysis was carried out.

In Studies 2 and 3, subsequent versions of the SE-IS questionnaire were analysed in terms of descriptive statistics, internal reliability and factor validity. To verify the latent structure of the SE-IS questionnaire, an exploratory factor analysis (EFA) was conducted on each of the questionnaire's scales using the JASP software (ver. 0.19.3). The EFA was employed to identify the factors underlying the items and to assess whether the emerging structure was consistent with the theoretical framework.

Construct validity concerns the relationship between different variables within a scale. Different items (questions) that refer to the same latent variable should have a strong correlation with that variable, or 'factor', and a weaker correlation with the other variables (DeVellis, 2017). The 'strength' of this correlation is indicated by 'factor loadings' ranging from -1 to 1, where 1 indicates a perfect correlation.

The polychoric correlation matrix was chosen as it is best suited to the nature of the data collected. Indeed, the questionnaire items were expressed on an ordinal Likert scale (from 1 to 5), and the use of polychoric correlation allowed for a more accurate estimation of the relationships between continuous latent variables underlying the observed responses. It is specifically designed for ordinal variables and yields more reliable estimates in the context of psychometric instruments.

This methodological choice is particularly recommended in the validation of educational and psychological questionnaires, as it improves the precision of the estimates and the robustness of the factor model (Holgado–Tello et al., 2010).

Principal axis factoring was used for factor extraction, whilst the factor solution was rotated using oblique rotation in order to a) allow for correlation between the resulting factors to minimise the loss of valuable information (Costello & Osborne, 2005) and b) because it was the type of rotation employed by Usher & Pajares (2009) for their scale of sources of self-efficacy in mathematics. Factor loadings below |0.35| were suppressed, as done by Usher & Pajares (2009).

Once the factor structure of the scales had been examined, the internal consistency of the factors was assessed using Cronbach's alpha and McDonald's omega. Cronbach's alpha is one of the most common measures of internal reliability (sometimes referred to as internal consistency) and assesses how well the items within a scale are correlated with one another (Vask et al., 2017). McDonald's omega was also calculated as a complementary and more robust estimate of internal reliability.

The coefficient values range from 0 (no correlation) to 1 (perfect correlation). In line with the guidelines in the literature, values of α and ω equal to or greater than 0.70 were considered indicative of good internal reliability, whilst values greater than 0.80 were interpreted as indicative of high internal consistency (Nunnally & Bernstein, 1994; Hair et al., 2019).

Study 3 also examined the convergent and discriminant validity of the questionnaire. These allow for a deeper exploration of construct-related validity (Hair et al., 2019). Convergent validity checks whether the questionnaire is associated with other measures that, in theory, should measure the same construct or very closely related constructs. Discriminant validity, on the other hand, checks whether the questionnaire can be distinguished from measures of different constructs. It therefore examines whether the instrument does not overlap excessively with other constructs that, theoretically, should remain separate. Similar constructs with good convergent validity should correlate well with one another. To this end, the average factor scores for each participant were calculated and a matrix of Pearson's bivariate correlations between the factors was constructed (Hair et al., 2019). Moderate positive correlations between theoretically related factors were interpreted as preliminary evidence of convergent validity, whilst the absence of excessively high correlations between theoretically distinct factors was considered indicative of sufficient distinction between the measured dimensions. This analysis was intended as preliminary, as convergent and discriminant validity were subsequently examined in greater depth in Study 4 using specific indices calculated within the framework of confirmatory factor analysis.

Finally, in Study 4, a Confirmatory Factor Analysis (CFA) was conducted on an independent sample, with the aim of verifying the robustness of the factor model that emerged from the previous studies. The analytical methodology is described in detail in section 7.9.2

7.5 The initial construction of the SE-IS

The development of the SE-IS followed the recommendations set out by Bandura (2006) in his “Guide to the Construction of Self-Efficacy Scales”. Following a thorough review of existing self-efficacy instruments, an initial set of items was generated. The resulting questionnaire (Appendix A) contained five scales presented as five sections (A to E), each addressing different aspects related to beliefs and sources of self-efficacy in science (SSE).
In general, these questionnaires contain a series of statements, hereinafter referred to as “items”. Items that assess the same latent variable (identified through a review of the literature) are grouped into “scales”. Scales that assess more than one latent variable are often subdivided into ‘subscales’. For each item, participants are asked to select a response by choosing a value from a predefined response scale.

The items in the SE-IS were drawn from two different questionnaires found in the literature. The first refers to the IS-SEC-Q (Carroll et al., 2023), designed for Irish primary school pupils. The second refers to the OECD PISA questionnaire (OECD, 2019). The latter was administered to 15-year-old Italian students. It contains items covering various subject- s (Italian, mathematics, science), both content-based and non-content-based. For the purposes of our analysis, only the items relating to the construct of self-efficacy were extracted.
We translated the items from the Irish questionnaire using the TRAPD method (Harkness et al., 2010). Two psychometric experts, native Italian speakers with excellent knowledge of English, carried out the translation from English into Italian.
The items extracted from the OECD PISA questionnaire (OECD, 2019) were adapted for younger pupils.
For the first version of the SE-IS, responses are provided on a 5-point Likert scale and an 11-point Likert scale to: a) allow respondents to discern subtle differences between items, b) reduce the risk of participants over-interpreting the distances between points (which is more likely with wider scales), and c) provide a ‘neutral’ midpoint to improve the quality of the scale (Krosnick, 2018). Each response point has been labelled unambiguously to enhance children’s understanding (Furr, 2011). The 5-point Likert scales range from 1 = ‘not at all’ to 5 = ‘totally’, from 1 = ‘terribly’ to 5 = ‘perfectly’, and from 1 = ‘completely disagree’ to 5 = ‘completely agree’.

An ‘a priori’ analysis of students’ potential responses to the questionnaire items was conducted (Brousseau, 1997). To further enhance the validity of the questionnaire, the a priori analysis was carried out independently by two researchers (see A in Fig. 1). Consensus was then reached through discussion, leading to a final version that was agreed upon and optimised for the research objectives. Following this initial analysis, two items were amended. The first, “I get bored during science lessons”, was changed to “I lose interest during science lessons”. The second item, “When the teacher explains the science lesson, I understand the concepts very well”, was changed to “When science topics are explained to me, I understand the concepts very well”.

To further verify the validity of the questionnaire and highlight any other issues with the questions, such as unclear or ambiguous terminology, a face validity check (Jensen, 2003) was conducted involving a Year 6 class from the same school. Most of the respondents (10 pupils) reported difficulties in interpreting two items in Section B (Using science in everyday life; How scientists can improve the world). For this reason, it was decided to remove these two items from the second version of the SE-IS.
Following these validations, the SE-IS was ready for use in the pilot phase (B in Tab. 1).

In its initial version, the SE-IS questionnaire was divided into five sections (A to E) and comprised a total of 51 items. In the first four sections, participants were asked to respond using a 5-point Likert scale, whilst the final section (E) used an 11-point Likert scale (from 0 to 10).
Section A consisted of 7 items designed to assess certain factors related to self-efficacy, such as the desire to learn and perceived growth mindset (Dweck, 2016). The items in this section are taken from the OECD PISA questionnaire (OECD, 2019).
Section B included 4 items designed to analyse students’ perception of their general academic self-efficacy in certain school subjects (mathematics, Italian, English and science). This section is based on the Irish IS-SEC-Q questionnaire (Carroll et al., 2023).
Section C contained 13 items designed to assess perceived self-efficacy in relation to scientific content. This section also draws on the IS-SEC-Q questionnaire (Carroll et al., 2023), whose items were adapted on the basis of the National Curriculum Guidelines (2018).
Section D comprised 20 items designed to measure students’ level of engagement with the four sources of scientific self-efficacy and their attitude towards science. The items in this section were drawn from both the OECD PISA questionnaire (OECD, 2019) and the IS-SEC-Q (Carroll et al., 2023).

Finally, Section E consisted of 7 items designed to assess the perception of scientific self-efficacy in relation to specific skills and tasks. Here too, the items were selected from the IS-SEC-Q questionnaire (Carroll et al., 2023).

A summary of the sections, the number of items, the purposes, the sources, representative examples for each scale and the response formats is provided in Table 2.

Table 2. Details of the Self-Efficacy in Science (SE-IS) scales upon completion of the initial construction

Section	Purpose	Source	Examples	Likert scale
A	Assessing pupils' desire to learn and their growth mindset	OECD, 2019	Which of these statements do you agree with? "I enjoy learning new things" "When tasks get difficult, I stop and don't carry on"	From 1 to 5 (from not at all to completely)
B	Assessing pupils' self-efficacy in Italian, maths, science and English	Carroll et al., 2023	I feel more capable when the teacher covers... "Italian" "science"	From 1 to 5 (not at all to completely)
C	Assessing pupils' self-efficacy in scientific content	Carroll et al., 2023	I feel more capable when the teacher covers... "Plants" "Magnets"	From 1 to 5 (from strongly disagree to strongly agree)
D	Assessing pupils' engagement with the four sources of ESD and their attitude towards science	OECD, 2019; Carroll et al., 2023	Which of these statements do you agree with? "Science is one of my favourite subjects" "I do well even at the most difficult science homework"	From 1 to 5 (from strongly disagree to strongly agree)
E	Assessing pupils' self-efficacy in performing science tasks	Carroll et al., 2023	Give a score from 0 to 10 to explain how capable you think you are of carrying out these activities "Linking science topics together"	From 0 to 10

7.6 Study 1: pilot study

Study 1, described in Chapter 6 and conducted in March/April 2024, constituted the pilot phase of the questionnaire development process. In this study, the first version of the SE-IS was administered, comprising 51 items divided into 5 sections (see Table 2). The SE-IS was administered at the start of a 12-hour TLS on energy, delivered using the Investigative Science Learning Environment methodology (Etkina, 2006), to analyse differences in scientific self-efficacy following the use of an active methodology. For further information on the pilot study, please refer to the study [see Chapter 6]. The version of the SE-IS used in Study 1 is available in the Appendix (Appendix A).

7.6.1 Participants and procedure

The SE-IS was completed via the Google Forms platform by 75 participants (F=40, M=35) from the same primary school. Data were collected anonymously. Completing the questionnaire took approximately 10–15 minutes per pupil.

Six participants (3 boys and 3 girls), aged 10, who completed the SE-IS were randomly selected to take part in semi-structured interviews. The interviews were audio-recorded (duration: 8–15 minutes). Participants were asked about their interpretation, understanding and use of the questionnaire.

7.6.2 Analysis methodology

Based on the literature (Carroll et al., 20213; Webb-Williams, 2006; Dweck, 2016), we identified 11 variables in the first version of the SE-IS (see Table 3), which are closely linked to the sub-dimensions of learning we aim to explore in this research and can be examined through the questionnaire items. To calculate the scores for the variables, the response scores for the questions relating to each specific variable were summed and then divided by the total number of questions for each participant.

Table 3. SE-IS variables in Study 1

	Factors
F1	Desire to learn and expand
F2	Growth Mindset
F3	General academic self-efficacy
F4	Specific self-efficacy in life sciences
F5	Specific self-efficacy in physics/chemistry
F6	Attitude towards science
F7	Master Experience
F8	Vicarious Experience
F9	Verbal Persuasion
F10	Emotional State
F11	Specific self-efficacy in scientific tasks

The data collected were analysed using descriptive methods. For each variable, the mean scores, standard deviation and standard error were identified and analysed. The mean scores of the pre-test and post-test questionnaires were analysed for both boys and girls. Subsequently, a comparison of the data between the two genders was carried out, a t-test analysis was conducted, and Cohen's d was calculated. This analysis made it possible to observe any statistically significant changes in the variables identified in the questionnaire between the first and second administrations.

On a qualitative level, semi-structured interviews were used for exploratory purposes and to support the face validity of the questionnaire. In particular, they enabled a deeper understanding of the items by the pupils, verified the linguistic appropriateness of the wording, and gathered examples useful for interpreting the responses provided. Given the small size of the sample, the qualitative results were used for descriptive and interpretative purposes, without any intention of generalization.

7.6.3 Results of Study 1

The results of the qualitative analysis (interviews) and the quantitative analysis carried out in Study 1 are presented below.

Results of the descriptive statistical analysis

The data collected from the pilot study confirm that the first version of the SE-IS revealed some gender differences in scientific self-efficacy between boys and girls, starting from primary school.

Our results are consistent with studies that have highlighted gender differences in the components of SSE (Carroll et al., 2023; Toma et al., 2019; George, 2006). We found statistically significant, albeit not particularly pronounced, differences in the Experience of Mastery, Verbal Persuasion and Emotional State, indicating that female students experience more anxiety and stress regarding science. In the post-test, the data collected showed a reduction in gender differences across the various factors. Statistically significant differences remained evident in Emotional State, although the gap between boys and girls had narrowed (see Chapter 6).

Analysis of the results of the pilot study allows us to state that it is necessary and desirable to promote scientific research in this area within the context of Italian primary schools. Gender differences between boys and girls in the development of scientific self-efficacy are evident as early as primary school, although they are not particularly pronounced. For this reason, we believe it is essential that research develops a rigorous and valid scientific tool that allows for a more precise and rigorous analysis of the factors that most influence scientific self-efficacy in Italian primary schools.

Interview results

The semi-structured interviews, conducted individually with six pupils (M=3, F=3) selected at random from the participants in Study 1, provided useful insights into the understanding and interpretation of the questionnaire items. Overall, the pupils demonstrated an understanding of the general meaning of the statements and were able to provide coherent justifications for their responses.

However, some specific issues emerged. Several pupils reported greater difficulty in understanding or interpreting certain items in Section D, and one of the most problematic items turned out to be ‘I feel very tense when I have to do science’, which was perceived as less straightforward than other formulations.

During the interviews, the pupils also enriched their answers with concrete examples drawn from their school experience, describing situations in which they felt confident in their abilities and others in which they perceived difficulties in carrying out scientific tasks. Frequent reference was made to group work as a context perceived as facilitating, capable of supporting participation and a sense of personal efficacy.

The interviews confirmed, in terms of general comprehensibility, the suitability of the questionnaire for the target group in question but also highlighted the need to reformulate certain items to make them clearer and more in line with the pupils’ language.

7.6.4 Discussion and modifications to the SE-IS

At the conclusion of Study 1, the SE-IS was reviewed by a group of experts (Boateng et al., 2018) comprising two educational researchers, an expert in experimental pedagogy and two primary school teachers (see A in Fig. 1).

The group recommended the adoption of a single 5-point response scale, ranging from 1 = “not at all true for me” to 5 = “completely true for me”. This choice was intended to ensure greater consistency across the different sections of the questionnaire and to improve its comprehensibility for primary school pupils.

Some items were modified, such as: ‘I feel very tense when I have to do science’ was changed to ‘I feel nervous when I think about science tests’; ‘I cannot think clearly when I have to do science homework' was changed to 'I feel confused when I think about science homework'.

A number of items have been added: ("When I watch a cartoon or film about scientists, I imagine myself as the main character" and "My parents tell me I'm very good at science") to increase the number of items in the Verbal Persuasion and Vicarious Experience variables. Some items have been removed. Specifically, Scale A, which investigated the desire to learn and expand one's knowledge, the items relating to Growth Mindset, and Scale B, which investigated general academic self-efficacy (Italian, Maths, English, Science), have been entirely removed.
In Scale C, one item ("Liquids") was removed, as pupils often asked for further explanations whilst completing the questionnaire, stating that they had not fully understood its meaning. In Scale D, the item "I generally manage to answer science questions or assignments well" was removed.

Finally, the items attributed to the 'Attitude towards science' factor ('Science is one of my favourite subjects', 'I enjoy learning about science topics'; 'I am interested in learning science topics'; 'I lose interest in doing science'; 'I can't wait to do science') were excluded from the final structure of the instrument.
Although the omitted dimensions are relevant within the field of science education, they represent constructs distinct from scientific self-efficacy. In line with Bandura's theoretical model (1997) and with validated instruments in the literature (Usher & Pajares, 2009; Webb-Williams, 2018), it was decided to limit the questionnaire solely to scientific self-efficacy beliefs, avoiding overlap with motivational and attitudinal variables.

In the final version, the SE-IS questionnaire comprises three scales structured as follows:

1. Domain self-efficacy scale
2. Task self-efficacy scale
3. Scale on sources of self-efficacy

Table 4 describes the structures of the different scales in detail.

Table 4. Details of the SE-IS scales at the conclusion of Study 1

Scale	Purpose	Origin	Examples	Likert scale
A: Domain self-efficacy	To assess pupils' self-efficacy in scientific content	Carroll et al., 2023	I feel more capable when the teacher discusses... "Plants" "Magnets"	From 1 to 5
B: Task self-efficacy	Assessing pupils' self-efficacy in performing scientific tasks	Carroll et al., 2023	"Linking science topics together"	From 1 to 5
C: Sources of self-efficacy	Assessing pupils' engagement with the four sources of SSE	OECD, 2019; Carroll et al., 2023	Which of these statements do you agree with? "Science is one of my favourite subjects" "I do well even with the most difficult science homework"	From 1 to 5

The changes introduced necessitated a further psychometric investigation of the questionnaire's structure. In particular, there was a need to empirically verify the internal consistency of the scales and their factor structure. For this reason, in the next phase (Study 2), an exploratory factor analysis was conducted on a larger sample.

7.7 Study 2

In Study 2, conducted in October/November 2024, the SE-IS questionnaire—revised following the pilot study—was administered. It consisted of 34 items divided into 3 sections (A, B, C, D). In each section, participants were asked to respond to a 5-point Likert scale. The various scales of the second version, their purpose, origin, examples and Likert scales are shown in Table 4.

During Study 2, the SE-IS was administered to a sample of 320 primary school pupils and the responses were analyzed statistically, descriptively and via factor analysis, in order to validate a tool suitable for assessing the scientific self-efficacy of pupils aged between 8 and 11.

The version of the SE-IS administered in Study 2 can be found in the Appendix (Appendix B).

7.7.1 Participants and procedure

The second version of the S-EIS was administered to a sample of 320 pupils (F=161, M=158), aged between 8 and 11 years. The pupils came from three different schools: the first two located in the city of Palermo, the third in a small town in the province of Agrigento. The pupils completed the questionnaire via the Google Forms online platform, using tablets and/or computers. The data were collected anonymously. Completing the questionnaire took approximately 10–15 minutes per pupil.

Table 5. Sample composition (N=320)

Demographic category		*N (320)*	*Percentage*
Gender			
	Female	161	50.31%
	Male	158	49.38%
Age			
	8	50	15.63%
	9	106	33.13%
	10	119	37.19%
	11	32	10%
Origin			
	Palermo	201	62.81%
	Agrigento	119	37.19%

7.7.2 Results of Study 2

In this section, we will discuss the results of the construct validity of the various scales (A, B, C) that make up the SE-IS.

The EFA was performed on the four scales in the questionnaire (A, B, C), using the JASP software version 0.19.3**.** At the end of Study 2, 6 items were added.

Table 6 shows the mean, median, standard deviation and standard error for each item.

Table 6. Descriptive statistics for each item (Study 2)

Item	**Mean**	**Median**	**Standard deviation**	**Standard error**
1	3.313	3	1.122	0.063
2	4,085	4	0.969	0.054
3	3,633	4	1,152	0.064
4	3,329	3	1,122	0.063
5	3,354	3	1,384	0.077
6	2,915	3	1,386	0.077
7	3,234	3	1,351	0.076
8	3,226	3	1,346	0.075
9	3,884	4	1,068	0.060

10	2,734	3	1,323	0.074
11	3,668	4	1,363	0.076
12	2,897	3	1,324	0.074
13	3,481	3.5	1,142	0.064
14	3,192	3	1,237	0.069
15	3,239	3	1,248	0.070
16	3,522	3	1,199	0.067
17	3,264	3	1,373	0.077
18	3,094	3	1,377	0.077
19	3,333	3	1,311	0.073
20	3,459	4	1,144	0.064
21	3,733	4	1,146	0.064
22	3,705	4	1,067	0.060
23	3,592	4	1,191	0.067
24	3,668	4	1,164	0.065
25	3,714	4	1,136	0.063
26	1,972	2	1,099	0.062
27	2,442	2	1,361	0.076
28	1,790	1	1,053	0.059
29	3,749	4	1,149	0.064
30	4,000	4	1,233	0.069
31	3,739	4	1,382	0.077
32	3,862	4	1,298	0.073
33	3,286	3	1,227	0.069
34	2,940	3	1,462	0.082

Scale A

Scale A investigates students' perceived self-efficacy in specific science topics covered during primary school in Italy (e.g. energy, heat and temperature, states of matter).

The Kaiser-Meyer-Olkin index (KMO = 0.825) indicated good sample adequacy, whilst Bartlett's sphericity test was highly significant ($\chi^2(55) = 1571.932$, $p < .001$), confirming the presence of significant correlations between the items. The overall internal reliability of the scale, calculated using Cronbach's alpha, was $\alpha = 0.862$, indicating excellent internal reliability among the retained items. McDonald's ω coefficient ($\omega = 0.842$) was also calculated, as it is considered a more robust estimate of internal reliability, and confirmed good consistency among the scale items.

The initial analysis yielded a four-factor solution with eigenvalues greater than 1, which together explained 61.5% of the total variance. However, the third factor was defined by a single item (1 – *Plants*), and for methodological reasons it was excluded from the final solution. The final structure therefore comprises three factors, which account for 48.3% of the variance: Factor 1 accounts for 18.9%, Factor 2 for 17.1% and Factor 3 for 12.2%. Two items (*"Plants"* and *"Solutions and mixtures"*) did not load significantly on any factor.

Table 7. EFA results for Scale A

Item	**F1**	**F2**	**F3**	**I feel more capable when we study...**
3			0.827	States of matter
9			0.721	The water cycle
4			0.704	Heat and temperature
5			0.655	The human body
2			0.609	Animals
6	0.887			Forces
8	0.603			Energy
11		0.853		The Universe and the Solar System
12		0.571		Magnets
10		0.504		Electricity

Scale B

Scale B assesses perceived self-efficacy in scientific tasks.

The sample adequacy was found to be very good, as indicated by the Kaiser-Meyer-Olkin index (KMO = 0.811), and Bartlett's sphericity test yielded a significant result ($\chi^2(21) = 708.950$, $p < .001$), confirming the presence of adequate correlations between the items. The overall internal reliability of the scale, calculated using Cronbach's alpha, was $\alpha = 0.811$, indicating high internal consistency among the retained items. McDonald's ω coefficient ($\omega = 0.809$) was also calculated, as it is considered a more robust estimate of internal reliability, and this confirmed the good consistency among the scale items.

The analysis revealed two factors with eigenvalues greater than 1, which together explain 48% of the total variance (Factor 4 = 26%, Factor 5 = 22%).

Table 8. EFA results for Scale B

Item	**F4**	**F5**	**I can…**
14	0.676		Explain science topics to my classmates if they haven't understood something
13	0.557		Make connections between science topics
18	0.523		Encourage classmates to participate in discussions
15	0.520		Work together with my classmates to better understand science topics

16	0.495		Write down the activities we do in science
17		1.018	Use materials during experiments
19		0.557	Do science experiments using hands-on materials

Scale C

Scale C assesses the sources of pupils’ SSE beliefs.

The suitability of the sample was excellent, as indicated by the Kaiser-Meyer-Olkin index (KMO = 0.909), and Bartlett’s sphericity test yielded a significant result (χ^2 (105) 2267.313, $p < .001$), confirming the presence of adequate correlations between the items. The overall internal reliability of the scale, calculated using Cronbach’s alpha, was $\alpha = 0.881$, indicating high internal consistency among the retained items. McDonald’s ω coefficient ($\omega = 0.886$) was also calculated and confirmed good consistency among the scale’s items.

The analysis yielded three factors with eigenvalues greater than 1, which together explained 52% of the total variance: Factor 6 explains 35%, Factor 7 9% and Factor 8 8%.

Item 34 (*“When I watch a cartoon or film about scientists, I imagine myself as the main* character”) did not load on any factor.

Table 9. EFA solutions in Scale C

Item	**F6**	**F7**	**F8**	**For each statement, indicate how true it is for you.**
20	0.841			I do even the most difficult science homework
21	0.786			I get excellent grades in science
29	0.768			My teacher tells me I’m very good at science
23	0.737			I am always successful in science
30	0.714			My parents tell me I’m very good at science
22	0.700			When they explain science topics to me, I understand the concepts very well
33	0.693			My classmates like working with me during science lessons because they think I’m good
25	0.692			I learn science topics quickly
24	0.675			Science is easy for me
31		0.857		When I see my teacher doing science experiments, I imagine doing them myself
32		0.638		When I see a classmate doing a science experiment, I would like to do it too
26			0.703	When I think about my science homework, I feel confused
27			0.497	When I think about science tests, I feel nervous
28			0.426	Even when I try hard in science, I do badly

Table 10. Summary of the scales included in the SE-IS in Study 3

Scales	***KMO***	***Bartlett's test***	***Cronbach's coefficient (α)***
A	0.836	$\chi^2(105) = 2189.644, p < .001$	0.862
B	0.809	$\chi^2(21) = 708.950, p < .001$	0.811
C	0.909	$\chi^2(105) = 2267.313\ p < .001$	0.881

7.7.3 Discussion and modifications to the S-EIS

At the conclusion of Study 2, the S-EIS questionnaire was revised in light of the results obtained.

The factor analysis carried out on Scale A of the ES-IS revealed a three-factor structure. The aim of these factors was to assess self-efficacy in specific scientific content areas. Our initial hypothesis predicted the presence of two factors: on the one hand, content relating to physics and chemistry; on the other, content relating to life sciences. Instead, F1 contained two items (energy; force); F2 contained three items (magnets; electricity; the universe and the Solar System); F3 contained five items (e.g. heat and temperature; states of matter; the water cycle). Furthermore, two items (Plants; Solutions and mixtures) were excluded from the analysis as they did not load sufficiently on any factor. The structure that emerged is not fully consistent with the theoretical division of scientific content set out in the curriculum, limiting its interpretability. To improve the scale's effectiveness, three new items relating to biology content—such as the cell, leaves, the digestive system and the skeletal system—were introduced in the third version of the questionnaire.

The EFA of Scale B identified a two-factor solution, the interpretation of which is ambiguous and not fully defined, as the items do not cluster according to criteria clearly attributable to distinct dimensions of task self-efficacy.

The EFA of Scale C identified a solution with 3 factors. Factor 6 included items related to Mastery Experience and Verbal Persuasion, without a clear distinction between the two sources, in contrast to Bandura's (1996) theoretical model. This solution indicates the need to reformulate or expand the items to improve factor clarity. The two items relating to F9 can be interpreted as Vicarious Experience (Bandura, 1996; Usher & Pajares, 2009) and those relating to Factor 8 can be interpreted as Emotional State: both were consistent with the literature (Bandura, 1997; Usher & Pajares, 2009).

New items have been added to better capture the various sources of self-efficacy and improve the distinction between the theoretical dimensions: “My classmates tell me that I am good at science”; “Watching my classmates use scientific equipment helps me understand what to do”; and “I feel worried when I have to answer science questions”.

Overall, the results of Study 2 indicate that the SE-IS shows good potential as a tool for measuring scientific self-efficacy in primary school, but at the same time highlight some critical issues in the factor structure of specific scales. To verify the stability and replicability of the factor structure that emerged, a new analysis was carried out on an independent sample (Study 3).

7.8 Study 3

In Study 3, conducted in January/February 2025, the version of the SE-IS questionnaire modified at the end of Study 2 was administered. It is divided into three sections or scales (A, B, C) and initially contained 40 items. In each section, participants were required to respond to a 5-point Likert scale.

Following the analysis, 7 items were removed: the third version of the SE-IS, comprising 33 items divided into 3 sections, can be found in the Appendix (Appendix C).

7.8.1 Participants and procedure

The third version of the SE-IS was administered to a sample of 266 pupils (F=117, M=148), aged between 8 and 11 years. The pupils came from two different schools: the first located in the city of Palermo, the second in a town in the province of Agrigento.

The pupils completed the questionnaire via the Google Forms online platform, using tablets and/or computers. The data were collected anonymously. Completing the questionnaire took approximately 10–15 minutes per pupil.

Table 11. Sample composition (N = 266)

Demographic category	*N (266)*	*Percentage*
Gender		
Female	117	43.98%
Male	148	55.64%
Age		
8	40	15.04%
9	45	16.92%
10	142	53.38%
11	37	13.91%

Origin		
Palermo	191	71.80%
Agrigento	75	28.20%

7.8.2 Results of Study 3

Initially, the questionnaire comprised 40 items designed to measure primary school pupils' perception of their scientific self-efficacy. Following the analysis process, 7 items were removed. In the final version, available in the Appendix (Appendix C), the SE-IS contains 33 items or variables.

Table 12 shows the mean, median, standard deviation and standard error for each item in the questionnaire.

The EFA, conducted using principal axis factoring and oblique rotation (oblimin), was performed on the scales present in the questionnaire (A, B, C). As in Study 2, the polychoric correlation matrix was chosen for the factor analysis. Items with factor loadings below .35 on any factor were eliminated (Usjer & Pajeres, 2009).

Table 12. Descriptive statistics for each item (Study 3)

Item	Mean	Median	Standard deviation	Standard error
1	3.672	4	0.974	0.060
2	3,634	4	1,014	0.062
3	3,879	4	1,041	0.063
4	3,819	4	0.976	0.060
5	3,660	4	1,269	0.077
6	3,852	4	1,169	0.071
7	3,139	3	1,199	0.073
8	3,471	3	1,177	0.072
9	3,203	3	1,198	0.073
10	3,222	3	1,202	0.066
11	2,973	3	1,277	0.078
12	3,853	4	1,170	0.071
13	3,139	3	1,199	0.073
14	3,472	3	1,178	0.072
15	3,204	3	1,198	0.073
16	3,223	3	1,203	0.073
17	3,467	3	1,048	0.064
18	3,550	4	1,025	0.062
19	3,633	4	1,014	0.062
20	3,558	4	1,068	0.065
21	3,834	4	1,049	0.064

22	3,694	4	1,062	0.065
23	2,094	2	1,056	0.064
24	2,271	2	1,063	0.065
25	1,962	2	1,120	0.068
26	2,237	2	1,048	0.064
27	3,660	4	0.979	0.060
28	3,822	4	1,012	0.062
29	3,645	4	0.989	0.060
30	3,581	4	1,251	0.076
31	3,694	4	1,063	0.065
32	3,468	3	1,048	0.064
33	3,823	4	1,013	0.062

Scale A

Exploratory factor analysis (EFA) was conducted on 15 initial items relating to the perception of self-efficacy in the scientific content covered during primary school (e.g. animals and their classification, plants, energy, magnets, the human body).

The Kaiser-Meyer-Olkin (KMO) index yielded a value of 0.836, indicating excellent sample adequacy. Bartlett's sphericity test was significant ($\chi^2(105) = 2189.644$, $p < .001$), confirming the existence of adequate correlations between the items. The overall internal reliability of the scale, calculated using Cronbach's alpha, was $\alpha = 0.852$, indicating excellent internal consistency among the retained items. McDonald's ω coefficient ($\omega = 0.853$) was also calculated and confirmed good consistency among the scale items.

The initial solution suggested the presence of four factors with eigenvalues greater than 1, which together explained 61.2% of the total variance. However, the fourth factor contained only one significant item (*The Universe and the Solar System*). For methodological purposes of our analysis, the presence of a single item of this nature is not necessary; therefore, it was excluded from the final analysis. Three items with factor loadings below .35 (*States of Matter, The Water Cycle* and *Heat and Temperature*) were removed; these had loadings of .317, .323 and .343 respectively. The variances explained after rotation are: Factor 1 = 19.5%, Factor 2 = 18.3%, Factor 3 = 13.7%.

Table 13. Scale A – Factor Analysis Results

Item	F1	F2	F3	I feel more capable when we study...
9	0.861			Forces
8	0.794			Energy
10	0.738			Electricity
11	0.696			Magnets
7	0.407		0.308	Solutions and mixtures

6	0.933		The Skeletal System
5	0.884		The Digestive System
4	0.522		The cell
1		0.690	Plants
2		0.624	Animals and their classification
3		0.579	Leaves

Scale B

Exploratory factor analysis (EFA) was conducted on 7 initial items relating to the perception of self-efficacy in scientific tasks.

The adequacy of the sample was confirmed by the Kaiser-Meyer-Olkin index (KMO = 0.809), which indicates good data adequacy, and by Bartlett's sphericity test, which yielded a significant result ($\chi^2(21) = 442.541$, $p < .001$), confirming the presence of sufficient correlations between the items. The overall internal reliability of the scale, calculated using Cronbach's alpha, was $\alpha = 0.789$, indicating good internal consistency among the retained items. McDonald's ω coefficient ($\omega = 0.789$) was also calculated and confirmed good consistency among the scale's items.

Initially, the analysis revealed two factors. However, the second factor contained only one significant item (*Writing down the activities we do in science*). For the methodological purposes of our analysis, the presence of a single item of this nature is not necessary; therefore, it was excluded from the final analysis. Furthermore, an additional item (*Using materials during experiments*) was removed from the analysis as it did not load sufficiently on any factor. In conclusion, the solution comprises a single factor, which explains a total of 29.0% of the total variance.

Table 14. Scale B – Factor Analysis Results

Item	**F4**	**I can…**
13	0.746	Explain science topics to my classmates if they haven't understood something
14	0.561	Work together with my classmates to better understand science topics
15	0.522	Encourage classmates to take part in discussions.
12	0.449	Make connections between science topics with each other
16	0.408	Do science experiments using hands-on materials

Scale C

Exploratory factor analysis (EFA) was conducted on 18 initial items relating to the perception of self-efficacy in science in primary school. These items refer to the sources of self-efficacy outlined by Bandura (1996) and to questionnaires found in the literature (Carroll, OECD).

The suitability of the sample was confirmed by the Kaiser-Meyer-Olkin index (KMO = 0.909), which indicates excellent data suitability, and by Bartlett's sphericity test, which yielded a significant result ($\chi^2(153) = 2321.117$, $p < .001$), confirming the presence of sufficient correlations between the items. The overall internal reliability of the scale, calculated using Cronbach's alpha, was $\alpha = 0.853$, indicating excellent internal consistency among the retained items. McDonald's ω coefficient ($\omega = 0.850$) was also calculated and confirmed good consistency among the scale items.

The analysis revealed a four-factor solution, which together account for 54.0% of the total variance. The individual factors accounted for 18%, 14.0%, 13% and 9% of the variance, respectively.

One item was excluded from the analysis as it did not load sufficiently on any factor (*My classmates like working with me during science lessons because they think I am good at it*).

Table 15. Scale C – Factor Analysis Results

Item	F5	F6	F7	F8	For each statement, indicate how true it is for you.
20	0.791				I am always successful in science
18	0.720				I get excellent grades in science
19	0.687				When science topics are explained to me, I understand the concepts very well
21	0.683				Science is easy for me
22	0.632				I learn science topics quickly
17	0.560				I do even the most difficult science homework well
24		0.888			I feel nervous when I think about science tests
23		0.878			When I think about science homework, I feel confused
26		0.837			I feel worried when I have to answer science questions
25		0.449			Even when I try really hard in science, I do badly
29			0.962		My classmates tell me I am good at science
28			0.809		My parents tell me I am good at science
27			0.596		My teacher tells me I am very good at science
30				0.781	When I see my science teacher doing science experiments, I imagine doing them myself
32				0.682	Watching my classmates use the science equipment helps me understand what to do
31				0.502	When I see a classmate doing a science experiment, I want to do it too
33				0.466	When I watch a cartoon or film about scientists, I imagine myself as the main character

Table 16. Summary of the scales included in the SE-IS in Study 3

Scales	***KMO***	***Bartlett's T-test***	***Cronbach's α***
A	0.836	$\chi^2(105) = 2189.644$, $p < .001$	0.852
B	0.809	$\chi^2(21) = 442.541$, $p < .001$	0.789
C	0.909	$\chi^2(153) = 2321.117$, $p < .001$	0.853

A summary of the factors emerging from the EFA is presented in Table 17.

Table 17. Description of the SE-IS factors

Factor	*Name*	*No. of items*
F1	Specific self-efficacy in physics and chemistry	4
F2	Specific self-efficacy in human biology	3
F3	Specific self-efficacy in plant and animal biology	3
F4	Self-efficacy in scientific tasks	5
F5	Mastery Experience	6
F6	Emotional State	4
F7	Verbal Persuasion	3
F8	Vicarious Experience	4

7.8.3 Convergent and Discriminant Validity

From the results obtained, it can be seen that the convergent validity of the questionnaire is ensured by the high factor loadings of the items associated with each factor (Bagozzi, 1981). To further examine this type of validity of the SE-IS questionnaire and to obtain indications regarding its discriminant validity, a Pearson correlation matrix was calculated based on the mean scores of the subscales (Hair et al., 2019). The results show numerous moderate correlations between the factors, supporting the consistency between theoretically related constructs (Table 18) and the fact that the subscales measure distinct constructs. Most correlations are positive and statistically significant ($p < .05$), with several of moderate magnitude ($r \geq .30$), which highlights the questionnaire's good convergent and discriminant validity.

F5 (Mastery experience) shows the highest number of positive correlations: it has moderate correlations with F1 (Self-efficacy in physics and chemistry), F2 (Specific self-efficacy in human biology) and F3 (Specific self-efficacy in the plant/animal world); it also shows high correlations with F4 (Self-efficacy in scientific tasks), with F7 (Verbal persuasion) and with F8 (Vicarious experience). The results are consistent with other studies describing the

Experience of mastery as one of the main sources of scientific self-efficacy (Bandura, 1996; Webb-Williams, 2018).

In contrast, F6 (Emotional State) shows generally lower correlations, confirming the relative autonomy of this affective dimension compared to the remaining cognitive and motivational components of scientific self-efficacy (Usher & Pajares, 2009).

Overall, the inter-scale correlations support the validity of the instrument and suggest that the various subscales of the SE-IS contribute to the measurement of distinct but related dimensions of scientific self-efficacy. These results are consistent with the literature (Webb-Williams, 2006; Usher & Pajares, 2009).

This evidence provides initial support for the convergent and discriminant validity of the instrument, which will need to be further verified through a confirmatory factor analysis (CFA) conducted on a different sample (see section 7.9) and using statistical indices calculable during the CFA.

Table 18 – Pearson correlation matrix

Factors	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
F1	--									
F2	0.48*	--								
F3	0.46*	0.25	--							
F4	0.47*	0.33*	0.36*	--						
F5	0.44*	0.39*	0.33*	**0.54**	--					
F6	0.10	0.21	0.11	0.10	0.30*	--				
F7	0.36*	0.39*	0.27	**0.51**	**0.59**	0.22	--			
F8	0.32*	0.24	0.27	**0.53**	0.41*	0.01	0.38*	--		

*Moderate correlations (.30–.50)
In bold: high correlations (>.50)

7.8.4 Discussion and modifications to the SE-IS

The results of the analyses indicate that the SE-IS questionnaire exhibits good preliminary psychometric properties and appears to be a promising tool for assessing the multiple aspects of scientific self-efficacy in primary school pupils.

The various factors identified through exploratory factor analysis provide a comprehensive and detailed representation of the construct, which has been extensively investigated and explored in the literature (Bandura, 1996; Webb-Williams, 2006; Usher & Pajares, 2009).

The high factor loadings of the items associated with each factor and the Pearson correlation between the factors—which revealed positive relationships, mostly of moderate strength—support the convergent and discriminant validity of the instrument.

Scale A revealed a 3-factor structure, which is also significant and useful for potential educational implications. Specifically, F1 analyses self-efficacy in physics/chemistry content; F2 assesses self-efficacy in content describing and classifying living organisms (plants and animals); F3 examines self-efficacy in human biology content (the skeletal system, the organ systems). Within the scientific community, the distinction between the so-called 'hard sciences' and the 'life sciences' is well established. This distinction is reflected in data on university and career choices, with a higher proportion of women in medical and biological degree programmes and a persistent under-representation in STEM fields such as physics, chemistry and engineering (NSF, 2023). The factors identified are therefore extremely useful for exploring possible gender differences in the perception of scientific self-efficacy as early as primary school.

Scale B revealed a single-factor structure (F4) describing perceived self-efficacy in performing scientific tasks (Bandura, 2006). This dimension is consistent with the literature on task-specific self-efficacy, which represents one of the most proximal and predictive aspects of behaviour (Carroll et al., 2023).

Scale C revealed a 4-factor structure, consistent with the theoretical model of the sources of self-efficacy proposed by Bandura (1996) and adopted by numerous subsequent studies (Webb-Williams, 2006; Usher & Pajares, 2006; Carroll et al., 2023). In detail: F5 assesses Mastery Experience in science and represents the component that Bandura defined as Mastery Experience (Bandura, 1996); F6 analyses Emotional State and represents the component that Bandura defined as Emotional State (Bandura, 1996); F7 focuses on Verbal Persuasion and represents the component that Bandura defined as Verbal Persuasion (Bandura, 1996); F8 analyses Vicarious Experience and represents the component that Bandura defined as Vicarious Experience (Bandura, 1996).

The clear distinction between the four sources represents an important element of the instrument's theoretical validity. The identification of these eight factors supports the theoretical coherence of the instrument and provides preliminary evidence of its factor structure, suggesting that the SE-IS is a promising tool for analysing scientific self-efficacy in primary schools.

However, the findings must be further explored through confirmatory factor analysis in order to verify the stability and validity of the identified structure.

7.9 Study 4: confirmatory factor analysis

In Study 4, conducted in January/February 2026, the third version of the SE-IS—revised following the completion of Study 3—was administered. It is divided into three sections or scales (A, B, C) and initially contained 33 items. In each section, participants were asked to respond to a 5-point Likert scale.

Confirmatory factor analysis (CFA) was used to verify the goodness of fit of the factor model emerging from the previous exploratory analyses on a sample of students different from those used previously, including in terms of geographical location. Following the analyses, two items were further removed.

The latest version of the SE-IS, comprising 31 items divided into 3 sections, can be found in the Appendix (Appendix D).

7.9.1 Participants and procedure

The SE-IS questionnaire was administered to a sample of 246 pupils (F=123, M=123), aged between 8 and 11 years. The pupils came from three different schools, located in the province of Pisa. The sample was therefore geographically expanded in order to validate the instrument with pupils from different locations and contexts.

The pupils completed the questionnaire via the Google Forms online platform, using tablets and/or computers. The data were collected anonymously. Completing the questionnaire took approximately 10–15 minutes per pupil.

Table 19. Sample composition (N = 246)

Demographic category	N (246)	Percentage
Gender		
Female	123	50%
Male	123	50%
Age		
8	67	27.24%
9	87	35.37%
10	69	25.94%
11	23	9.35%

7.9.2 Analysis methodology

In line with the results of Study 3, the measurement model includes eight latent variables: specific self-efficacy in physics/chemistry, specific self-efficacy in biology, specific self-efficacy in the plant/animal world, self-efficacy in specific tasks, mastery experience, emotional state, vicarious experience and social persuasion.

Unlike exploratory factor analysis (EFA), in which the number of factors is unknown, CFA requires researchers to have a defined theoretical hypothesis regarding the number of latent variables present in the model (Thompson, 2004).

The factors were allowed to covary (Lent et al., 1996), whilst the error terms were assumed to be uncorrelated. The items were specified so as to load exclusively on the relevant theoretical factor, without cross-loading. To ensure model identification, the first factor saturation coefficient was set at 1.0.

The model's goodness of fit was assessed using several indices commonly employed in literature, including the Comparative Fit Index (CFI), the Root Mean Square Error of Approximation (RMSEA), and the Standardised Root Mean Square Residual (SRMR) (Kline, 2016; Hu & Bentler, 1999). Furthermore, the significance tests of the factor loadings and the R^2 values were examined in order to assess the contribution of the items to their respective factors.

Finally, the Average Variance Extracted (AVE) and Heterotrait-Monotrait Ratio (HTMT) parameters relating to the factors were estimated, with the aim of conducting an in-depth study of the convergent and discriminant validity of the questionnaire, respectively.

The analysis was carried out using the JASP software (version 0.19.3).

7.9.3 Results of Study 4

The fit indices were interpreted according to the criteria suggested in the literature, with CFI and TLI values ≥ 0.90 indicating an acceptable fit and ≥ 0.95 a good fit, whilst RMSEA values ≤ 0.08 and SRMR ≤ 0.08 indicating an adequate model (Hu & Bentler, 1999; Kline, 2016).

The initial analysis revealed an unsatisfactory fit of the model hypothesised on the basis of exploratory factor analysis, with CFI = 0.860 and TLI = 0.840.

In order to improve the model fit, the structure was revised by removing certain items. Specifically, two items were removed, in line with theoretical and psychometric considerations: the item ‘Electricity’ from Scale A and the item ‘Linking science topics together’ from Scale B.

The final analysis showed an improvement in the fit indices, with values indicating a good fit of the model to the data: CFI = 0.932, TLI = 0.927, RMSEA = 0.064 and SRMR = 0.045. The chi-square test was significant ($\chi^2 = 814.350$, df = 406, $p < .001$), formally suggesting a suboptimal fit of the model. However, given the sensitivity of this index to sample size, the interpretation was supplemented with other fit indices, which collectively indicate a good fit of the model.

The factor loadings were all statistically significant ($p < .001$), and the R^2 values indicate that the items are effective in explaining the variance of their respective factors.

The AVE values are all above 0.50, indicating good convergent validity (Fornell & Larcker, 1981), whilst the HTMT values are below the threshold of 0.85, confirming adequate discriminant validity between the factors (Henseler et al., 2015).

Overall, the results obtained via CFA confirm the validity of the questionnaire’s factor structure, indicating a generally satisfactory fit of the model to the data and supporting the robustness of the model for measuring scientific self-efficacy among primary school pupils. The final version of the SE-IS questionnaire is provided in the appendix (Appendix D).

Table 20 CFA results

Index	**Value**
CFI	0.932
TLI	0.927
RMSEA	0.064
SRMR	0.045
χ^2	814.350
df	406

Table 21. Average Variance Extracted (AVE) results

Average Variance Extracted	
Factors	AVE
F1	0.543
F2	0.559
F3	0.577
F4	0.515
F5	0.540
F6	0.510
F7	0.503
F8	0.566

Table 22 Heterotrait-monotrait (HTMT) ratio

Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
1,000							
0.195	1,000						
0.163	0.830	1,000					
0.554	0.138	0.131	1,000				
0.414	0.301	0.298	0.649	1,000			
0.486	0.144	0.247	0.706	0.524	1.000		
0.271	0.141	0.110	0.390	0.678	0.166	1.000	
0.575	0.214	0.151	0.633	0.814	0.403	0.775	1.000

7.9.4 Discussion

At the conclusion of Study 4, the SE-IS questionnaire demonstrates robust psychometric properties that characterise it as a statistically adequate tool for analysing the scientific self-efficacy of primary school pupils (Kline, 2016).

CFA allowed us to empirically confirm the multi-factor structure that emerged in the exploratory analyses, strengthening the construct validity of the instrument (Brown, 2015), and eliminating some items for which the data did not fit the model. The improvement in fit indices following the model revision highlights that the changes made to the items were consistent from both a theoretical and psychometric perspective. These results support the suitability of the model for measuring scientific self-efficacy in the population under consideration.

The latest version of the SE-IS comprises 31 items divided into 8 factors. The structure of the instrument is multidimensional and allows for a comprehensive assessment of the various dimensions of scientific self-efficacy in primary school, including domain aspects, task-specific components and the main sources of self-efficacy (Bandura, 1996; Webb-Williams, 2018).

The results of the CFA indicate that the questionnaire is psychometrically sound and can be reliably used to assess aspects of scientific self-efficacy in primary school pupils (aged 8–11).

7.10 Conclusion

The aim of the research was to develop and validate a multidimensional questionnaire suitable for investigating the various aspects of scientific self-efficacy in primary school pupils. This need arose from reflections on young people's interest in and participation in the STEM field, a fertile and innovative area that is central to today's world of work (Liou et al., 2023).

In this regard, analysing scientific self-efficacy from primary school onwards allows us to focus on this construct from the earliest stages of learning, enabling us to design appropriate programmes to stimulate pupils' curiosity and interest in science.

Although tools for investigating scientific self-efficacy already exist in the literature (Trujillo & Tanner, 2014; Hu et al., 2022; Carroll et al., 2023), these have mostly been designed for older students and in contexts different from the Italian one. Following Bandura's (1996) guidelines, a questionnaire aimed at investigating self-efficacy must be developed in relation to a specific domain of activity, a particular context and a precise target population. From this perspective, the development of the SE-IS represents an innovative step, as there are still few tools specifically designed and validated to investigate scientific self-efficacy among primary school pupils in the Italian context.

Initially, the questionnaire was designed to investigate scientific self-efficacy alongside certain related constructs, deemed relevant on the basis of the literature, such as attitude towards science, general self-efficacy in the main school subjects, and certain aspects linked to motivation to learn. However, the analyses conducted during the validation process highlighted the need to progressively narrow the scope of the instrument to dimensions exclusively related to science self-efficacy. This methodological choice allowed for an increase in the theoretical coherence and psychometric accuracy of the questionnaire (Usher & Pajares, 2009).

The final questionnaire, comprising 31 items (Self-Efficacy - In Science), reflects a multidimensional structure of scientific self-efficacy and possesses psychometric properties suitable for analysing this construct in primary school pupils (Kline, 2016). The multidimensional nature of the instrument is a strength, as it allows for the investigation not only of the general perception of competence in science, but also of more specific dimensions related to content areas, scientific tasks, experiences of mastery, emotional states, verbal persuasion and vicarious experience.

Studies conducted during the validation process led to several changes in the structure of the items. In particular, items that were not adequately linked to scientific self-efficacy or that showed less consistency with the theoretical structure of the instrument were progressively eliminated. Exploratory factor analyses, conducted on the various versions of the questionnaire, enabled the modification, addition and removal of several items and provided evidence of high content validity, internal consistency and criterion validity. Subsequently, confirmatory factor analysis allowed the quality of the emerging structure to be verified, consolidating the evidence of the instrument's validity.

The results obtained are consistent with existing studies in the literature on self-efficacy and its sources (Usher & Pajares, 2009; Trujillo & Tanner, 2014; Carroll et al., 2023). In particular, Pearson's correlation analysis revealed significant associations between the various factors of the questionnaire. Among these, the factor relating to the experience of mastery shows particularly strong correlations with almost all other dimensions, suggesting the central role of this source in the development of self-efficacy, in accordance with Bandura's (1996) theory.

However, as Usher & Pajares (2009) have already pointed out, the relationship between sources and self-efficacy should not be generalised to other contexts. The sources that fuel students' confidence in science may differ from those in other areas, such as writing or foreign language learning, or at other educational levels. Furthermore, the processes by which individuals integrate information regarding their own efficacy may be non-linear. For this reason, whilst providing encouraging results, the present study requires further investigation on larger and more diverse samples, in order to strengthen the generalisability of the instrument to the entire Italian context.

Future research may involve testing the validity of the items across different contexts and domains, as well as further expanding the sample.

In this regard, the SE-IS represents not only a contribution to research on scientific self-efficacy but also a potential resource for teaching practice. Teachers could use it to understand the extent to which classroom activities promote the development of students' scientific self-efficacy and to identify any particularly critical areas requiring intervention. Furthermore, the instrument may prove useful for the early analysis of any gender differences in scientific self-efficacy, enabling the design of more inclusive teaching interventions that ensure the participation of all students.

In light of these considerations, the SE-IS questionnaire can be regarded as an innovative tool for the Italian primary school context. Whilst requiring further analysis on larger and more representative samples, it offers an initial empirical basis for the multidimensional study of scientific self-efficacy and for the design of teaching programmes geared not only towards conceptual learning but also towards strengthening students' perception of competence in the scientific domain.

In the following chapter, the third version of the SE-IS questionnaire, developed at the end of Study 3, was used within a TLS, with the aim of analysing its applicability in a real-world context.

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CHAPTER 8

EXPERIMENTAL STUDY: DESCRIPTION

The results obtained at the end of the pilot study presented (Chapter 6) were encouraging and highlighted the need to continue the research, focusing on gender differences in Science Self-Efficacy in primary school.

Based on the discussions in the previous chapters, we conducted a second TLS on energy: the underlying hypothesis is that the use of an active methodology such as ISLE (Investigative Science Learning Environment) can promote both the acquisition of knowledge and skills regarding the concept of energy in primary school pupils and contribute to the development of scientific self-efficacy (SSE) to a greater extent than a traditional methodology.

This study represents the experimental phase of the research project, in which 71 primary school pupils took part, divided into a control group (CG) and an experimental group (EG). The sample was constructed using a non-probabilistic approach, taking into account the school's particular focus on STEAM subjects, gender differences, and the openness shown by teachers and all staff towards experimentation and research.

8.1 Research objectives and experimental study design

The TLS was conducted using a quasi-experimental design with two equivalent groups. The experimental design used is defined as quasi-experimental (Benevento, 2015) because the sample is not representative of the target population and we cannot know to what extent the changes observed in the dependent variable were the result of the independent variable or were caused by confounding variables (maturation of the subjects, history, administration of the tests).

The design used in this research, namely the quasi-experimental design with two equivalent groups, is very commonly used in educational research (Benvenuto, 2015), due to the fact that it is more complex to randomise participants in schools.

We therefore identified two groups: the experimental group (EG) and the control group (CG). The first receives the experimental treatment and the second continues to follow traditional educational practice. Initially, we verified that the members of the two groups had similar characteristics in relation to the variable under study, which in this case concerns the importance attributed by pupils to intrinsic professional values: age, year group, gender, cognitive abilities. Subsequently, we verified the equivalence between the two groups.

The fundamental principle underpinning this design can be formulated as follows: if two distinct treatments (in our case, the ISLE methodology and a traditional methodology) are administered to two homogeneous groups (i.e. classes from the same year group and the same area), which at the end of the treatment are subjected to the same test designed to measure the effects of the treatments themselves, the results may be either identical or different. In the first case, the two treatments would be equivalent, whilst in the second case, one of the treatments would prove more effective than the other (Ferrara & Anello, 2025).

This design involves an initial and a final instruction: pre-instruction and post-instructions. After administering the pre-instruction, a comparison was made between the results obtained by the two groups in order to ensure equivalence between them. Subsequently, both groups underwent a TLS of the same duration, covering the same educational content but using different methodologies.

The results of both the pre-instruction and post-instruction will be presented in Chapter 9.

8.2 Research questions and methodological approach

Based on the results obtained at the end of the pilot study, we redesigned a 12-hour TLS on the topic of energy for Italian fifth-grade pupils (aged 10–11). The main objectives of the planned methodological activities were to help pupils become aware of the concept of energy whilst promoting their Scientific Self-Efficacy (SSE).

The five participating classes came from a single school and volunteered to take part in the project. The programme was delivered by one of the researchers who had developed the TLS in all participating classes. These were divided into an Experimental Group (EG) and a Control Group (CG). It was not possible to randomly assign students to one of the two groups, but the classes chose independently to participate in either the experimental or control group. Within the first group, the sequence was implemented using the ISLE methodology (Etkina, 2015), consistent with the constructivist approach (Dui & Treagust, 1998). Within the second group, the pupils did not play an active role but a more traditional one, as the experiments and activities were carried out by the researcher, following a more traditional and transmissive methodology.

The comparison between the EG and GC groups therefore allows us to isolate the specific effect of the ISLE approach on both the acquisition of scientific knowledge relating to energy and the development of students' scientific self-efficacy.

The following three research questions (RQ) were posed in the study:

RQ1. What common-sense conceptions of energy emerge in fifth-grade primary school students before the TLS?

RQ2. To what extent does an ISLE-based TLS, compared to a traditional intervention, facilitate the transition from common-sense knowledge to scientific knowledge of energy in fifth-grade primary school students?

RQ3. To what extent does an ISLE-based TLS, compared with a traditional teaching intervention, promote the development of science self-efficacy in male and female fifth-grade primary school students?

8.3 Research context and participants

The study sample consists of 71 pupils (M= 39, F=32) aged between 10 and 11 years attending Year 5, divided into the control group (CG) and the experimental group (EG). The control group (CG) consists of 26 pupils, whilst the experimental group (EG) consists of 45 pupils. The various classes chose independently to be part of one of the two groups.

8.3.1 The broader context

The students involved in the experiment come from the 'Karol Wojtyla – Pontefice' State Comprehensive School, located in Santa Flavia, a small town situated approximately 30 km east of the metropolitan city of Palermo.

The local economy is predominantly based on deep-sea and coastal fishing. Tourism-related activities, as well as the canning and food industries—often family-run businesses dating back to the early 20th century—are also significant. Industry (comprising small and medium-sized enterprises) and craft trades are not particularly significant in economic terms. The economic crisis, which is affecting families with increasing severity, the limited opportunities offered by the local area for sport and leisure activities, and the lack of cultural and/or recreational facilities and spaces, as well as child-friendly urban areas, make the School's role as a bastion of legality and a privileged meeting place for peers and across generations essential.

In this context, the School reaches out to the local community, collaborating with associations and institutions, positioning itself as an important cultural centre and hub for young people and families.

The Institute currently has service delivery points located in the municipality of Santa Flavia and in the hamlets of Porticello and Sant'Elia. This results in a diverse student population drawn from the three different municipalities (Santa Flavia, Porticello, Sant'Elia).

8.3.2 The micro-context: control group

The control group (CG) consists of 26 students (M= 11, F= 15), belonging to classes 5A and 5B at the Porticello school complex. The two classes have had the same subject teachers since the first year of primary school and have always shared similar educational objectives and curricula.

The pupils are predominantly Italian, with the exception of three pupils (one from Venezuela and two from Egypt).

Their socio-cultural background is lower-middle class, with several disadvantaged family situations, in line with the school's general context.

Class 5A has one pupil with a hearing impairment and a support teacher for 12 hours a week. During the 2024/2025 academic year, a new pupil from Venezuela was admitted to the class, whose understanding of Italian is barely sufficient.

Class 5B has one pupil with an autism spectrum disorder. He benefits from Law 104/92, Article 3, paragraph 3, and a support teacher for 22 hours a week.

All pupils actively participated in the TLS. No adjustments were made for pupils with disabilities. Due to language difficulties, the Venezuelan pupil was supported by the class teacher in writing down activities and carrying out the pre-instruction and post-instruction.

8.3.3 The micro-context: experimental group

The experimental group (EG) consists of 45 pupils (M=25, F=20) from class 5A at the S. Elia school complex and classes 5B and 5C at the S. Flavia school complex. The classes have not had the same teachers— over the years, but the latter have developed joint lesson plans with the aim of creating similar learning pathways across the different classes.

The socio-cultural background of the pupils is lower-middle class, with several disadvantaged family situations, in line with the general context of the school.

In class 5A of the S. Elia school complex, there are three pupils with disabilities. All benefit from Law 104/92, Article 3, paragraph 3, and a support teacher for 22 hours per week. Pupil 1: spastic diplegia, generalised psychomotor and language delay in a child with corpus callosum atrophy. Pupil 2: learning difficulties and executive function (EF) disorders in a child with conotinal CMV, graphic EE anomalies and graphic MRI findings. Pupil 3: Autism Spectrum Disorder. Pupils took part in teaching activities with some adaptations.
In particular, pupil 1 took part in the teaching activities with some adaptations; he was supported by the class teacher, described experiences verbally rather than in writing, and completed neither the SE-IS nor the knowledge test. Instead, a brief simplified oral assessment of the contents addressed during the TLS was carried out. The learning objectives were differentiated according to his abilities, in agreement with the teachers.
The remaining two pupils took the TLS without any modifications but they were supported by the class teacher.

In class 5B at the S. Flavia school complex, there is a pupil with global developmental delay. He benefits from Law 104/92, Article 3, paragraph 3, and receives support from the support teacher for 22 hours per week. He took the TLS without any modifications. During the 2024/2025 academic year, a new pupil from Germany, with limited knowledge of the Italian language, was placed in the class. Due to language difficulties, the pupil was supported by the class teacher in writing the activities and carrying out the Pi and Pf.

In class 5C at the S. Flavia school complex, there is a pupil with an autism spectrum disorder. He benefits from Law 104/92, Article 3, paragraph 3, and receives support from a special needs teacher for 22 hours a week. In addition, there is a pupil with special educational needs (BES in Italian version) who has dysgraphia, for whom an Individualised Education Plan (PEI in Italian version) has been drawn up. Both pupils completed the TLS without any modifications. The pupil with dysgraphia was given an extra 15 minutes to complete the written and practical tests.

8.4 Design of the TLS

The TLS has a dual purpose: on the one hand, it aims to foster the development of pupils' scientific self-efficacy; on the other, it seeks to promote the acquisition of scientific knowledge and skills relating to energy through practical and engaging teaching activities.

The implementation was carried out by l'autrice di questa tesi who developed the TLS in all participating classes, in both the EG and the GC. The activities within the two groups are the same, but conducted in different ways.

Although the number of pupils is adequate given the exploratory and applied nature of the intervention, the samples are limited and do not allow the results obtained to be generalised to the entire population of primary school pupils. The pupils involved belong to specific schools and geographical contexts; consequently, the characteristics of the classes, teachers, schools and the socio-cultural context may have influenced the results obtained.

In this study, the EG serves to verify the effectiveness of the ISLE both in the acquisition of new energy-related skills and in the development of SSE in Year 6 pupils, by comparing the results obtained in the GC. The ISLE therefore represents the experimental treatment administered in the EG. The experimental design is presented in Table 1.

Table 1 Experimental design

Groups	Pre- instruction	Experimental treatment	Post- instruction
Experimental group (EG)	Yes	Yes	Yes
Control group (CG)	Yes	_	Yes

8.5 Data collection and analysis methodology

Among the various methodological approaches that can be used in the field of educational research, we have decided to adopt so-called mixed-methods models, which represent an approach that integrates both quantitative and qualitative tools and techniques, with the aim of obtaining a more comprehensive and nuanced understanding of the phenomena under study. According to Creswell and Garrett (2008), this approach allows for the combination of objective measurement of outcomes (via standardised tests) with the exploration of the subjective experiences of students and teachers (through recordings, interviews or focus groups), thus offering a richer and more nuanced view of teaching and learning processes.

There are various data collection tools suitable for the research questions. Given the mixed-methods approach mentioned above, both qualitative and quantitative tools were used.

Among the highly structured tools, the SE-IS questionnaire (Appendix C), the knowledge test and systematic observations were used. Among the less structured tools, documents produced by the pupils themselves were used, such as parts of their exercise books, diagrams and recordings made during classroom activities. Both the SE-IS and the knowledge questionnaire were administered at the start and end of the TLS, representing the pre-instruction and the post- instruction. Comparison between the pre and post-instruction allows for the assessment of changes that occurred in the two groups during the intervention. In the control group (GC), these changes are attributed to the ordinary factor (Fo), i.e. normal teaching activity; in the experimental group (EG), however, they are related to the experimental factor (Fe), i.e. the proposed intervention. The comparison between the results obtained by the control group (CG) and those obtained by the experimental group (EG), therefore allows us to estimate the effectiveness of the educational intervention and to verify whether the improvement observed in the experimental group is greater than that attributable to ordinary teaching alone (Benvenuto, 2015).

8.5.1 The knowledge questionnaire

The knowledge questionnaire was previously used in the pilot study (see Chapter 6). It is based on the research conducted by Colonnese et al. (2012), carried out in a primary school with pupils aged between 10 and 11.

Validation had already been carried out previously (see 6.5.2) and no changes were made to it following the pilot study.

The questions in the questionnaire are as follows:

- Question 1. What do you know about energy?
- Question 2. As far as you know, are there things that provide energy?
- Question 3. As far as you know, are there things that have or possess energy?
- Question 4. Can energy be conserved? In your answer, explain what you mean by ‘conserved’.
- Question 5. Can energy be transformed? Explain, giving some examples.
- Question 6. Is it possible to lose energy? Explain, giving some examples.
- Question 7. What ‘types’ of energy do you know of?
- Question 8. What is the difference between renewable and non-renewable energy sources?

Data analysis was conducted using an integrated qualitative and quantitative approach.

In particular, the qualitative analysis was carried out using a phenomenographic analysis: open-ended responses were classified into common sense knowledge, partially scientific knowledge and scientific knowledge (Marton, 1981), using a classification rubric (see 6.5.2), devised and used during the pilot study.

In order to compare the EG and the GC using statistical methods, different scores were assigned to the responses. Responses classified as common knowledge were awarded 1 point; responses classified as partially scientific knowledge were awarded 2 points; finally, responses classified as scientific knowledge were awarded 3 points. No responses were awarded 0 points. Each student therefore received a specific score.

The quantitative analysis was carried out using Linear Mixed Models (LMM), considering the group (experimental group vs control group), time (pre- instruction vs post- instruction) and their interaction as fixed effects. This analysis made it possible to verify not only any general improvement between the first and second assessments, but above all whether this improvement differed between the two groups, and was therefore attributable to varying degrees to the teaching methodologies adopted (West et al., 2022).

8.5.2 The SE-IS questionnaire

During this study, the Self-Efficacy in Science (SE-IS) questionnaire was administered, with the aim of analysing the pupils' level of Scientific Self-Efficacy (SSE) at the start and end of the TLS.

Compared to the pilot study, the third version of the SE-IS was administered (see Chapter 7). It was validated through Exploratory Factor Analysis (EFA), conducted with a sample of 266 Sicilian pupils (F=117, M=148), aged between 8 and 11 years (Costello & Osborne, 2005; Pajares & Uscher, 2006; DeVellis & Thorpe, 2021). In addition to construct validity and internal consistency (Cronbach's alpha), convergent validity was also examined in Study 3. At the conclusion of the analysis process for Study 3, the SE-IS comprises 33 items divided into 3 sections (A-B-C). The questionnaire items were rated on a Likert-type ordinal scale (from 1 to 5).

The third version of the SE-IS is available in the Appendix (Annex C).

The results confirmed that the SE-IS questionnaire is a statistically valid and significant tool for assessing the multiple aspects of scientific self-efficacy (SSE) in primary school pupils. Through EFA, eight factors were identified, consistent with the literature (Bandura, 1997; Usher & Pajares, 2009; Carroll et al., 2023). To examine the convergent validity among these factors, a Pearson correlation matrix was calculated based on the mean scores of the subscales (DeVellis & Thorpe, 2021). The results show numerous moderate correlations between the factors, supporting the consistency among the theoretically related constructs. For further information on the validation process of the SE-IS questionnaire, please refer to Chapter 7.

Table 2 presents the 8 factors identified in the SE-IS.

Table 2. SE-IS factors at the end of the third validation

Factor	Name	No. of items
F1	Specific self-efficacy in physics and chemistry	4
F2	Specific self-efficacy in human biology	3
F3	Specific self-efficacy in plant and animal biology	3
F4	Self-efficacy in scientific tasks	5
F5	Mastery Experience	6
F6	Emotional State	4
F7	Verbal Persuasion	3
F8	Vicarious Experience	4

The SE-IS questionnaire was administered as a pre- instruction and post-instruction in both the EG and the GC.

Given the study's longitudinal design (pre/post) and the presence of repeated measures on the same participants, the analysis was conducted using Linear Mixed Models (LMM), employing the JASP software. This approach allows for the simultaneous modelling of the effects of time (pre- instruction vs post- instruction), group (Control Group vs Experimental Group) and gender (males vs females), as well as their interactions.

This analysis allowed us to observe and analyse the baseline situation of the two groups, identify statistically significant differences between males and females, and any statistically significant changes in the variables between the first and second administrations.

In the next chapter, we will present the results obtained from the SE-IS questionnaire and the knowledge questionnaire, reporting the data obtained from the CG and the EG.

8.6 Implementation of the TLS

In both the GC and the EG, the TLS consisted of 12 hours divided into an initial session, a final session (each lasting one hour) dedicated to administering the tests, and five sessions (each lasting two hours).

The goals, objectives and content proposed are the same as those presented for the pilot study (see 6.5).

8.6.1 Methodological choices: Experimental Group

In the Experimental Group (EG), the ISLE (Investigative Science Learning Environment) methodology was adopted, consistent with a constructivist approach to science learning (Duit & Treagust, 1998; Etkina, 2015). ISLE therefore represented the Experimental Factor (EF) applied in the EG. The activities were conducted by the external researcher.

From a theoretical perspective, the ISLE approach explicitly integrates the affective dimension into its educational objectives, positing that the learning process should not only facilitate the construction of knowledge but also promote student well-being, motivation, a sense of belonging and confidence in one's own abilities (Etkina, 2015).

The students were actively involved in all stages of the inquiry process: observation of phenomena, formulation of hypotheses, design and conduct of experiments, data collection and interpretation, and collective discussion of the results.

The activities were structured around a guided inquiry cycle, in which the teacher took on the role of facilitator and cognitive mediator, posing stimulating questions and supporting pupils' metacognitive reflection, without providing pre-established explanations. This approach fosters the active construction of scientific knowledge and the reorganisation of common-sense conceptions (Brookes et al., 2020).

The students worked predominantly in cooperative learning groups, comparing their ideas within the group and negotiating shared meanings. This structure fostered both conceptual deepening and the development of cross-curricular skills, such as argumentation and collaboration.

The activities and lesson plans were implemented taking into account the different phases of the ISLE methodology model (Etkina, 2006).

The teacher stimulated the students' attention and interest by providing opportunities to make connections between prior knowledge and new learning experiences, thereby directing their thinking towards the learning objectives (Abdi, 2014). This was achieved through brainstorming and guided discussions, fostering a supportive emotional atmosphere. The activities were structured with the aim of creating learning environments that would allow students to observe scientific processes, record data, design and plan experiments, formulate hypotheses and organise their own observations. The teacher limited their role to asking questions, suggesting approaches, providing feedback and assessing the level of understanding achieved. These activities supported a qualitative understanding of the content, whilst promoting the experience of mastery and vicarious experience, two key sources of self-efficacy. In the group discussions following each activity, the students articulated their observations, during which the teacher guided them towards coherent and consistent generalisations, supported them in the use of specific scientific vocabulary, and asked questions to help them use that vocabulary to explain the results of their explorations (Abdi, 2014). Furthermore, activities were proposed to encourage the application of emerging energy concepts in new situations, reinforcing conceptual integration and the students' sense of competence. Finally, assessment phases were incorporated throughout the TLS, via ongoing discussions and pre/post questionnaires.

From this perspective, ISLE was not used exclusively as a set of teaching strategies, but as a framework for designing the intervention, capable of combining conceptual learning on the topic of energy with the motivational dimensions linked to scientific self-efficacy (SSE). The distinctive features of this methodology—namely, the active involvement of students, the cyclical nature of the inquiry process, and the collaborative dimension of learning—characterised the proposed TLS, activating the main sources of self-efficacy identified by Bandura (1997) and supporting pupils' perception of competence in scientific activities (Etkina et al., 2019; Brookes et al., 2020).

8.6.2 Methodological choices: Control Group

In the control group (CG), the same TLS was implemented in terms of content, duration and materials, but using a more traditional and transmissive teaching approach. Laboratory activities and experiments were predominantly conducted by the researcher, whilst pupils were asked to observe, listen to explanations and, in some cases, replicate the procedures demonstrated.

This approach reflects a widely adopted teaching practice in science education, particularly in school settings where the teacher assumes the role of primary knowledge mediator and guides the learning process through frontal explanations and guided demonstrations (Fensham, 2009; Osborne, 2014). In this approach, the experimental activity primarily serves to illustrate and confirm the concepts presented, rather than facilitating independent exploration by the students.

Although the GC took part in practical activities, the pupils' role remained largely observational and guided, with limited scope for the independent formulation of hypotheses, the design of experimental tests and peer discussion. The activities were not structured according to an inquiry cycle, nor was there any systematic use of cooperative learning, elements that the literature identifies as central to promoting meaningful learning (Hmelo-Silver et al., 2007; Minner et al., 2010). Neither discussion nor exploration of the concepts involved is encouraged. This tends to neglect critical thinking and the unifying concepts essential for genuine scientific literacy and an appreciation of science (Yore, 2001). The underlying principle was that knowledge should take the form of information transmitted directly to the students.

The CG, therefore, did not receive the experimental treatment—that is, the systematic use of the ISLE methodology—but was subjected to the ordinary factor (Fo). In this sense, the CG constitutes a fundamental point of comparison for assessing whether and to what extent the systematic adoption of ISLE produces differential effects on learning and on the dimensions of Scientific Self-Efficacy (SSE) analysed.

8.7. Classroom activities

The activities have been structured on the basis of the results obtained in the pilot study. The learning outcomes, objectives and content have remained the same (see Chapter 6).

Some changes were made to the activities concerning renewable and non-renewable energy sources, potential energy and thermal energy.

In the pilot study, the pupils had divided a number of images (power stations, wind turbines, solar panels) into two groups, identifying whether they were renewable or non-renewable energy sources. The activity had been carried out during circle time, using images displayed on the interactive whiteboard. It was perceived as too simple and did not allow for the development of hypotheses or discussions among the pupils. For this reason, the images were modified in the trial, with new ones being added.

In the pilot study, on the fourth day, the pupils carried out some group experiments on potential energy. Each group carried out a different experiment and, once the time was up, the pupils moved on to the next station, carrying out a different activity. Finally, they compared their hypotheses with the observed results. This approach caused confusion in some classes. For this reason, during the trial phase, it was decided to have all pupils carry out the same experiment simultaneously (while maintaining the cooperative learning structure), and at the end of this, an initial comparison phase between the groups took place. Subsequently, all pupils moved on to the next experiment. This ensured greater concentration and understanding of the content.

On the fifth day, an experiment on the conversion of thermal energy (the plate and the hammer) was added. The reason for this was that the pilot study confirmed that this topic was particularly complex for the students; therefore, it was deemed necessary to provide a further practical demonstration.

Finally, at the end of the activities, a video summarising the concept of energy transformation was shown, which covered many of the experiments carried out in class.

Below is a summary table (Tab. 3) of the five sessions with the corresponding activities carried out in both groups. At the end of each session, in both groups, there was a collective oral discussion phase, followed by individual reflection in the notebook.

After the description of each day of the teaching-learning sequence conducted with the experimental group, day-by-day tables were added (Tables 4–8). These tables summarise the activities carried out and explicitly map them onto the corresponding ISLE components, highlighting the role of each activity within the ISLE framework.

Table 3. Outline of activities

Lesson	Activity	Experimental group	Control group
1st	Introduction to the concept of energy	Brainstorming on energy. Activity carried out during circle time.	Brainstorming on energy. Activity carried out during circle time.
	Introduction to the difference between renewable and non-renewable energy.	The pupils are divided into small groups and given worksheets with images of different energy sources. They must sort them into two groups and explain the reasons behind their choices. Once finished, the groups discuss their findings and present their hypotheses.	The pupils look at pictures of various renewable energy sources and must sort them into two distinct groups. Activity carried out on the interactive whiteboard during circle time and led by the teacher.
	Viewing and discussion of the characteristics of renewable and non-renewable energy.	Viewing of a video on renewable and non-renewable energy. Guided discussion during circle time.	Watching a video on renewable and non-renewable energy. Guided discussion during circle time.

	Creation of a concept map on renewable and non-renewable energy.	Working in pairs, the pupils create a map in their workbooks summarising the main characteristics of renewable and non-renewable energy sources.	The teacher collects the students' ideas and, together with them, creates a mind map summarising the main characteristics of renewable and non-renewable energy sources.
	Reading and analysing food labels.	Analysis of nutritional values on food products and discussion of the meaning of the energy values shown. The activity is carried out in small groups using products brought in by the pupils.	Analysis of nutritional values on food products and discussion of the meaning of the energy values shown. The activity is carried out during circle time and the teacher displays various labels on the interactive whiteboard.
	Verbal and written summaries of the activities carried out.	During circle time, the pupils describe the activities carried out during the lesson verbally and then write them down in their notebooks.	During circle time, the pupils describe the activities carried out during the lesson verbally and then write them down in their exercise books.
2nd	Summary of the previous lesson.	The teacher asks the pupils to summarise the activities carried out in the previous lesson.	The teacher asks the pupils to summarise the activities carried out in the previous lesson.
	Teacher-led discussion	During circle time, the teacher asks open-ended questions to encourage reflection on the topic of 'human energy'.	During circle time, the teacher asks open-ended questions to encourage reflection on the topic of 'human energy'.
	Practical activity on kinetic energy: *The bicycle and the dynamo*	Experiment carried out in pairs. The pupils will try to understand how to power the dynamo battery using the bicycle. Each pair tries out and tests their own hypotheses, until one pupil spins the bicycle with their hands and the other places the light bulb on the wheel. The teacher asks the pupils to describe the phenomenon they have observed and to analyse its consequences.	During circle time, the pupils will discuss how to power the dynamo battery using the bicycle. The teacher demonstrates the correct procedure for the experiment and explains the phenomenon observed. The pupils then replicate the experiment they have observed.

	Practical activity on kinetic energy: *The speed of the bike*	Experiment carried out in pairs. The pupils formulate hypotheses on how the speed of the wheel will change before and after placing the light bulb on the wheel. Each pair carries out the experiment and proposes an explanation for the observed phenomenon.	The pupils formulate hypotheses about how the wheel's speed will change before and after placing the light bulb on the wheel. The teacher demonstrates the experiment and leads a discussion to understand the observed phenomenon.
	Verbal and graphical description of the activities carried out	During circle time, pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Joint discussion of a definition of kinetic energy.	During circle time, pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Joint discussion of a definition of kinetic energy.
3rd	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Practical activity on kinetic energy	The pupils are divided into small groups and each is given a small generator connected to an LED. They suggest different ways to light up the LED.	During circle time, the teacher shows a small LED connected to a generator and asks the pupils for other ways to light it up, without using their hands.
	Experiment: building *a water turbine*	Working in small groups, the pupils build a small, rudimentary water turbine, to which the LED used previously is connected.	The teacher shows the micro-energy generator to which they have attached small wind blades.
	Practical activity on kinetic and potential energy: *the water turbine*	Working in groups, the students try to light the bulb by pouring water from different heights. The pupils note down what happens to the light bulb depending on the height from which the water is poured.	The children watch the teacher carry out the experiment. Water is poured onto the blades from different heights.
	Guided discussion	During circle time, the teacher asks open-ended questions about the activity and highlights various concepts: obtaining energy from non-living things	During circle time, the teacher asks open-ended questions about the activity and focuses on various concepts: obtaining energy from non-living sources (water and

		(water and wind), the transformation of energy (from kinetic to light), and the concept of height.	wind), the transformation of energy (from kinetic to light), and the concept of height.
	Verbal and written expression	During circle time, pupils describe the activities carried out during the lesson verbally and then write them down in their notebooks.	During circle time, the pupils describe the activities carried out during the lesson verbally and then write them down in their exercise books.
4th	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Practical activity on kinetic energy	The teacher shows a toy turbine to demonstrate the fall of objects (sand, stones, balls) to introduce the concept of potential energy.	The teacher shows a toy turbine to demonstrate the fall of objects (sand, stones, balls) to introduce potential energy.
	Practical activity on potential energy: *sand and balls*	The pupils are divided into small groups. Each group is given a container with sand, balls and a ruler. They are not given any instructions on how to use the equipment. They note down their observations in their notebooks.	The teacher carries out the experiment using a container with sand and balls and demonstrates the effects obtained by dropping them from different heights.
	Guided discussion	The teacher asks the various groups to present their hypotheses and observations noted down during the experiment. The pupils discuss their findings with one another.	The teacher asks the children thought-provoking questions to focus their attention on height and weight.
	Practical activity on potential energy: *toy cars*	The pupils are divided into small groups. Each group is given wooden planks of different lengths and two or more toy cars. They are not given any instructions on how to use the materials. They note down their observations in their notebooks.	The teacher shows wooden planks of different lengths and two toy cars. Through guiding questions, the teacher invites the pupils to suggest different experiments to carry out with the materials provided.

			The teacher demonstrates what happens when the same toy car is dropped from different heights.
	Guided discussion	The teacher asks the various groups to present their observations. The focus is on the different heights from which the toy cars are dropped and the different results obtained.	The teacher draws attention to the effects observed in the different situations, carefully noting the speed of the various toy cars. The teacher asks the children open-ended questions about the height of the ramps.
	Verbal and written expression	During circle time, the pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Joint discussion of a definition of potential energy.	During circle time, the pupils describe the activities carried out during the lesson and then write them down in their exercise books. The class agrees on a definition of potential energy.
5th	Summary of the previous lesson	The teacher asks the pupils to summarise the activities carried out in previous lessons.	The teacher asks the pupils to summarise the activities carried out in previous lessons.
	Guided discussion on the concept of transformation and energy transformation	During circle time, the teacher asks open-ended questions that refer back to the experiments already carried out to focus attention on the concept of energy transformation.	During circle time, the teacher asks open-ended questions that refer back to the experiments already carried out to focus attention on the concept of energy transformation.
	Practical activity on thermal energy: *The whisk and water*	Each pair is given a container of water and a whisk (not electric). The pupils stir the water with the whisk and reflect on the concept of kinetic energy.	The teacher rotates a whisk (non-electric) in a container of water and uses a thermal camera to show the different temperatures recorded before, during and after the experiment.
	Practical activity on thermal energy: *The metal plate and the hammer*	Working in pairs, the children strike a metal plate with a hammer and observe the temperature change using the thermal camera.	The pupils watch the teacher strike the plate with the hammer and observe the temperature change using the thermal camera.
	Practical activity on thermal energy:	The pupils rub a section of the desk with an eraser and use the	The pupils rub a section of the desk with an eraser and observe the rise

	the eraser and the desk	thermal camera to observe the rise in temperature.	in temperature using the thermal camera.
	Watching a summary video on energy conversion.	The pupils watch a video showing various experiments on energy conversion, some of which are carried out in the classroom.	The pupils watch a video showing various experiments on energy conversion, some of which are carried out in the classroom.
	Verbal and written expression	During circle time, pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Group discussion of a definition of thermal energy.	During circle time, pupils verbally describe the activities carried out during the lesson and then write them down in their notebooks. Joint discussion of a definition of thermal energy.

8.7.1 DAY 1

The first session was divided into three stages.
The first activity was a brainstorming session on energy. The second part of the lesson was devoted to renewable and non-renewable energy sources, through the study of a map, watching videos and a guided discussion. Finally, an in-depth exploration of the link between food and energy was proposed. The activity served a dual purpose. On the one hand, it capitalised on the pupils’ natural interest in their own bodies by introducing ‘human energy’ as something that can be obtained from the food we eat, within a purely vitalistic, ‘ ’ view of energy. On the other hand, the topic of healthy and mindful eating is a hotly debated issue in this day and age, when childhood obesity is increasingly prevalent.

Learning objectives

-Identify the main characteristics of renewable energy sources
-Identify the main characteristics of non-renewable energy sources
- Recognise and analyse the relationship between energy and food
-Reflect on mindful eating

Description (Experimental Group)

The pupils were encouraged to suggest words they thought might be linked to this scientific concept (Fig. 1).

Common themes emerged across all classes, namely words related to movement (running, jumping) and food (sugar, fizzy drinks), linking energy to movement and living beings. However, some elements differed.

In class VA, many words related to everyday electrical appliances (PCs, tablets, washing machines, TVs) and power stations (nuclear, hydroelectric) emerged.

In class 5B, many words related to means of transport (car, scooter, petrol) and elements such as the sun, water and wind (including solar panels and wind turbines) emerged.

In class VC, many words related to forms of energy emerged, some scientifically accurate such as wind and hydroelectric power, others linked to common knowledge, such as muscle power and solar energy.

In no instance was the concept of energy linked to heat or to non-technological inanimate objects.

In the second activity, the pupils were divided into small groups and given worksheets featuring images of various energy sources. The groups worked independently to categorise the energy sources into two different groups. The groups shared a variety of hypotheses with one another.

The first classification used was one that identified a group comprising wind, sun, water, natural gas and heat (as these are natural elements) and a group comprising uranium, petrol and coal (as these are artificial elements). A further hypothesis put forward was to group together elements that can be harmful to humans (uranium, coal, the sun as it is dangerous due to ultraviolet rays, petrol). Another hypothesis was to group together elements that can cause a rise in temperature or fires (the sun, coal, geothermal heat, petrol).

With the help of the teacher's guiding questions, the pupils ruled out the least plausible hypotheses and focused on the first hypothesis described, analysing the characteristics of the individual energy sources and identifying the correct classification.

Issues related to the pollution caused by these sources, their longevity and the relative ease with which they can be obtained were discussed at length.

The final part of the lesson was devoted to exploring the link between food and energy. The pupils brought some food packets into the classroom, such as pasta, milk, biscuits, almonds and chocolate. The teacher asked leading questions, such as "Which do you think gives us more energy: 100g of pasta or 100g of milk?", "If you and your teacher ate 100g of pasta, who would have more energy in the end?".

Initially, almost all the pupils agreed that the ‘most energy-giving’ food was pasta or ‘energy drinks’. Furthermore, many claimed that if a child and an adult ate the same amount of the same food, the child would have ‘more energy’.

A simple example is given to make the concept clearer: “If a child and a lion eat 100g of peanuts, who will have more energy?”. The pupils immediately understand that the subject’s digestion is the key process. It is explained to them that the digestive process influences the transfer of energy from food to the body and therefore people can eat the same amounts of food but have different body shapes due to differences in metabolism.

The students were divided into groups and studied the nutritional labels on food products, discussing the meaning of the energy values shown.

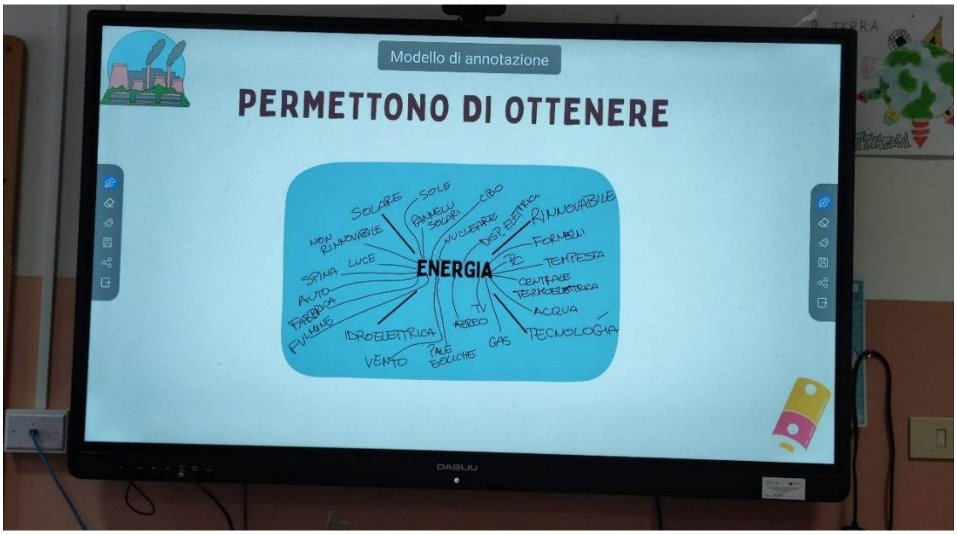
Modello di annotazione
PERMETTONO DI OTTENERE
ENERGIA
SOLARE
SOLE
PANNELLI SOLARI
CIBO
NUCLEARE
DISP. ELETTRICI
RINNOVABILE
NON RINNOVABILE
FORNELLI
LUCE
PC
TEMPESTA
SPINA
CENTRALE TERMOELETTRICA
AUTO
FABBRICA
TV
ACQUA
FULMINE
AEREO
IDROELETTRICA
TECNOLOGIA
GAS
VENTO
PALE EOLICHE
DABLIU

Fig.1 Brainstorming

From an ISLE perspective, this session mainly functioned as an initial stage for eliciting prior knowledge, creating a need to know, encouraging students to justify and revise their classifications, and introducing multiple representations of energy, including images, concept maps, verbal explanations and numerical values on food labels. The session did not aim to provide a complete scientific model of energy, but to make pupils’ initial ideas visible and to prepare the ground for the observational and experimental activities developed in the following sessions.

Table 4. Mapping of ISLE Components to the TLS Activities – Day 1

Phase of the activity	ISLE components
Brainstorming on energy	Activation and verbalisation of pupils’ initial ideas, making explicit their spontaneous associations with movement, food, living beings and technological devices.

Classification of energy sources	Exploratory activity carried out in small groups, fostering peer discussion, comparison of ideas, formulation of classification criteria and practical organisation of information.
Guided discussion on renewable and non-renewable sources	Collective refinement of pupils' explanations through teacher-guided questioning and gradual transition towards a scientifically appropriate classification.
Creation of a concept map	Multiple representations; organisation of knowledge. Pupils represent and organise the emerging concepts, linking verbal explanations to visual representations.
Guided discussion on food and energy	Activation and verbalisation of pupils' ideas about "human energy", with teacher-guided refinement towards the relationship between food, body and energy.
Analysis of food labels	Exploratory activity carried out in small groups, fostering interpretation of real-world representations of energy and connection between numerical information and everyday experience.
Final verbal and written summary	Reflective reorganisation of the experience and consolidation of the main ideas introduced during the session.

Description (Control Group)

During the brainstorming activity, both classes named technological objects (such as phones, TVs, interactive whiteboards, tablets). However, some elements differed.

In Class 5A, many words related to food, transport and weather conditions (sun, wind, water) emerged.

In Class 5B, words related to power stations (thermal, hydroelectric, nuclear), wind turbines, solar panels and electricity (light, current, electrical wires) emerged.

The activity on renewable and non-renewable energy sources was carried out during circle time. The teacher displayed the map with the images on the interactive whiteboard and encouraged the pupils to suggest their ideas on the correct categorisation.

The most common suggestion was a group comprising elements that are dangerous to humans (coal, uranium, geothermal energy and petrol) and a group comprising elements that are not dangerous to humans (natural gas, sun, water, wind). A second suggestion proposed a group consisting of natural elements (natural gas, sun, water, wind) and a group of artificial elements (coal, petrol, uranium and geothermal energy). In the latter case, the main doubts concerned the placement of the 'geothermal energy' source.

The pupils understood the correct solution thanks to the video and the teacher's explanation.

The final part of the lesson was devoted to analysing the food labels of the items the teacher displayed on the interactive whiteboard. A guided discussion was held during circle time to reflect on foods considered low in energy and those considered high in energy. The pupils asked many questions on the topic of nutrition, particularly discussing the nutritional values of foods such as crisps, packaged snacks and fizzy drinks. Here too, it was discussed that the energy content stated on labels must be considered in relation to the individual in question and their digestive processes.

8.7.2 DAY 2

The second session focused on the transition from 'human energy' – understood as the energy of movement inherent in living beings – to the introduction of the concept of kinetic energy, linked to the movement of both living and non-living things.

In both groups, the teacher linked back to the previous lesson and initiated a guided discussion, asking the pupils: "What can we do with the energy we have in our bodies?". The pupils suggested a list of activities, such as dancing, jumping, singing, running, playing sport, writing, etc. The pupils' answers were directed towards finding a name that describes this form of energy linked to movement.

In the first phase, the discussion focused solely on the movement performed by living beings; subsequently, a practical experiment on kinetic energy and the concept of transformation was proposed, carried out using a bicycle, a dynamo-powered light bulb and a speed detector.

Learning objectives

-Identify examples of kinetic energy

-Describe the transformations of energy in the experiment involving the *bicycle and the dynamo-powered light bulb*

Description (Experimental Group)

During the guided discussion, the pupils suggested many examples of what can be done with the energy obtained from food. The teacher asked the pupils to identify what all these activities have in common and, consequently, to try to name a form of energy that could group them together. The pupils suggested 'kinetic energy' and 'muscle energy'. Everyone understood that the common element in the various examples is movement itself.

Next, the teacher divided the pupils into pairs to carry out the experiment *'The bike and the dynamo'*. The pupils observed the upside-down bike and had to work out how to light the bulb. The pairs independently explored different ways of activating the dynamo, formulating and testing successive hypotheses until they identified the working configuration (Fig. 2).

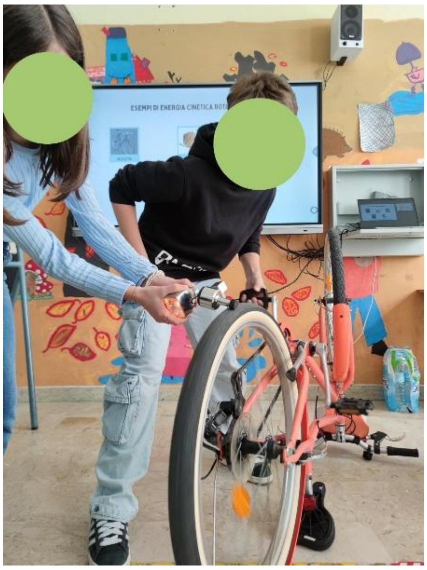

Fig. 2 Practical activity: The bicycle and the dynamo

The pupils discuss the phenomenon they have observed. They argue that:

"The energy from the bike went to the light bulb"
"The light bulb lit up because we were pedalling"
"Some of the energy from the wheel is transferred to the light bulb and becomes light energy"
"It is we who give our energy to the bike"

The teacher guides the discussion and suggests that the pupils use the terms 'transform', 'kinetic energy' and 'rotational kinetic energy'. Together, they describe what they have observed as a transformation of energy. This is defined as the partial conversion of their own energy into the energy of the wheel and subsequently as the partial conversion of the wheel's energy into the energy of the light bulb, defined as light energy.

The teacher then attaches a speed sensor to the bike and asks the pupils to make predictions about how the speed will change before and after connecting the dynamo.

Almost all the pupils agree that the speed will decrease. The pairs repeat the experiment and record the results obtained (Fig. 3). They observe that the speed always decreases when the bulb is placed on the bicycle wheel and try to explain the phenomenon.

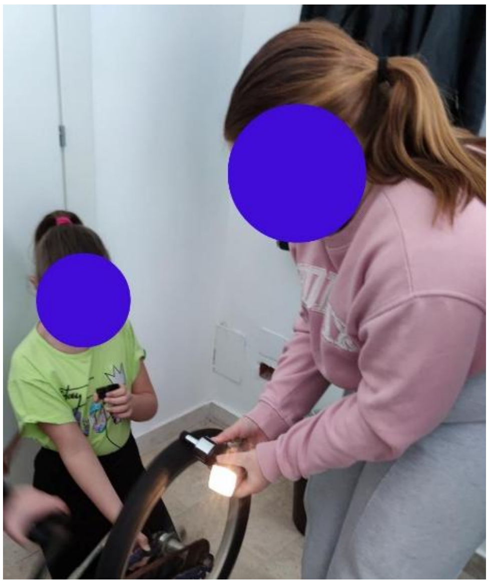

Fig. 3 Practical activity: The bicycle and the dynamo II

"The speed decreases because the light bulb takes some of it"
"The speed decreases because some of the wheel's energy goes into the light bulb"

The teacher guides the discussion with prompting questions. The students finally conclude that:

"The speed detector is a test that helps us understand that some of the bike's energy has actually gone into the bulb"
"Some of our energy has been converted into the bike's energy, and some of the bike's energy has been converted into light energy, which is why the bike's speed is slowing down."

During circle time, they decide to define kinetic energy as "A form of energy linked to movement".

Table 5. Mapping of ISLE Components to the TLS Activities – Day 2

Phase of the activity	ISLE components
Guided discussion on "human energy"	Activation and verbalisation of pupils' initial ideas, with teacher-guided refinement towards scientific language.
Experiment 1: The bicycle and the dynamo	Pair-based exploratory activity supporting observation of the system, comparison of ideas, formulation of hypotheses and direct practical experience.
Guided discussion after Experiment 1	Collective construction and refinement of explanations based on the observed phenomenon, with progressive introduction of scientific terminology.
Experiment 2: The bicycle, the dynamo and the speed sensor	Prediction, observation and comparison with measurable evidence to support the testing and refinement of pupils' explanations.

Final circle-time discussion	Reflective reorganisation of the experience and shared construction of an initial definition of kinetic energy.

Description (Control Group)

The teacher leads the discussion, starting with the concept of food and “human energy”, inviting the pupils to suggest concrete examples of what can be done with this energy. Everyone suggests activities related to their daily lives (playing sport, doing homework, getting up, talking, playing). The teacher asks the pupils to identify what all these activities have in common and, consequently, to try to identify the name of a form of energy that can group them together. Initially, they suggested ‘human energy’, ‘brain energy’ and ‘kinetic energy’. The teacher poses leading questions to guide the elimination of the first two alternatives.

Next, the experiment with the bicycle and the dynamo is carried out. The pupils observe the upside-down bicycle and the light bulb, and it is explained to them that the light bulb contains no batteries and is not switched on by buttons. The teacher demonstrates how to light the bulb using the movement of the wheels. They then explain that the kinetic energy has been partly converted into energy for the bulb. Next, the pupils repeat the experiment in pairs (one pupil holds the bulb against the wheel, the other turns the pedals with their hands).
During the experiment, the pupils state that:

“The energy has been transformed”
“When we ride a bike, the energy is transferred to the bike and so it has energy too”
“Some of the bike’s energy goes into the light bulb and it lights up”

In the second part of the experiment, the teacher attaches a speed sensor to the bike and asks the pupils to make predictions about how the wheel’s speed will change before and after placing the light bulb on the wheel. Most predict that the speed will decrease, whilst a small group predict that it will remain the same.
The teacher demonstrates the experiment and leads a discussion to understand the observed phenomenon. The pupils demonstrate that they have understood why the measured speed decreases when the light bulb is placed on the wheel.

8.7.3 DAY 3

During the third session, experiments are proposed to reflect on kinetic energy and the concept of transformation. The energy sources in this case will be air and water, with the aim of moving further and further away from a vitalistic view of energy. In particular, water mills and wind turbines are discussed and observed. In the *water turbine* experiment, the teacher guides the pupils to reflect on the relationship between energy and height.

Learning objectives

-Identify wind and water as ‘sources’ of energy
-Explore kinetic energy through a rudimentary water wheel
-Describe the conversion of kinetic energy into light energy in the *water turbine* experiment

Description (Experimental Group)

The pupils are divided into small groups and each is given a small generator connected to an LED. The teacher asks the pupils to suggest other ways of lighting the LED without using their hands.

The pupils try to build small structures to attach (pieces of card, erasers) to the generator so they can blow on it, but none of them work properly. Finally, the teacher gives each group some small plastic blades to attach, and the children can make small wind turbines to blow on to simulate the wind and light up the LED. They discuss wind energy and look at images on the interactive whiteboard of various wind turbines located across Sicily.

Subsequently, the teacher asks the pupils to suggest another way to light up the LED. The pupils suggest water.

Working in cooperative learning groups, the pupils build a small, rudimentary water turbine. Small wooden sticks are glued into a plastic bottle cap, with small plastic caps attached to their ends. The LED used previously is connected behind the central cap.

The pupils then try to test their hypothesis; in pairs, they pour water onto the caps and observe whether the LED lights up. Initially, it does not light up. The students discuss and reflect.

“It doesn’t light up because we need to pour more water”
“It doesn’t light up because I need to pour the water harder”
“It doesn’t light up because I’m pouring the water the wrong way round”

The pupils then try to change the way the water is poured based on these statements, but the LED does not light up (Fig. 4).

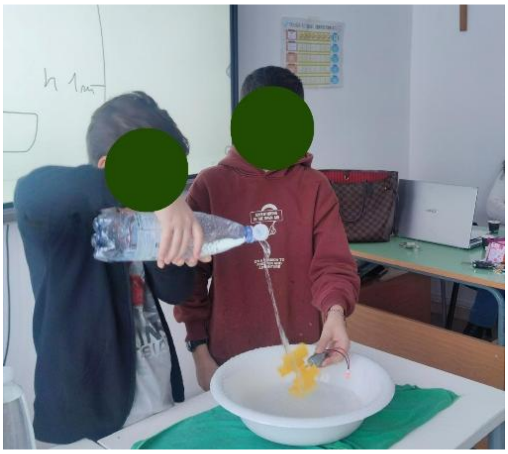

Fig. 4 Practical activity: the water turbine

A pupil says:

“Perhaps I need to pour the water from a greater height”

At this point, the LED lights up. The students observe how height affects the energy of the water. They discuss the phenomenon and conclude that:

“If you pour the water from low down, it has little power and energy”
“If you pour the water from low down, it doesn’t have enough energy to transform”
“Water from a height has more energy and speed”

Table 6. Mapping of ISLE Components to the TLS Activities – Day 3

Phase of the activity	ISLE components
Guided discussion on alternative ways to light the LED	Activation and verbalisation of pupils’ ideas; extension of the problem to non-living sources of energy, with teacher-guided refinement towards scientific language.
Experiment: The wind turbine	Exploratory activity carried out in small groups, fostering observation of the system, practical manipulation, comparison of ideas and direct experience of energy transformation.
Guided discussion on wind energy	Collective interpretation of the observed phenomenon and connection between the classroom activity and real-world examples of wind turbines.
Experiment: The water turbine	Exploratory activity carried out in small groups, fostering peer discussion, practical manipulation, formulation and testing of hypotheses, and direct experience with a simple physical system.
Guided discussion on the role of height	Collective refinement of pupils’ explanations through teacher-guided questioning and evidence from the experiment.

Final interpretation of the water turbine experiment	Reflective reorganisation of the experience and shared construction of the relationship between height, water movement and energy transformation.

Description (Control Group)

Looking at the LED brought by the teacher, the pupils initially suggest spinning it on the ground to light it up. The idea is immediately dismissed.

The teacher shows some small wind turbines to attach to the generator, and at this point a pupil suggests blowing on them, effectively imitating the wind. The class discusses wind energy and looks at images on the interactive whiteboard of various wind turbines located across Sicily.

Next, the pupils are asked to suggest another way of generating energy from the generator. Immediately, one pupil suggests pouring water onto the blades to make them turn.

Initially, the teacher pours the water from a very low height and the LED does not light up. Only when the water is poured from a greater height does the LED light up.

The experiment is used to explain to the pupils the relationship between height and energy, explaining that the greater the height, the greater the energy, and vice versa.

The teacher asks leading questions and guides a discussion on the observed phenomenon. The pupils state that:

"The energy of the water has been transformed into light energy"
"Water from below has little force; from above it has more force"
"Water from above has more power and energy"

Images of modern and historical windmills are examined, with a focus on their usefulness and their role in human history.

8.7.4 DAY 4

The teacher proposes various playful activities aimed at introducing and explaining potential energy. A toy turbine was used to demonstrate that falling objects can also cause a wheel to rotate. The students observed the behaviour of various balls dropped into bowls filled with sand and noted the different effects produced. Experiments were conducted in which the balls were dropped from different heights, producing craters of varying depths. The change in the state of the sand was taken as evidence of an interaction – and a transformation of energy. The students concluded that the height from which an object falls determines the amount of its ‘falling’ energy.

A similar experiment was carried out using toy cars, sliding them down wooden planks from different heights. Finally, the focus shifted to the conversion of the cars’ potential energy into kinetic energy.

Learning objectives

-Identify height as a key characteristic of potential energy

-Identify and describe the conversion from potential energy to kinetic energy in the *toy car* experiment

Description (Experimental Group)

The teacher shows a toy turbine (Fig. 4) and asks the pupils to find a new way to make the wheels spin, without using their hands, water or wind. The pupils reflect and suggest using objects found in the classroom, such as erasers and pencil sharpeners. Through prompting questions, they conclude that sand might be the appropriate solution. The sand was slowly poured onto the turbine blades to mimic the flow of water. Then a stream of beads and finally a single ball was dropped.

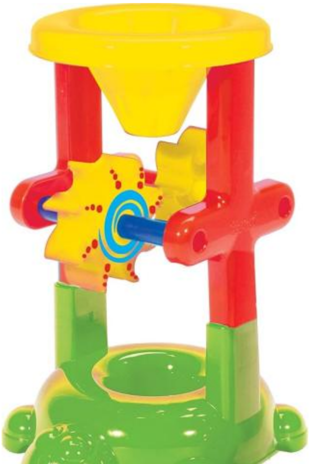

Fig. 5 Practical tool used

The students discovered that balls dropped from different heights produce different effects in the sand.

They were then divided into small groups. Each group was given a container of sand, several balls and a tape measure. They were not given any instructions on how to use the tools. They carried out various experiments and noted down their observations (Fig. 5). The main experiments carried out are as follows

-One group tried to calculate the area and perimeter of the container.
-One group tried to understand how the balls might bounce on the sand.
-One group tried to determine whether the rate at which the balls fell differed.
-One group measured the size of the balls.
-One group tried to tie the balls to a tape measure and throw them.
-One group noted the differences between the balls on the table and in the sand.

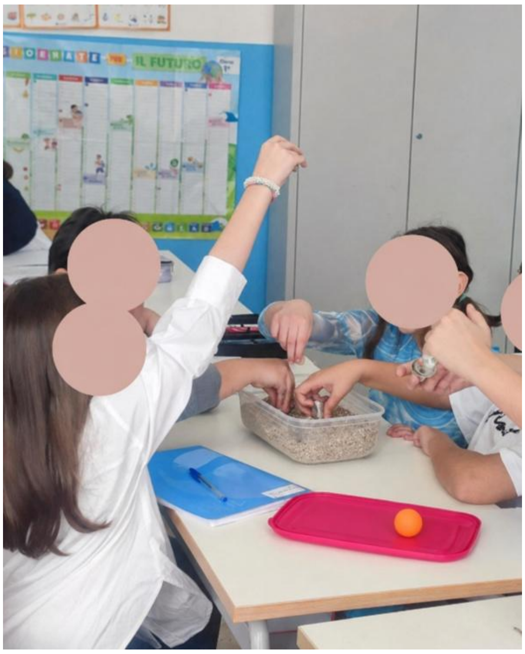

Fig. 6 Practical activity: Sand and balls

After the initial trials and guided by prompting questions, the pupils began to observe that the balls produce craters of varying depths when dropped from different heights. The pupils concluded that the height from which the ball falls determines the amount of its 'falling' energy.

Initially, they defined this form of energy as 'precipitation energy' and 'falling energy'. The teacher guides this common definition towards the scientific definition of 'potential energy'. Subsequently, a second experiment is proposed to be carried out in small groups. Each group is given wooden planks of different lengths and two or more toy cars. They are given no instructions on how to use the materials. They carry out various tests and record their observations (Fig. 6). We report the main tests carried out.

-One group focused on the different weights of the plywood sheets.
-One group used the time available to build different types of ramps.
-One group reflected on the ascent and descent of the toy cars.
-One group tried to build a ramp that allowed for both ascent and descent.
-One group tried to build a ramp that started at the desk and ended at the chair.

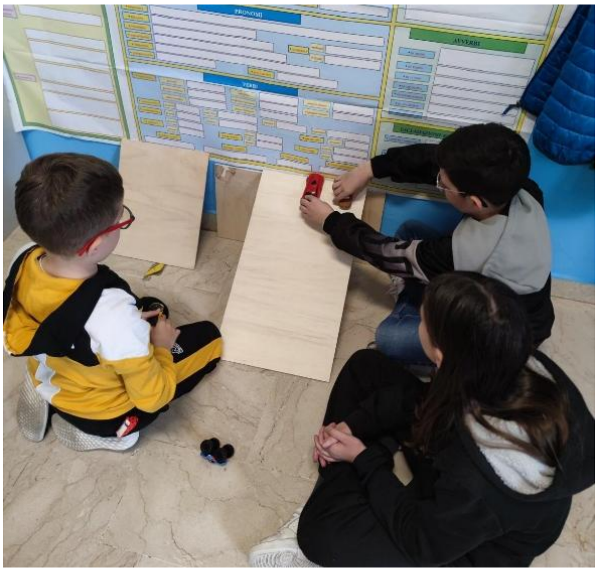

Fig. 6 Practical activity: the toy cars

After the initial trials and guided by prompting questions, the pupils used the wooden boards to drop the toy cars from different heights. They observed that the toy cars reached different points on the floor when dropped from different heights. They immediately made a connection with the previous activity, stating that the height from which the toy car falls determines the amount of its 'falling' energy.

The teacher draws attention to the transition from potential energy to kinetic energy. The pupils observe that the greater the potential energy, the greater the kinetic energy of the toy car (it will travel further across the floor).

"If the toy car falls from a high point, it has more energy and will therefore travel further. Just like with the balls. If the ball falls from a height, it has more energy and makes a deeper dent."

"The car stops later if I drop it from a height. It stops sooner if I let it slide from the bottom because it has less speed."

Table 7. Mapping of ISLE Components to the TLS Activities – Day 4

Phase of the activity	ISLE components
Guided introduction with the toy turbine	Activation and verbalisation of pupils' ideas; extension of the problem to falling objects as possible sources of motion, with teacher-guided refinement towards scientific language.
Experiment: Balls and sand	Exploratory activity carried out in small groups, fostering observation of the system, practical manipulation, comparison of different procedures and direct experience of the effects produced by falling objects.
Guided discussion after Experiment	Collective interpretation of the observed effects and refinement of pupils' explanations through teacher-guided questioning and evidence from the different depths of the craters.
Introduction of the concept of potential energy	Gradual transition from pupils' spontaneous expressions, such as "falling energy", towards the scientific concept of potential energy.
Experiment: Toy cars	Exploratory activity carried out in small groups, fostering peer discussion, practical manipulation, comparison of different ramp configurations and observation of the relationship between height and motion.
Guided discussion after Experiment	Collective refinement of pupils' explanations through comparison with the previous activity and recognition of the relationship between height, potential energy and kinetic energy.
Final interpretation of the toy cars experiment	Reflective reorganisation of the experience and shared construction of the idea that potential energy can be converted into kinetic energy.

Description (Control Group)

The teacher brings a sand mill into the classroom, often used by children on the beach. They use it to show how sand can be poured slowly onto the turbine blades to cause the wheel to rotate and thus generate kinetic energy.

The teacher asks thought-provoking questions to encourage the pupils to reflect on this new form of energy, which is defined as "the form linked to falling objects".

Next, they demonstrate what happens when beads and then stones are dropped onto the windmill. The pupils observe how the rotation of the wheel varies depending on the objects and the height from which they are dropped. They link the example shown to the experiment carried out in the previous lesson (the water turbine), highlighting that a greater height indicates greater energy.

The teacher conducts an experiment using a container filled with sand and small balls. They demonstrate what happens by dropping the same ball from two different heights. The pupils immediately notice that the balls have left two different indentations in the sand, and these are interpreted as the objects having different 'potential'.

They define this form of energy as ‘gravitational energy’ and ‘falling energy’. The teacher guides this common definition towards the scientific definition of ‘potential energy’.
Finally, the toy car experiment is demonstrated. Initially, a single toy car is dropped from the highest point of a wooden board, and a tape measure is used to record the distance the object travels before hitting the floor. The process is then repeated from a lower height, and the differences are observed. Finally, the experiment is carried out with two cars, which are dropped from different heights at the same time. The teacher explains the phenomenon the children have observed and highlights the similarities with the previous activity. A guided discussion is held, focusing on the concept of height.

“If we place the toy car at the bottom of the board, it will have very little energy”
“If the teacher lets the toy car slide from the top, it travels further”
“The toy car from the top has more speed and therefore more energy”

The teacher shows the pupils a short video of the experiment just carried out and explains the difference between potential energy and kinetic energy.

8.7.5 DAY 5

During the final session dedicated to practical and laboratory activities, the teacher proposed several experiments aimed at introducing a new form of energy: thermal energy. These were carried out using a thermal imaging camera, provided by the University of Palermo, to help the pupils immediately observe changes in temperature, which are often imperceptible.
The teacher demonstrated how the temperature of a liquid (in the case of the experiment with the whisk and water) and of two solids (the desk and a metal plate) varied. The pupils linked the changes in temperature of the different objects to changes in ‘internal’ energy. Furthermore, these examples served to demonstrate that energy is not lost but is transformed into a different form.

Learning objectives

- Link energy transfers (heat and/or work) to changes in temperature
- Describe the transformation from kinetic energy to thermal energy

Description (Experimental Group)

The teacher divides the pupils into pairs and provides each with a container of water and a hand-held whisk fitted with a wheel. The teacher asks the pupils to ‘stir’ the water with the whisk. The circular movement of the wheel reminds them of the bicycle experiment, confirming that this is rotational kinetic energy.

The teacher asks a few prompting questions to get the pupils thinking about what happens to the whisk’s energy when it stops. Various hypotheses are put forward; here are the most common ones.

“The whisk’s energy disappears when it stops”
“It goes into the air”
“It goes into the water”
“The energy of the whisk is no longer there if we don’t move it”

After discussing the various hypotheses, the teacher asks some questions about the water temperature, asking the pupils whether it changes or not during the experiment. Most pupils believe it will remain the same, while some believe it will increase. None believe it could decrease.

A thermal camera is used to record the different temperatures before, during and after using the whisk in the bowl.

The students carry out the experiment in pairs: one of them uses the whisk and their partner records the changes with the thermal camera (Fig. 7). They observe a slight increase in the water temperature and suggest that this was caused by using the whisk.

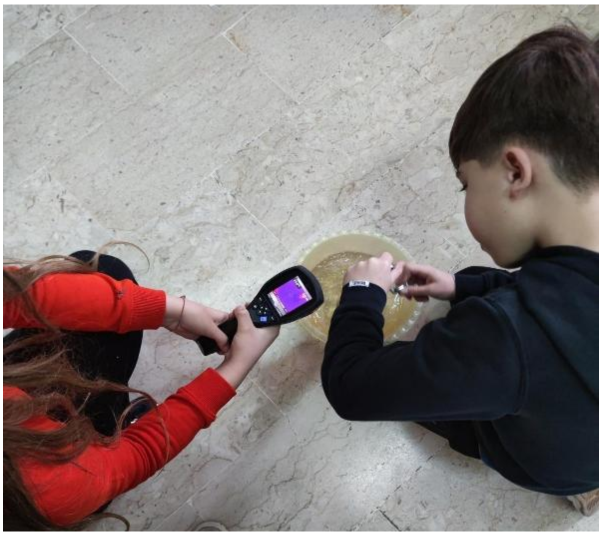

Fig. 7 Practical activity: The whisk and the water

They conclude that the kinetic energy has not been lost, but has changed.

“The kinetic energy of the whisk has turned into heat”
“The kinetic energy of the whisk remains in the water, in its temperature”

The teacher guides the discussion, encouraging the use of terms such as ‘kinetic energy’ and ‘temperature change’.

The next two experiments further confirm the students’ statements.

Working in pairs, they strike a metal plate with a hammer and record the temperature changes observed with the thermal camera in their notebooks. Finally, they rub an eraser on the desk and notice a considerable increase in temperature.

The pupils state that they have observed examples of energy transformation, in which energy is never ‘lost’. They define this phenomenon as being linked to temperature and its variations.

Table 8. Mapping of ISLE Components to the TLS Activities – Day 5

Phase of the activity	ISLE components/functions
Guided discussion on the whisk’s energy	Activation and verbalisation of pupils’ ideas; connection with previous activities on rotational kinetic energy, with teacher-guided refinement towards scientific language.
Experiment: The whisk and the water	Experimental activity carried out in pairs, fostering prediction, observation of temperature changes and comparison between pupils’ initial hypotheses and evidence from the thermal camera.
Guided discussion after Experiment	Collective refinement of pupils’ explanations through teacher-guided questioning and evidence from the observed temperature increase.
Experiment: The metal plate and the hammer	Experimental activity carried out in pairs, fostering practical manipulation, observation of temperature variation and direct experience of the transformation from kinetic energy to thermal energy.
Experiment: The eraser and the desk	Experimental activity carried out in pairs, supporting comparison with previous experiments and further observation of temperature increase produced by motion and interaction between objects.
Final interpretation of the toy cars experiment	Reflective reorganisation of the experience and shared construction of the idea that kinetic energy is not lost, but can be transformed into thermal energy.

Description (Control Group)

The teacher proposes various experiments aimed at discussing thermal energy and its transformations. These are carried out by the teacher, whilst the pupils observe and note down the most relevant aspects, in a circle time setting.

In the first activity, a bowl full of water and a hand whisk are used to ‘stir’. The class discusses what might change after performing this action.

Using the thermal camera, it is possible to see that what has changed during the experiment is the temperature of the water. The pupils state that this happened due to the movement of the whisk and therefore due to its kinetic energy. The observed change is described by the teacher in terms of the transformation of energy, from kinetic to thermal.

They are told that this also happens when making pesto (which is why it is preferable not to use an electric blender).

Subsequently, the teacher carries out two experiments in which they demonstrate the temperature change of two solid objects (a metal plate and a desk). In both cases, the change is more visible and more immediate, and the pupils can more easily observe how the kinetic energy (of the hammer and the rubber, respectively) has been transformed.

All the pupils then try rubbing the erasers on the desk and, by touching the area with their fingers, immediately feel the change. This is identified as a change in the object’s ‘internal’ energy and is proof that the energy has not ‘run out’.

8.8 Conclusion

This chapter has described in detail the design and implementation of the educational experiment, highlighting the methodological choices adopted and the characteristics of the contexts involved. In particular, the structure of the TLS allowed for a comparison of two different teaching approaches, whilst maintaining control over the main educational variables.

The description of the activities and intervention methods forms the fundamental basis for interpreting the results, which will be analysed in the following chapter in order to assess the effectiveness of the ISLE methodology compared to traditional teaching, both in terms of conceptual learning and scientific self-efficacy.

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CHAPTER 9

EXPERIMENTAL STUDY: RESULT

This chapter presents the results obtained during a 12-hour Teaching-Learning Sequence (TLS) on energy, conducted through a quasi-experimental design with 71 primary school pupils divided into an Experimental Group (EG) and a Control Group (CG).

The research questions (RQs) that guided the study are:

RQ1. What common-sense conceptions of energy emerge in fifth-grade primary school students before the TLS?

RQ2. To what extent does an ISLE-based TLS, compared to a traditional intervention, facilitate the transition from common-sense knowledge to scientific knowledge of energy in fifth-grade primary school students?

RQ3. To what extent does an ISLE-based TLS, compared with a traditional teaching intervention, promote the development of science self-efficacy in male and female fifth-grade primary school students?

This chapter presents the results obtained in the pre- instruction and post-instruction of the knowledge questionnaire in the CG and the EG, followed by a comparison between the two groups. Similarly, the results of the pre- instruction and post- instruction of the SE-IS questionnaire in the CG and the EG will be analysed, highlighting the differences that emerged between boys and girls. Finally, the results obtained by the two groups will be compared. This will make it possible to understand the extent to which the use of the ISLE methodology has influenced the acquisition of new knowledge and the improvement of scientific self-efficacy (SSE).

9.1 Knowledge questionnaire: analysis methodology

The knowledge questionnaire, developed based on the study by Colonnese et al. (2012), was administered at the start and end of the TLS, as a pre-instruction and a post- instruction. The instrument made it possible to identify both the students' prior conceptions of the concept of energy and any changes that occurred following the teaching experience.

Data analysis was conducted using an integrated qualitative and quantitative approach, consistent with the nature of the research questions. In particular, qualitative analysis was carried out through a phenomenographic analysis of the open-ended responses (Marton, 1981), whilst quantitative analysis was performed on the scores assigned to the responses, in order to compare the trends in results across the two groups and at the two assessment points.

From a qualitative perspective, the pupils' responses were classified into three levels of knowledge: common-sense knowledge, partially scientific knowledge and scientific knowledge, based on the classification rubric presented and discussed in section 6.5.2. The categorisation was carried out in light of the main misconceptions regarding the concept of energy documented in the literature and enabled the identification of the conceptual categories emerging in the various responses (Åkerlind, 2005).

The responses were analysed independently by three researchers. Each researcher carried out an independent classification of the responses; the results were subsequently compared and discussed until a shared agreement was reached. The initial agreement between evaluators was high (91% between researcher 1 and researcher 2, 92% between researcher 1 and researcher 3, 94% between researcher 2 and researcher 3), and any remaining disagreements were resolved through group discussion.

To enable a quantitative analysis of the data, each response was assigned a score in ascending order based on the level of knowledge expressed: 0 for unanswered questions, 1 for responses classified as common-sense knowledge, 2 for responses classified as partially scientific knowledge, and 3 for responses classified as scientific knowledge. In this way, it was possible to obtain an overall score for each student, which was useful for describing performance trends over time.

The comparison of scores was analysed using Linear Mixed Models (LMM), , considering the group (experimental group vs control group), time (pre- instruction vs post- instruction) and their interaction as fixed effects. This analysis made it possible to verify not only any general improvement between the first and second assessments, but above all whether this improvement differed between the two groups, and was therefore attributable to varying degrees to the teaching methodologies adopted (West et al., 2022).

In this chapter, we will first present the results of the phenomenographic analysis, through a description of the categories that emerged and the responses provided by the students in the two groups and at the two measurement points; subsequently, we will discuss the results of the quantitative analysis conducted using LMM.

9.2 Levels of knowledge and categories identified

Tables 1, 2 and 3 provide a summary of the categories emerging from the phenomenographic analysis of the responses to the questionnaire questions across the levels of common-sense, partially scientific and scientific knowledge. For each level of knowledge, the emerging categories, representative examples of students' responses, classification criteria and a brief description have been identified. The tables serve a descriptive and interpretative function: they provide the conceptual framework used for the analysis of the data in the following sections.

Table 1. Common-sense knowledge

Question	Category	Criterion	Examples of answers	Description
1. What do you know about energy?	Food	Intuitive explanations; references to everyday experiences	"When I eat, I have energy"	The answers refer to everyday physical experience (eating = having energy) and interpret energy as a physical sensation of strength or vitality, without using scientific language and with an intuitive understanding of the concept.
	Technological objects/electricity	Conceptual errors; references to everyday experiences	"The phone, the computer or the tablet have energy"	The responses associate energy with everyday objects and electricity, without distinguishing between energy and the devices that use it, demonstrating an intuitive and non-scientifically structured understanding.
	Daily life	References to everyday experiences	"We use energy all day long"	The answers are based on general observations of daily life, without any scientific explanation.
	Body and movement	Intuitive explanations	"Everything that moves has energy"	The answers interpret energy as synonymous with movement or physical activity, drawing on personal experience rather than a formalised scientific concept.
	Non-material substance	Conceptual errors	"It is invisible"	The answers describe energy as a vague, non-material entity, without defining its scientific properties, highlighting an intuitive explanation.

2. As far as you know, are there things that provide energy?	*Food*	Intuitive explanations; references to everyday experiences	“If you eat pasta, you have lots of energy”	The answers attribute to food the function of “producing energy”, confusing biological energy intake with the physical concept of energy.
	Technological objects/Electricity	Conceptual errors; references to everyday experiences	“Light, the telephone, the power lines”	The answers regard technological objects or infrastructure as energy producers, highlighting confusion with the concept of electricity.
	Natural elements	References to everyday experiences	“Wind, water, sun”	The answers identify wind, water and sun as sources in a descriptive and intuitive way, without specifying their role in energy conversion processes.
	Combustible materials	References to everyday experiences	“Petrol, oil”	The answers associate petrol and oil with the idea of energy production in an empirical way, without explaining the processes of combustion or energy conversion.
	Energy as a universal property	Conceptual errors	“Everything gives us energy”	The answers express a broad and undifferentiated view, based on an intuitive and non-scientific interpretation of the concept.
3. As far as you know, are there things that have or possess energy?	*Food*	Intuitive explanations; references to everyday experiences	“Food like pasta has energy”	The answers attribute the possession of energy to food, confusing biological energy intake with the physical concept of energy.
	Technological objects	Conceptual errors; references to everyday experiences	“Light, the telephone, electrical wires”	The answers regard objects as direct carriers of energy, confusing the concept of energy with electricity.
	Living beings	Intuitive explanations; conceptual errors	“Humans”	The answers associate energy with the vitality of living beings, based on an intuitive understanding.
	Natural elements	Intuitive explanations	“Wind, water, sun”	The answers attribute energy to natural elements in a descriptive manner, without explicitly stating causal relationships or energy transformations.
4. Can energy be	*Setting aside for future use*	Intuitive explanations;	“It means storing energy inside	The answers interpret energy conservation as a concrete act of

conserved? Explain what ‘conserved’ means.		conceptual errors	something and using it later, for example in a power bank”	accumulation, based on everyday examples rather than on the scientific principle of conservation.
	Storing energy in the body	Intuitive explanations; conceptual errors	“When we sleep, we store energy in the body”	The responses associate energy conservation with rest or sleep, referring to bodily sensations rather than the scientific principle of conservation.
	Electrical dissipation	Conceptual errors; references to everyday experiences	“You conserve energy when you switch off the light or the heater”	The responses equate conservation with saving or not wasting electricity, demonstrating an intuitive and non-formalised understanding of the concept.
5. Can energy be transformed? Explain, giving some examples.	*Technological objects*	Intuitive explanations; references to everyday experiences	*“Energy is transformed into the light from the bulb”*	The answers describe the transformation of energy in general terms without specifying the type of initial energy or the transformation process.
	Body	Intuitive explanations; references to everyday experiences	“The energy in our body turns into tiredness”	The answers interpret the transformation as a change in physical state or sensation, with reference to personal experience and one’s own body.
	Natural elements	Intuitive explanations	“Wind, water, sun”	The responses refer to natural phenomena without describing their energy mechanisms.
	Everyday life	References to everyday experiences	*“It can be transformed into mental energy”*	The answers use vague categories linked to everyday language rather than scientific terminology.
	Negative response	Conceptual errors	“No, it cannot be transformed”	The answers deny the possibility of energy transformation, revealing a naive understanding of the concept.
6. Is it possible to lose energy? Explain, giving some examples	*Body and movement*	Intuitive explanations; references to everyday experiences	“Running, walking, jumping”	The answers interpret the loss of energy as physical tiredness, referring to bodily experience.
	Waste and consumption of electricity	Conceptual errors	“For example, if we leave the lights on for too long”	The responses associate energy loss with the waste of electricity, confusing the concept of energy dissipation with practical consumption.

	Negative response	Conceptual errors	“No, energy cannot be lost”	The answers deny the possibility of energy loss without referring to scientific principles.
7. What “types” of energy do you know?	*Electricity*	Non-scientific language	“The energy from light, the telephone, the computer”	The answers identify types of energy with objects or with the everyday use of electricity.
	Human energy	References to everyday experiences; intuitive explanations	“The energy of the body, the energy of the muscles”	The responses conceive of energy as a property of the human body and muscles, according to an intuitive conception.
	Energy associated with natural elements	References to everyday experiences	“Wind, sun, water”	The responses link energy directly to natural elements without explicitly describing the processes of transformation.
	Energy of different objects	Conceptual errors		
8. What is the difference between renewable and non-renewable energy sources?	*Literal meaning*	Non-scientific language	“Renewable ones can be replenished, whereas non-renewable ones cannot”	The answers refer to the linguistic meaning of the terms, without an understanding of the underlying physical or environmental processes.

Table 2 Partially scientific knowledge

Question	Category	Criterion	Examples of answers	Description
1. What do you know about energy?	*Unsubstantiated academic definition*	Statement-based answers that list concepts without context	“It is the ability of a body to perform work”	The answers provide a formal definition of energy without explaining it or using concrete examples, demonstrating unsubstantiated declarative knowledge.
	Forms of energy	Partially scientific language	“There are many forms of energy”	The answers use scientific terms ambiguously or without specifying their meaning or providing explanations of the processes involved.
	Devices and infrastructure for energy production	Incomplete or imprecise logical connections	“For example, wind turbines or solar panels have energy”	The answers associate energy with devices or infrastructure without analysing the energy conversion process or

				providing further conceptual explanations.
	Renewable/non-renewable energy sources	Partially scientific language	“I know that energy can be renewable or non-renewable”	The answers introduce the distinction between renewable and non-renewable sources using basic scientific vocabulary, without further conceptual explanations.
2. As far as you know, are there things that provide energy?	*Devices and infrastructure for energy production*	Incomplete or imprecise logical connections	“Wind turbines, solar panels, power stations”	The answers identify devices or infrastructure as energy producers, without clarifying the energy conversion processes involved.
3. As far as you know, are there things that have or possess energy?	*Devices and infrastructure for the production of energy*	Incomplete or imprecise logical connections	Wind turbines, solar panels, power stations”	The answers attribute the possession of energy to devices and infrastructure, without distinguishing between energy, source and means of production or transformation.
4. Can energy be conserved? Explain what ‘conserved’ means.	*Examples explored during the course*	Partially correct but incomplete and/or unsubstantiated descriptions; partially scientific language	“For example, in the whisk experiment, we saw that the energy wasn’t lost but ended up in the water, so it was conserved”	The answers refer to experimental examples covered in class, describing the phenomenon correctly but not in depth, without a complete scientific explanation and using partially scientific language.
	Devices and infrastructure for energy production	Incomplete or imprecise logical connections	“Yes, energy can be stored, for example, in solar panels or wind turbines”	The answers associate energy conservation with technological devices, confusing the concept of conservation with that of storage or production.
	Energy transmission	Partially scientific language	“Energy is transmitted; for example, I can transfer my energy to the bike”	The answers use partially scientific terms, without explaining the mechanisms involved.
	No reasoning	Statement-based answers that present concepts without context	“Yes, it can be conserved”	The answers state that energy can be conserved without providing explanations or examples.

5. Can energy be transformed? Explain, giving some examples.	*Examples explored during the course*	Partially correct but incomplete and/or unsubstantiated descriptions; partially scientific language	“The child’s kinetic energy was transferred to the bike and the light bulb and became light energy”	The answers correctly describe an observed energy transformation, but without a complete explanation of the process and using partially scientific language.
	Devices and infrastructure for energy production	Incomplete or imprecise logical connections	“For example, the sun is converted into light in solar panels”	The answers attribute the energy transformation to devices or infrastructure, without clarifying the nature of the initial and final energy and the transformation process.
	No argumentation	Declarative answers that state facts without providing context	“Yes, it always transforms”	The answers state that energy is transformed without providing examples or explanations.
	Energy transfer	Partially scientific language	“The bike transferred its energy to the light bulb”	The answers use partially scientific terms, without explaining the mechanisms involved.
	Relationship between food and human energy	Incomplete or imprecise logical connections	“When we eat, food is converted into energy for the body thanks to cells”	The answers link food to energy production in the body using scientific terms, but without a structured and comprehensive explanation.
6. Is it possible to lose energy? Explain, giving some examples	*Examples explored during the course*	Partially correct but incomplete and/or unsubstantiated descriptions; partially scientific language	“It is not lost because, for example in the whip experiment, the energy ends up as heat”	The answers refer to experimental examples to support the claim that energy is not lost, without a formalisation of the scientific principle.
	Devices and infrastructure for energy production	Incomplete or imprecise logical connections	“It is not lost because it can be stored in solar panels”	The answers link the non-loss of energy to devices or infrastructure, confusing conservation with storage.
	No argument	Declarative answers stating	“No, energy is never lost”	The answers deny that energy is lost without providing explanations or examples.

		concepts without context		
	Energy transfer	Partially scientific language	“Energy can be transferred, so it is not lost”	The answers use partially scientific terms, without clarifying the process of transformation.
7. What ‘types’ of energy do you know?	*Types of energy associated with the state of a body*	Partially scientific language; declarative answers stating concepts without context	“Static energy, kinetic energy”	The answers use labels that refer to scientific concepts, without clarifying their physical meaning.
	Types of energy associated with sources	Partially scientific language; declarative answers that list concepts without providing context	“Wind energy, hydroelectric energy, solar energy”	The answers use scientific terminology without providing definitions or explanations of the meaning of the different categories.
8. What is the difference between renewable and non-renewable energy sources?	*Examples of different energy sources*	Partially scientific language	“Coal/petrol/uranium are non-renewable energy sources; the sun, water or wind are renewable energy sources”	The answers distinguish between renewable and non-renewable sources using examples, without explaining the scientific criteria for the distinction.
	Natural/artificial sources	Partially scientific language; incomplete or imprecise logical connections	“Renewable energy comes from natural sources, non-renewable energy from non-natural sources”	The answers distinguish between renewable and non-renewable sources based on their origin (natural vs artificial), showing an attempt at conceptual classification, but in an imprecise manner and highlighting a fairly widespread conflation of the ideas of ‘non-natural’ and ‘harmful’
	Use/non-use of energy	Incomplete or imprecise logical connections	“Renewable energy can be used many times; non-renewable energy cannot be used forever”	The responses identify a difference between renewable and non-renewable sources in terms of repeated use, without an explicit understanding of the processes that

				distinguish the two categories.

Table 3 Scientific knowledge

Question	Category	Criterion	Example of responses	Description
1. What do you know about energy?	*A quantity that changes*	Correct and consistent use of scientific language; reference to energy transformations	"I know that energy is always being transformed"	The answers define energy as a physical quantity subject to transformations, using appropriate scientific language consistent with the principles studied.
	A quantity that takes different forms	Correct and consistent use of scientific language	"I know that there are many forms of energy, such as kinetic or thermal energy"	The answers recognise the existence of different forms of energy and name them correctly, demonstrating a scientifically sound classification.
	All systems and bodies	Correct and consistent use of scientific language; reference to general principles	"Energy is found everywhere, both in living beings and in objects"	The answers attribute energy to all physical systems, demonstrating a generalised and scientifically correct understanding of the concept.
2. As far as you know, are there things that provide energy?	*Examples explored during the course*	Identification of cause-and-effect relationships; well-contextualised and clearly explained descriptions	"For example, objects have energy when they fall, as in the experiment with the balls we dropped into the sand"	The answers refer to experiments carried out, linking the observed phenomenon to the concept of energy through explicit causal relationships.
	All systems and bodies	Correct and consistent use of scientific language; reference to general principles	"Everything can provide energy, for example heat or speed or falling objects"	The answers extend the concept of energy to various physical phenomena, formulating a general statement consistent with the scientific principles studied.
3. As far as you know, are there things that have or possess energy?	*Examples explored during the course*	identification of cause-and-effect relationships; well-contextualised and clearly	"For example, during the waterwheel experiment, we saw that water falling from a height has more	The answers link amounts of energy to observable effects, referring to experimental experiences and explicit causal relationships.

		explained descriptions	energy and, in fact, the light bulb lit up”	
	All systems and bodies	Correct and consistent use of scientific language; reference to general principles	“Everything has energy because energy can be transferred”	The answers extend the concept of energy to various physical phenomena, formulating a general statement consistent with the scientific principles studied.
4. Can energy be conserved? Explain what ‘conserved’ means.	*Examples explored during the course*	Cause-and-effect relationships; well-contextualised and clearly explained descriptions; explicit description of energy transformations	“For example, in the whisk experiment, we mixed the water with the whisk. When we stopped stirring, we saw that the water still had energy, but in the form of temperature”	The answers interpret conservation as a transformation of energy, referring to concrete experiences and explaining the phenomenon in a detailed and coherent manner.
	Energy transformation	Explicit description of energy transformations	“Energy is always conserved through the continuous transformations it can undergo”	The answers formulate the principle of energy conservation in abstract and general terms.
	No loss	Reference to general principles	“It means that energy never runs out”	The answers express the principle of conservation in a simplified but scientifically correct form.
5. Can energy be transformed? Explain, giving some examples.	*Examples explored during the course*	Cause-and-effect relationships; well-contextualised and clearly explained descriptions; explicit description of energy transformations	“Yes, for example: we took a bike, we turned the wheel of the bicycle and our kinetic energy was transformed into the rotational kinetic energy of the wheel. Then we attached a dynamo bulb to the wheel which, as the wheel turned, was transformed into light energy. So the kinetic energy was transformed into light energy”	The answers describe energy transformations by correctly outlining the intermediate steps and cause-and-effect relationships, and by using scientific language appropriately.

6. Is it possible to lose energy? Explain, giving some examples	*Examples explored during the course*	Cause-and-effect relationships; well-contextualised and clearly explained descriptions; explicit description of energy transformations	“No, it cannot be lost. If we take a whisk and a bowl full of water and start whisking the water, the water heats up because the kinetic energy of the whisk has been converted into thermal energy. So the energy of the whisk has not actually been lost”	The answers deny the loss of energy, explaining it as a transformation, consistent with the principle of conservation.
	Energy transformation	Explicit description of energy transformations	“No, because energy is always transformed”	The answers explain the loss of energy in relation to the principle of energy transformation.
7. What ‘types’ of energy do you know?	*Kinetic energy*	Correct and consistent use of scientific language	“For example, kinetic energy, associated with motion”	The answers use scientific terminology and correctly associate it with physical quantities or observable phenomena.
	Potential energy	Correct and consistent use of scientific language	“For example, potential energy, associated with height”	The answers use scientific terms and correctly associate them with physical quantities or observable phenomena.
	Thermal energy	Correct and consistent use of scientific language	“For example, thermal energy, associated with temperature”	The answers use scientific terms and correctly associate them with physical quantities or observable phenomena.
	Luminous energy	Correct and consistent use of scientific language	“For example, light energy, associated with the sun”	The answers use scientific terms and correctly associate them with physical quantities or observable phenomena.
	Chemical energy	*Correct and consistent use of scientific language*		The answers use scientific terms and correctly associate them with physical quantities or observable phenomena.
8. What is the difference between renewable and non-renewable energy sources?	*Limitations of energy sources*	*Correct and consistent use of scientific language*	“Non-renewable energy causes pollution and can lead to environmental disasters, and one day it will run out. Renewable energy	The answers distinguish between sources based on their long-term availability and environmental impact.

			is not always available”	
	Advantages of sources	*Correct and consistent use of scientific language*	“Renewable energy does not pollute and does not run out. Non-renewable energy is always available to us”	The responses compare the sources in terms of sustainability and availability, demonstrating a scientifically sound understanding of the distinction.

The categorisation of responses was carried out in light of the main misconceptions regarding the concept of energy documented in the literature (Millar, 2005; Yuenyong & Yuenyong, 2007; Colonnese et al., 2012; Opitz et al., 2015; Nordine et al., 2016; Bezen et al., 2016; Detken & Brückmann, 2021; Detken, 2023).

The categories identified within the levels of common-sense, partially scientific and scientific knowledge reflect these conceptual models and enable an analysis of the evolution of pupils’ representations in relation to the proposed TLS.

Responses classified as common-sense knowledge predominantly reflect intuitive and everyday conceptions, in which energy is described as a resource associated with the body, food, movement or technological objects, or as a non-material substance with generic properties (Carr & Kirkwood, 1988; Millar, 2005; Delegkos & Koliopoulos, 2020; Detken, 2023). At this level, interpretations linked to the literal meaning of terms also emerge, along with the idea of energy as something that is consumed or lost through use, without reference to processes of transformation or conservation (Millar, 2005; Colonnese et al., 2012).

Responses attributable to partially scientific knowledge show an initial approach to scientific language and content, albeit in the absence of a fully developed conceptual framework. In this context, pupils use correct labels, such as references to devices and infrastructure for energy production or to renewable and non-renewable sources, without explicitly distinguishing between source and form of energy or describing the transformation processes involved. Consequently, an initial use of scientific language emerges, without an actual understanding of it. This level also includes responses that refer to experimental experiences or standard definitions that are not sufficiently substantiated, highlighting knowledge that is in the process of being consolidated.

Finally, responses classified as scientific knowledge are characterised by the use of more precise language and the presence of explanations consistent with the physical model of energy (Nordine et al., 2011; Opitz et al., 2015; Bezen et al., 2016). In these responses, energy is described as a quantity that transforms and manifests itself in different forms, often through explicit references to the experimental activities carried out during the TLS. More nuanced conceptual distinctions also emerge, such as that between renewable and non-renewable sources in terms of limitations, advantages and impacts, indicating a more advanced and integrated understanding of the concept of energy.

The classification of responses into the three levels of knowledge does not depend solely on the subject category, but on the degree of scientific accuracy, the type of argumentation, and the language used by the pupils. Consequently, similar references (for example, to technological devices or experimental experiences) may appear at different levels depending on the explanation provided. This is the case with references to solar panels, wind turbines and power stations, which were classified under the category ‘Devices and infrastructure for energy production’, placed at different levels of knowledge depending on whether or not an explanation consistent with the scientific model of energy as a transformable quantity was provided. Furthermore, a single answer may be linked to multiple categories. For example, the answer to question 2 (Are there things that provide us with energy?) ‘Lots of things, such as food, or chargers, or light’ was categorised into two categories: Food and Technological objects/Electricity.

The following sections will present a descriptive analysis of the students’ responses, followed by an analysis of the statistical data obtained through the analysis conducted using LMM.

9.3 Results of the knowledge questionnaire

This section presents the results of the knowledge questionnaire. Firstly, the results of the qualitative analysis conducted using a phenomenographic approach are presented, through a description of the responses provided by the pupils in the pre-instruction and post-instruction, separately for the Control Group (CG) and the Experimental Group (EG).

Subsequently, the results of the quantitative analysis of the scores, carried out using Linear Mixed Models (LMM), are reported, in order to examine the performance trends in the two groups at the various measurement points.

9.3.1 Qualitative results – Control group (CG)

In the control group (CG), in the first administration of the questionnaire, there were no responses classified as scientific knowledge; the majority of responses fell into the category of common-sense knowledge and, to a lesser extent, into partially scientific knowledge or among the unanswered responses. The questions relating to energy conversion and the forms of energy recorded the highest number of responses classified as partially scientific knowledge. Conversely, the question regarding the difference between renewable and non-renewable energy sources recorded the highest number of unanswered responses.

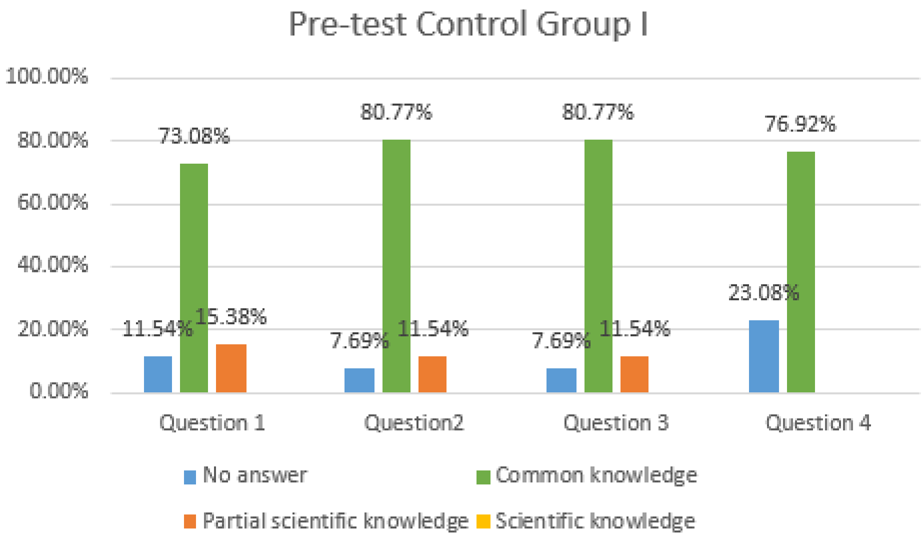

Fig. 1 Pre-instruction results: Control Group I

Question 1. What do you know about energy? 73% of the responses were classified as common-sense knowledge. In these responses, pupils described energy in relation *to technological devices/electricity* (8 responses), for example, *“Energy is what charges your phone or* tablet”, to *food* (8 responses) and to *physical movement* (5 responses), such as “When I run, I have lots of energy”. The answers classified as partial scientific knowledge refer *to devices and infrastructure for energy production* (2 answers), such as wind turbines and solar panels, or give the *standard definition of energy* (2 answers), namely “It is the ability of a body to do work”, without providing further explanation. Three pupils did not provide any answer.

Question 2. As far as you know, are there things that provide energy? The majority of responses were classified as common-sense knowledge (80.77%). In these, pupils identified *food* as the main source of energy (16 responses), followed *by technological objects/electricity* (3 responses). Furthermore, *energy was described as a universal property* (3 responses), such as “Everything has energy”. Three responses were classified as partial scientific knowledge, and all referred to *devices and infrastructure for energy production,* such as solar panels and/or wind turbines. Two pupils did not respond.

Question 3. As far as you know, are there things that have or possess energy? The pupils replied that things that possess energy are mostly technological *devices* or electricity (14 responses), such as chargers, sockets, light bulbs and telephones, and *food* (4 responses), for example, “Eating pasta gives us energy”. Three answers were classified as partial scientific knowledge and, in this case too, referred to devices *and infrastructure for energy production,* such as “Wind turbines provide energy and light to homes”. Two pupils did not answer.

Question 4. Can energy be stored? All the answers given were classified as common-sense knowledge (around 77%). The pupils describe energy conservation as *putting* energy *aside for future use* (13 responses), for example, “Storing energy in a power bank” or *“Energy is stored in the power* cables”, and as *storage within the body* (5 responses), for example, “We store energy in our bodies to do things later”. Six pupils did not respond.

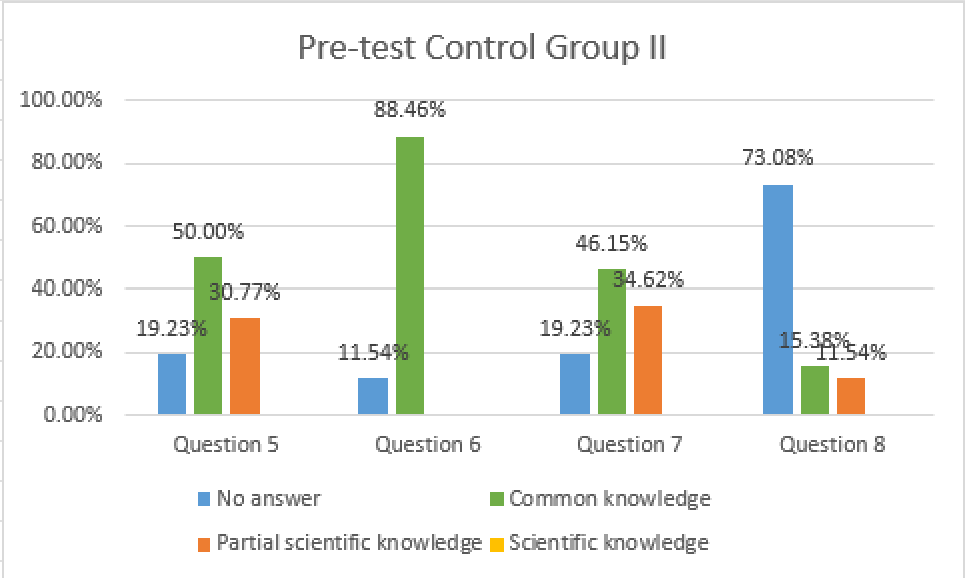

Fig. 2 Pre-instruction results: Control Group II

Question 5. Can energy be transformed? Explain, giving some examples. In the pre-instruction, this question recorded a high number of responses classified as partial scientific knowledge (30.77%), compared to the other questions in the questionnaire.

These students argued that energy can be transformed, giving as examples various *devices and infrastructure for energy production, such as* wind turbines/solar panels (4 responses), *food* (3 responses) such as “The food we eat is then transformed into energy that enables us to do things”, or providing no explanation at all (2 responses). Among the answers classified as common-sense knowledge (50%), the pupils were divided between those who provided answers related to technological objects/electricity (7 answers), such as “Batteries transform energy”, and answers related to the perception of their own *bodies* (6 answers), such as “When we run, energy is transformed into sweat”. Five pupils did not answer.

Question 6. Is it possible to lose energy? Explain, giving some examples. In the pre-instruction, all the answers given were classified as general knowledge (around 89%). The remaining answers were not provided. The pupils described energy conservation in terms of *movement* (14 answers), such as *‘Running or* jumping’, and in terms *of waste and electricity consumption* (9 answers), such as ‘When I leave the light on or when my phone runs out of battery’. Three pupils did not answer.

Question 7. What ‘types’ of energy do you know? In the pre- instruction, for this question, as with question 5, a high number of responses classified as partial scientific knowledge were recorded (approximately 34%). In this case, the pupils (9 responses) referred to incorrect ‘types’ of energy but with scientific references, such as *static energy or dynamic energy.* Answers classified as common-sense knowledge account for around 50%, and pupils cited forms of *electrical energy* (7 answers), such as “the energy of light”, *and* forms of energy related *to the body and movement* (5 answers), such as “muscle energy”. Five pupils did not answer.

Question 8. What is the difference between renewable and non-renewable energy sources? In the pre- instruction, this question recorded the highest number of unanswered responses (79%), i.e. 19 pupils. Among the answers classified as common-sense knowledge (around 15%), pupils referred to *the literal meaning* of the two terms (3 answers), for example “Some forms of energy return, others do not”. Finally, among the answers classified as partial scientific knowledge, the students attempted to explain the difference between renewable and non-renewable sources by providing *examples of different energy sources* such as wind turbines and/or solar panels (3 answers).

In the post- instruction, all pupils answered the questionnaire questions, so there are no longer any unanswered questions. The percentage of answers classified as common-sense knowledge has decreased, albeit to a highly variable extent: for some questions, it remains above 50%, for others below 20%. Furthermore, the percentage of answers categorised as partially scientific knowledge and scientific knowledge increased; again, to varying degrees depending on the answer. The questions that scored highest were those relating to energy conversion, forms of energy and the difference between renewable and non-renewable sources.

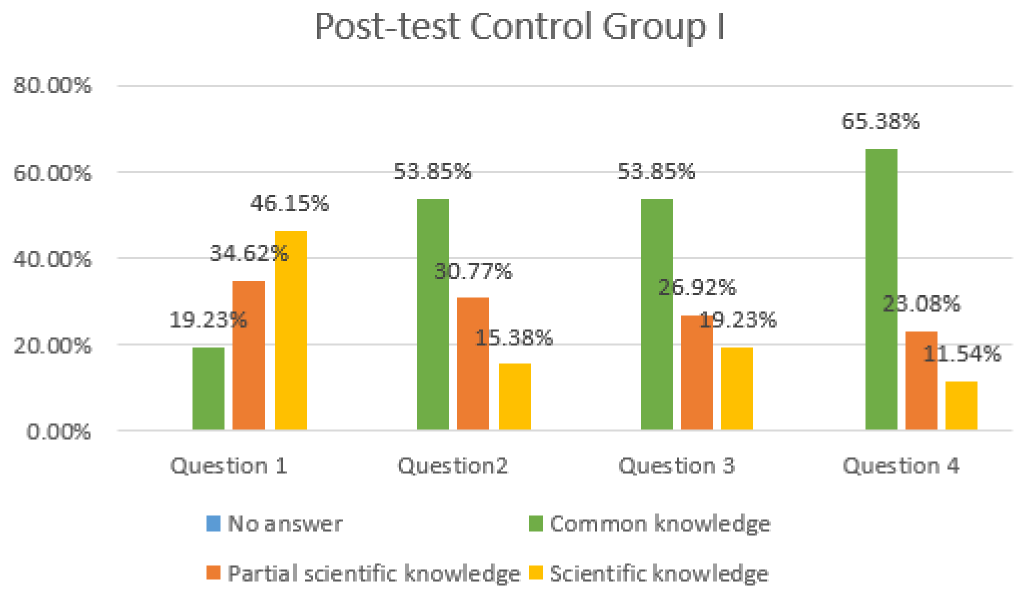

Fig. 3 Post instruction results: Control Group I

Question 1. What do you know about energy? In the post- instruction, most of the answers (46.15%) were classified as scientific knowledge. These refer to energy as *a quantity that can be transformed* (6 answers) and a *quantity that exists* in different forms (6 answers), such as "I know that energy can be transformed and that there are different types of energy, such as kinetic, chemical or thermal". In the answers classified as partial scientific knowledge, pupils described energy in relation to *renewable/non-renewable energy sources* (5 answers), such as "I know that wind turbines or solar panels produce renewable energy, whereas we get non-renewable energy from oil", and through *standard definitions that* were not sufficiently substantiated (4), such as "It is the ability of a body to do work". Among the answers classified as common-sense knowledge, pupils referred to energy as a *non-material substance* (5 answers), for example, "You can't touch energy, but it's everywhere", *to the body and movement* (3 answers) and to *everyday life* (2 answers), for example, "We need energy to run, play, move, to do everything".

Question 2. As far as you know, are there things that provide energy? In the post- instruction, the majority of responses (53.85%) to the second question were classified as common-sense knowledge. Among the things that provide energy, pupils cited the *natural elements* of wind, water and sun (6 responses), *food* (5 responses) and *technological objects/electricity* (3 responses). The answers classified as partial scientific knowledge all refer to the use of *devices and infrastructure for energy production,* such as solar panels, power stations and/or wind turbines (8 answers) to obtain renewable or non-renewable energy. Finally, in the answers classified as scientific knowledge (15, 38%), pupils cited the *experiments observed* during the course (4 answers), such as 'When objects move, for example the wheels of a bike, they have kinetic energy'.

Question 3. As far as you know, are there things that have or possess energy? The percentages obtained for this question are very similar to those obtained for the previous one. Around half of the pupils provided answers based on intuitive, everyday knowledge, specifically referring to *technological devices/electricity* (5 answers), *food* (5 answers) and *living beings* (4 answers). Around 27% of the answers were classified as partial scientific knowledge and, in this case too, they all refer to the use of *devices and infrastructure for energy production,* such as solar panels, power stations and/or wind turbines (6 answers) to obtain renewable or non-renewable energy. Finally, the responses classified as scientific knowledge (19.23%) contain references to *experiments observed* in the classroom (5 responses), for example, 'A bicycle has kinetic energy, or a dynamo has light energy'.

Question 4. Can energy be conserved? This question recorded the highest number of responses classified as common-sense knowledge (65.38%). Energy conservation was only briefly touched upon during the TLS course; therefore, we expected similar results. Among the answers classified as common knowledge, most refer to the literal meaning of the term, *setting aside for future use* (11 answers), such as "Energy is stored in solar panels and then you can turn on the light", and to the idea of storing energy in *the body* (6 answers), such as "Energy is inside us; we use it when we need it".

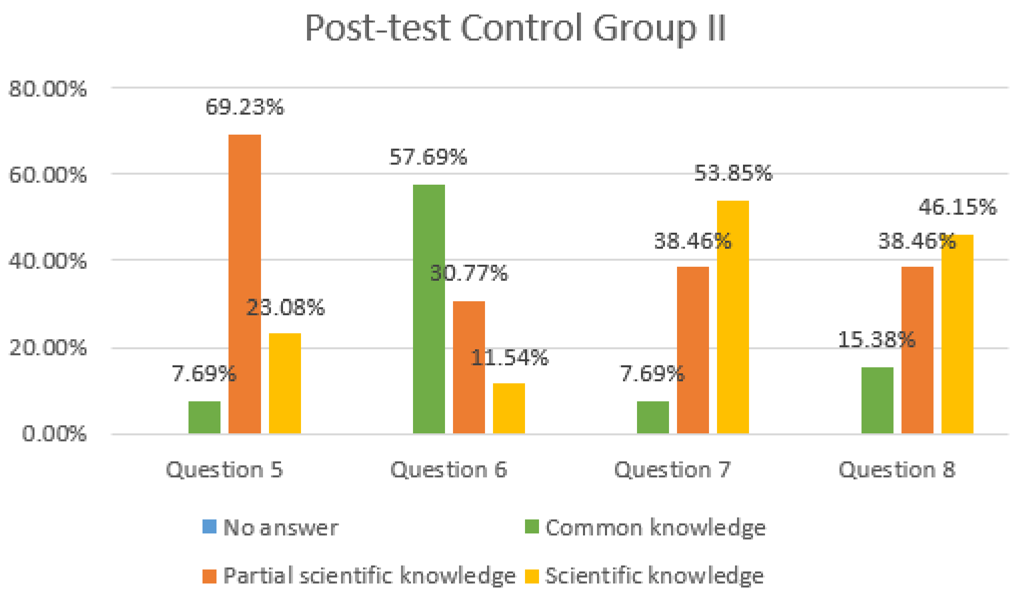

Fig. 4 Post instruction results: Control Group II

Question 5. Can energy be transformed? Explain, giving some examples. In this question, as in question 7, the lowest number of responses classified as common-sense knowledge was recorded compared to the questionnaire average. These accounted for 7.69% and consisted of two responses in which the pupils stated that energy *cannot be transformed*. Most of the answers were classified as partial scientific knowledge (69.23%); among these we find references to *the experiments observed* during the course (10 answers), such as “Yes, for example from kinetic energy to light energy, when the light bulb was lit thanks to the energy of the water” and *affirmative answers without argumentation* (8 answers), such as “Energy is always transformed” or “Energy can be transformed, for example from kinetic to thermal”. Finally, among the answers classified as scientific knowledge, we find references to *the experiments observed* during the course (6 answers), argued in a more comprehensive manner and using scientifically correct language, for example, “If we connect a light bulb to a dynamo on a bicycle and then pedal, the light bulb lights up because energy is transformed from kinetic energy into light energy”.

Question 6. Is it possible to lose energy? Explain, giving some examples. In the post-instruction, most of the answers were classified as common-sense knowledge (57.69%), as the pupils answered in the affirmative using examples related *to the body and movement* (9 answers), examples related to *the experiments* they had observed (2 answers), such as “When you stop turning the bike wheel, the light bulb goes out and the energy runs out” and *without providing* any reasoning (3 answers). In the remaining answers, the pupils stated that energy cannot be lost. In the answers classified as partial scientific knowledge, the reasons were linked to the concept of *transmission* (6 answers), such as “Energy is not lost; when you pedal the bike, your energy is transmitted to the wheel”, and to examples related to *the experiments* observed (2 answers), such as “Energy is not lost; for example, when the teacher turned the paddles, the energy went into the water”. In the answers classified as scientific knowledge, the explanations relate to the *concept of transformation* (3 answers).

Question 7. What ‘types’ of energy do you know? Most of the answers were classified as scientific knowledge (53.85%), in which pupils correctly cited the forms of energy explored during the course, such as *kinetic energy, potential energy and thermal energy* (14 answers). Among the answers classified as partially scientific knowledge, in addition to mentioning the above, there were also answers such as static energy (3 answers), light energy (3 answers), precipitation energy (2 answers) and kinetic energy (2 answers).

Question 8. What is the difference between renewable and non-renewable energy sources? Most of the answers were classified as scientific knowledge (46.15%): in these*,* pupils described the various *limitations of the sources (12 responses), such as* “Non-renewable sources pollute and can cause disasters” or “Non-renewable energy will run out and cannot be produced again”, the *advantages of the sources* (10 responses), such as “Renewable energy does not run out and does not pollute the planet”, and the difference *between natural and artificial sources* (6 responses). Among the responses classified as partially scientific knowledge, pupils described various *examples of energy sources* (5 responses), such as “Renewable energy comes from wind or water or the sun; non-renewable sources are oil and coal”, and referred to the possibility of *using or not reusing them* (5 responses), such as “Renewable energy can always be used”. Finally, four answers were classified as common-sense knowledge, as the pupils referred to *the literal meaning* of the two terms.

9.3.2 Qualitative results – Experimental Group (EG)

In the EG, in the first administration, most responses were classified as common-sense knowledge, with an average of around 60% across the entire questionnaire. The students answered almost all the questions, with the exception of question 8, which had a high number of unanswered responses. As in the CG, there were no responses classified as scientific knowledge in the pre- instruction, and the percentage of responses classified as partial scientific knowledge was very low.

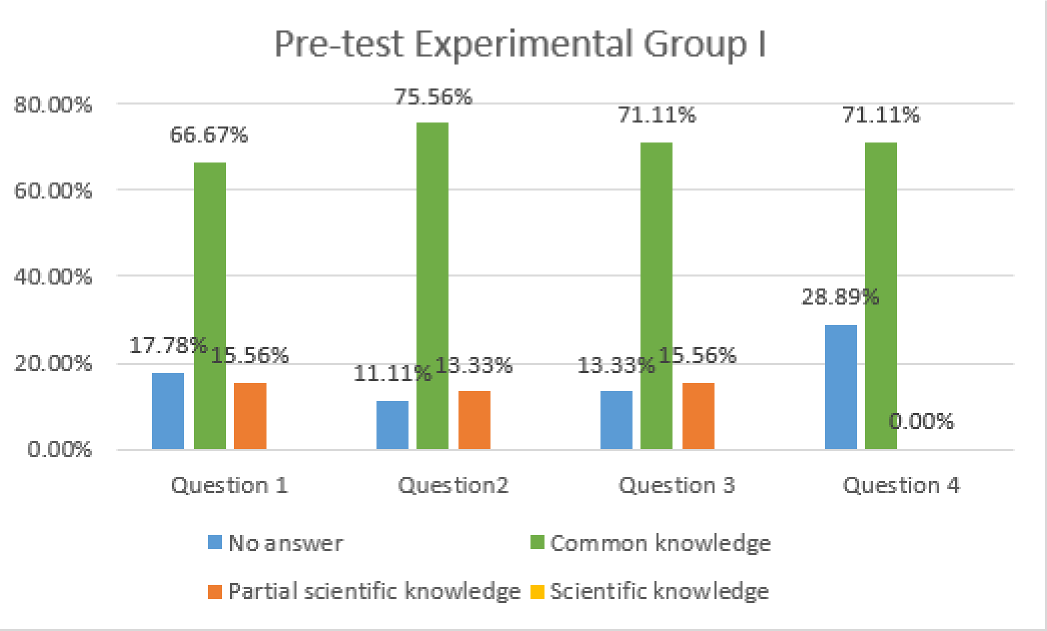

Fig. 5 Pre- instruction results: Experimental Group I

Question 1. What do you know about energy? 66.67% of the answers fall into the common-sense knowledge category. It is associated with: *everyday life* (10 answers), such as "It is what allows us to live"; *technology* (9 answers); *the body and movement* (7 answers), for example "It is needed to keep the body awake and to move"; and as *a non-material substance* (4 answers), for example "It is everything that surrounds us". The remaining answers were classified as partial scientific knowledge, in which a *standard definition* of *energy* is provided but is insufficient (5 answers) and in which *forms of energy* are mentioned (2 answers), for example "I know that energy can take many forms". Eight pupils did not answer.

Question 2. As far as you know, are there things that provide energy? The answers classified as common-sense knowledge (75, 56%) are divided into two categories: those referring to *food* (21 answers) and those referring *to technological objects/electricity* (18 answers), such as "Electricity wires" or tablets, PCs, and phones. The answers classified as partial scientific knowledge mention various *devices and infrastructure for energy production,* such as solar panels, power stations and/or *wind* turbines (6 answers). Five pupils did not answer.

Question 3. As far as you know, are there things that have or possess energy? Most of the answers are classified as common-sense knowledge (71.11%). According to the pupils, things that possess energy are *technological objects/electricity* (18 answers), for example 'electricity pylons', 'the charger', *food* (6 answers), *living beings* (4 answers) and *natural elements*, namely water, wind and sun (4 answers). The answers classified as partial scientific knowledge all refer to *devices and infrastructure for energy production,* such as solar panels, power stations and/or wind turbines (7 answers). Six pupils did not answer.

Question 4. Can energy be conserved? All the answers given to this question were classified as common-sense knowledge. In particular, the pupils stated that energy conservation refers to the possibility of *setting energy aside for future use* (26 responses) and to the conservation of energy in *the body* (6 responses), such as "A person can conserve their energy and use it when needed". Thirteen pupils did not answer.

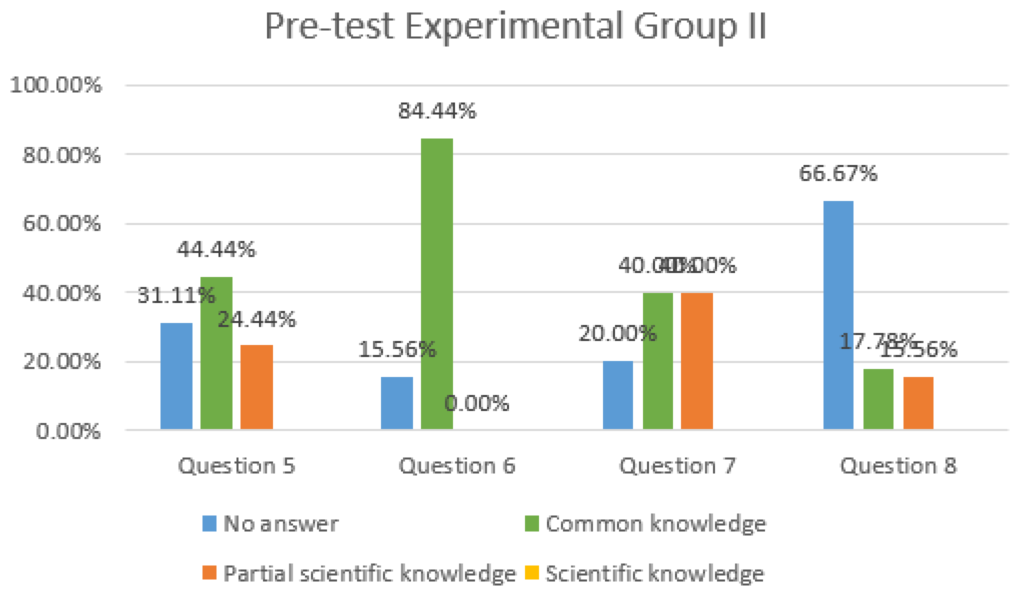

Fig. 6 Pre-instruction results: Experimental Group II

Question 5. Can energy be transformed? Among the answers classified as common-sense knowledge, pupils stated that energy can be transformed through *technological devices/electrical sources* (11 answers), for example "When you switch the light on and off", or within *the human body* (9 answers), for example "Our body's energy is transformed into tiredness". Among the answers classified as partial scientific knowledge, the pupils described the transformation of energy as a phenomenon that occurs in *devices and infrastructure for energy production* (7 answers), for example "Wind energy that is transformed into electrical energy", through *food* (3 answers), such as "The food we eat is transformed into energy by our cells". Only one pupil provided *a standard definition* (Energy is neither created nor destroyed) without elaborating on it. 14 pupils did not answer the question.

Question 6. Is it possible to lose energy? Explain, giving some examples. This question recorded the highest number of responses classified as common-sense knowledge, as all the answers provided were categorised in this group. Most answers refer to the idea that energy can be lost through *movement* (22 answers), for example by running or jumping, or through *the waste and consumption of electricity* (11 answers), such as "When the power goes out, it means there is no more light". Some pupils answered in the affirmative *without providing any explanation* (5 answers). Seven pupils did not answer.

Question 7. What 'types' of energy do you know? This question recorded the highest percentage of answers classified as partial scientific knowledge. In these answers, pupils listed forms of energy such as *'static energy', 'dynamic energy' and 'electric* energy' (18 answers). In the answers classified as common-sense knowledge, pupils referred to *the energy of various objects* (9 answers), such as "the energy of light bulbs, the energy of a car", and cited examples of forms of *energy in the body* (5 answers) and *electrical energy* (4 answers).

Question 8. What is the difference between renewable and non-renewable energy sources? As in the GC pre- instruction, this question also recorded the highest number of non-responses in the EG pre- instruction (66.67%). The answers classified as common-sense knowledge refer to *the literal meaning* of the two terms (8 answers), such as "It means that energy can be recycled". The answers classified as partial scientific knowledge refer to the concept of energy *use/non-use* (5 answers) and to *examples of different energy sources* (3 answers), such as "Wind turbines use the wind many times".

In the post- instruction, a markedly different situation emerges compared to the pre-instruction: there has been a significant decrease in unanswered questions and those classified as common-sense knowledge, in favour of answers demonstrating a greater understanding of energy from a physical perspective. The pupils made extensive reference to classroom activities when answering the questions. The questions that scored highest were those relating to the general description of energy, the transformation of energy, forms of energy, and the difference between renewable and non-renewable sources. Conversely, the question that recorded the lowest percentage of answers classified as scientific knowledge was No. 6 (conservation of energy). All pupils answered the questions.

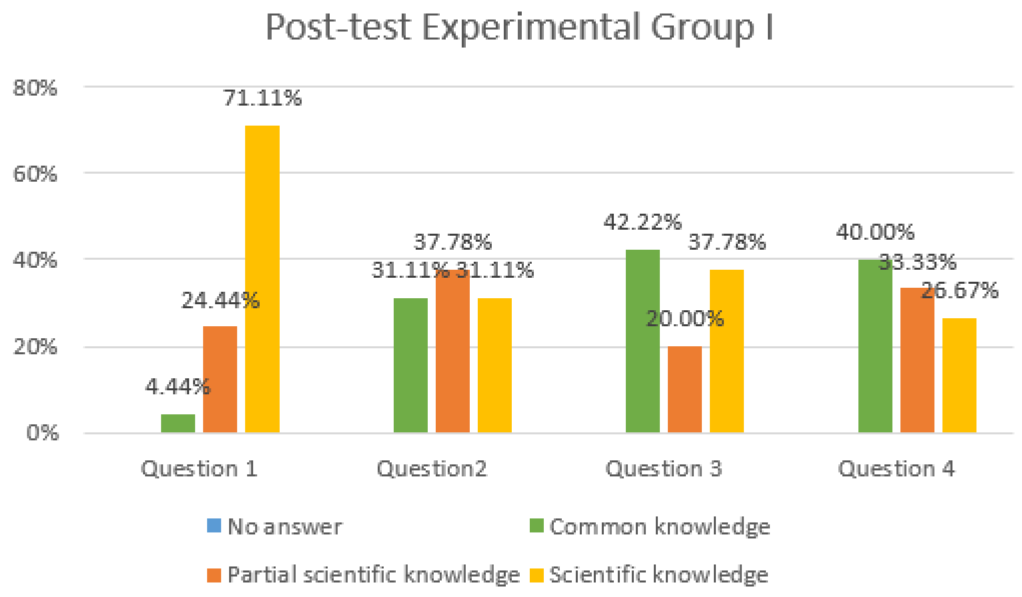

Fig. 7 Post-instruction results: Experimental Group I

Question 1. What do you know about energy? Among the answers provided, two were categorised as common-sense knowledge, within the categories *of movement* (1 answer) and *daily life* (1 answer). The answers classified as partial scientific knowledge refer to different *forms of energy* (7 answers), such as "I know there are different forms of energy", to *renewable/non-renewable energy* sources (2 answers), such as "I know that energy is divided into renewable, such as wind and water, or non-renewable, such as petrol", and contain *standard definitions of energy* without further explanation (2 responses). The majority of responses (71.11%) were classified as scientific knowledge. In these, the students responded by speaking of energy as a *quantity that transforms* (17 responses), a *quantity that takes different forms* (10 responses), such as "energy can be kinetic, for example when associated with movement, or thermal when associated with heat", and present in *all systems and bodies* (5 responses), such as "Energy is an abstract entity that exists in different forms. Everything possesses energy".

Question 2. As far as you know, are there things that provide energy? In the post- instruction, the response percentages were evenly distributed across the three categories. In all the answers classified as general knowledge, the pupils referred to *food* (14 answers) as a substance that provides energy. In all answers classified as partial scientific knowledge, pupils stated that *energy-producing devices and infrastructure,* such as solar panels, power stations and/or wind turbines (17 answers), provide energy. Finally, among the questions classified as scientific knowledge, most cited *examples explored during the course* (10 responses), describing falling objects, temperature changes or moving objects, and references to *all systems and bodies* (5 responses).

Question 3. As far as you know, are there things that have or possess energy? This was the question that yielded the highest percentage of answers classified as general knowledge (42.22%). In these, pupils mentioned *natural elements* (9 answers), *living beings* (5 answers) and *technological objects/electricity* (5 answers). In the answers classified as partial scientific knowledge, all pupils replied that *devices and infrastructure for energy production,* such as solar panels, power stations and/or wind turbines (9 answers), possess energy. Finally, in the answers classified as scientific knowledge, there are references to *examples explored during the course* (12 answers), such as "With the waterwheel experiment, we realised that water has energy; in fact, by letting water fall onto the wind turbine blades, we obtained light energy", and to *all systems and bodies* (5 answers).

Question 4. Can energy be conserved? Here too, the largest percentage (40%) relates to the group of answers classified as common-sense knowledge. In these, the pupils described energy as a substance that can be *set aside for future use* (12 answers) and as a substance that can be *stored and conserved within the body* (6 answers). In the answers classified as partial scientific knowledge, , the students attempted to explain the conservation of energy through the concept of *transmission* (6 responses), such as "We saw that the kinetic energy from the bike is transmitted to the light bulb, so the energy is conserved", through *devices and infrastructure for energy production* (5 responses)*,* such as "Energy is stored in wind turbines and used when there is no light". In the answers classified as scientific knowledge, the pupils spoke of *transformation* (7 answers), such as "It means that energy is always transformed, so it is conserved", and cited some *examples explored in the course* (5 answers).

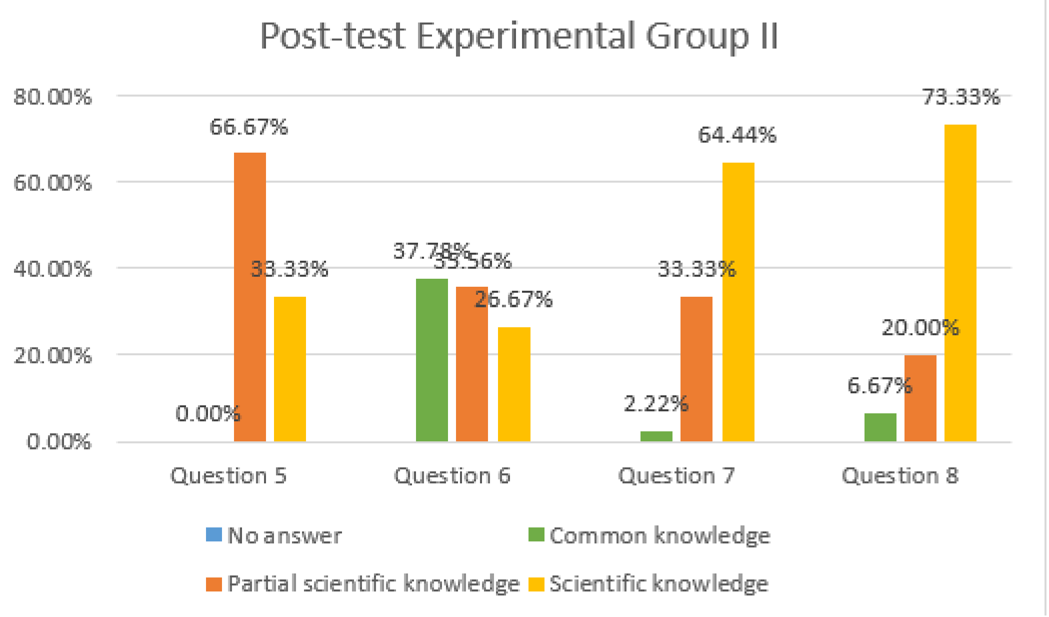

Fig. 8 Post- instruction results: Experimental Group II

Question 5. Can energy be transformed? None of the answers to this question were classified as common-sense knowledge. Most of the answers were classified as partial scientific knowledge (66.67%). All the pupils stated that energy is always transformed, though they justified their answers in different ways. Among the answers classified as partial scientific knowledge, , pupils referred to *the standard definition* (1 answer), namely ‘Energy is neither created nor destroyed’, to *devices and infrastructure for energy production* (2 answers), such as ‘For example, wind energy is converted into light energy thanks to wind turbines’, and to *the relationship between food and human energy (1 answer), namely* ‘The body’s cells convert food into energy’. All remaining answers refer to the *experiments carried out during the course*. In particular, 30 answers (66.67%) were classified as partially scientific knowledge and the remaining 15 as scientific knowledge (33.33%). The criteria used for this classification are a) the use of scientific language and b) precision and accuracy in the description of the phenomenon(s). In the first group, we find answers such as “For example, when we ride a bike, our energy goes into the wheel and becomes rotational kinetic energy; then we attached a small light called a dynamo, and the bike’s kinetic energy powers the bulb”. In the second group, we find answers such as “In the windmill experiment, we connected a dynamo-powered light bulb to some windmill blades and then tried pouring water onto the blades. We realised that if we pour the water from below, nothing happens, whereas if we pour the water from above, we get light energy. So the energy of the water was transformed into light energy”.

Question 6. Is it possible to lose energy? Explain, giving some examples. Most of the answers were classified as common-sense knowledge (37%), as the pupils replied that energy can be lost: due to *movement* (8 answers), *waste and consumption of electricity* (5 answers), or they answered in the affirmative without *providing explanations* (4 answers). In the answers classified as partially scientific knowledge, pupils referred to the concept of *transmission* (16 answers), such as "we have seen that energy is not lost because it is transmitted; it can go from the bike to the light". Responses classified as scientific knowledge account for 26.67%: these include references to *experiments carried out* in the classroom (7 responses) and to *the transformation of energy* (5 responses).

Question 7. What 'types' of energy do you know? Most of the answers were classified as scientific knowledge (64.44%), as the pupils correctly listed the various forms *of energy* covered during the course (*kinetic, thermal, potential and light energy*). In the answers classified as partially scientific energy, pupils cited both scientifically correct forms of energy and incorrect forms, such as *dynamic energy* (7 answers), *static energy* (5 answers) and *electrical energy* (3 answers). Only one pupil gave an example of *electrical energy*, namely 'the light in houses', so the answer was classified as common-sense knowledge.

Question 8. What is the difference between renewable and non-renewable energy sources? This question recorded the highest percentage of answers classified as scientific knowledge (73.33%). In these answers, pupils explained the difference between renewable and non-renewable sources by describing the various *limitations of the sources* (22 answers), such as "Non-renewable energy runs out, causes pollution and is produced, for example, from oil," and *the advantages of the sources* (15 answers). 20% of the answers, however, were classified as partially scientific: in these, pupils discussed the *use/non-use of energy* (5 answers), *examples of different energy sources* (4 answers) and analysed the *differences between natural and artificial sources* (4 answers), such as "Renewable energy is obtained from natural elements, such as wind and the sun, non-renewable energy is obtained from non-natural elements, such as uranium or oil", highlighting a fairly widespread association between the ideas of "non-natural" and "harmful". Finally, three pupils answered the question by analysing the *literal meaning of the two terms* renewable/non-renewable (3 responses), and their answers were therefore classified as common-sense knowledge.

9.3.3 Quantitative results (Linear Mixed Models)

The analysis of the scores obtained in the pre- and post- instruction was conducted using a Linear Mixed Model, considering the group (control vs experimental), time (pre-instruction vs post-instruction) and their interaction as fixed effects.

Table 4 presents the estimated marginal means for the two groups at the two measurement points (pre- instruction and post-instruction), allowing us to observe the trend in scores and the greater growth in the experimental group compared to the control group.

Table 4 Estimated marginal means by group and time

Group	Time	M	SE
Experimental	Pre	7.20	0.357
Control	Pre	7.35	0.470
Experimental	Post	18.00	0.357
Control	Post	15.39	0.470

Note. M = estimated marginal mean; SE = standard error.

Table 5 shows the coefficients of the fixed effects in the model, allowing for the interpretation of the direction and magnitude of the effects of group, time and their interaction.

Table 5 Coefficients of the model’s fixed effects

Term	b	SE	df	t	p
Intercept	7,200	0.357	138	20,171	< 0.001
Group (Control)	0.146	0.590	138	0.248	.805
Time (Post)	10.800	0.505	138	21,394	< 0.001
Group (Control) × Time	-2.762	0.834	138	-3.310	.001

Note. The experimental group and the pre- instruction represent the reference categories.

Fig. 9 shows a graphical representation of the trend in the mean scores of the EG and GC in the pre- instruction and post- instruction.

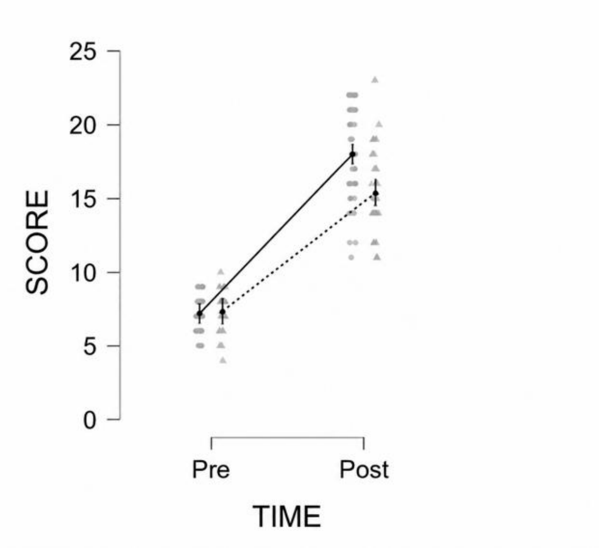

Fig. 9. Trend in average scores (CG vs EG)

Note. Solid line: EG; Dotted line: GC

An examination of the estimated mean scores shows (Table 4) that, at the pre- instruction, the two groups had essentially comparable levels (EG: M = 7.20; GC: M = 7.35), suggesting that they were comparable at the outset. At the post- instruction, both groups recorded an increase in scores; however, this increase was more pronounced in the EG (M = 18.00) than in the control group (M = 15.39). In terms of change, the EG showed an improvement of 10.80 points, whilst the GC recorded an increase of approximately 8.04 points.

This interpretation is consistent with the fixed-effect coefficients of the model (Table 5). In particular, the difference between the groups at the pre- instruction is not statistically significant (b = 0.146, p = .805), confirming the absence of any significant initial differences. The effect of time at the post- instruction, however, is large and significant (b = 10.800, p < .001), indicating a general improvement in performance. The negative interaction between the CG and post- instruction time (b = -2.762, p = .001) indicates that the improvement observed in the CG is significantly lower than that recorded in the EG.

Overall, the results therefore suggest that the TLS conducted in the EG produced a more favourable effect than in the GC.

It should be noted, however, that the model output reports a singular fit, with zero variance in the random intercept and a consequent simplification of the random effects structure. This suggests caution in the inferential interpretation of the results, as it may indicate limited adequacy of the model specification with respect to the data structure. Whilst not invalidating the general pattern that has emerged, this methodological issue suggests that the conclusions should be regarded as statistically sound but discussed with caution regarding the robustness of the model

9.4 Discussion of results – knowledge questionnaire

The results obtained from the knowledge questionnaire highlight both common elements between the two groups and significant differences that emerged at the end of the TLS.

In the pre- instruction, the initial picture is essentially homogeneous between the control group (CG) and the experimental group (EG), confirming the comparability of the two groups and the presence of similar prior knowledge. In both groups, the pupils' responses are predominantly attributable to common-sense knowledge and reflect the main misconceptions regarding the concept of energy documented in the literature (Millar, 2005; Yuenyong & Yuenyong, 2007; Nordine et al., 2011; Colonnese et al., 2012; Detken, 2023). In particular, energy is frequently interpreted as a resource linked to everyday experience, the body or food, or as a non-material substance with properties of its own, which can be stored or consumed. There is also frequent confusion between energy and electricity, as well as the idea that energy is 'lost' through use or physical exertion (Carr & Kirkwood, 1988; Millar, 2005; Abramovitch & Fortus, 2023).

References to technological objects, solar panels and wind turbines as entities that 'possess' or 'supply' energy are also common-sense; these responses reflect a conception of energy as an intrinsic property of objects, and highlight a confusion between energy, electricity and technological devices. In some cases, energy is attributed indiscriminately to all things, without making any distinction between objects, processes or forms of energy (Carr & Kirkwood, 1988; Millar, 2005; Optiz et al., 2015). Responses that associate energy loss with the use of electrical devices, such as leaving a light on or a phone running out of battery, reflect a conception of energy as a resource that is depleted through use.

The pre- instruction also reveals a significant proportion of unanswered questions, particularly in those requiring a higher level of abstraction, such as those relating to energy conservation and the distinction between renewable and non-renewable sources. Responses classifiable as partially scientific knowledge are limited and predominantly characterised by the use of nominal labels (e.g. references to devices or forms of energy), whilst responses attributable to scientific knowledge are absent. The absence of the latter in the pre-instruction suggests the presence of initial conceptual models that are poorly structured and consistent with the main misconceptions regarding the concept of energy documented in the literature (Millar, 2005; Optiz et al., 2015; Colonnese et al., 2012; Delegkos & Koliopoulos, 2020).

At the end of the TLS, both groups showed an overall improvement, as evidenced by both qualitative and quantitative analysis. In particular, there was a significant reduction in responses classified as common-sense knowledge and in unanswered responses, accompanied by an increase in partially scientific and scientific responses. The students begin to describe energy as a quantity that transforms and manifests itself in different forms, using language closer to the scientific model and moving beyond, at least in part, the substantialist and anthropocentric view typical of their initial conceptions (Besson, 2015).
The transformation of energy appears to be the best-understood concept in both groups: students in both the EG and GC provide relevant and often correct answers, referring to concrete examples and, in several cases, to the experiments observed during the TLS. The main categories that emerged in the post- instruction include: the description of energy as a transformable quantity, the recognition of different forms of energy (kinetic, thermal, potential, light), reference to devices and infrastructure for energy production (solar panels, wind turbines, power stations) and the distinction between renewable and non-renewable energy sources. Furthermore, in both groups, there was a significant decrease in responses interpreting energy exclusively as a substance linked to the body, food or movement, although these categories did not disappear entirely.

However, significant difficulties persist in questions relating to the conservation and loss of energy, which continue to be interpreted through intuitive models, such as the idea of accumulation (‘saving up’) or consumption linked to use. This confirms what has been highlighted in the literature regarding the particular resistance to change of these conceptual aspects (Grandrath et al., 2021; Etkina et al., 2023; Abramovitch & Fortus, 2023).
Despite these common elements, significant differences emerge between the two groups in the post- instruction. From a quantitative perspective, the results of the Linear Mixed Model reveal a significant effect of time and a significant interaction between group and time, indicating a general improvement in both groups but more pronounced in the EG. The estimated marginal means confirm that, despite starting from comparable initial levels, the

EG achieves higher mean scores in the post-instruction compared to the GC, highlighting a greater increase in performance.
These results are consistent with the findings of the qualitative analysis.

In the GC, although there was an improvement compared to the pre- instruction, responses remained more frequently rooted in intuitive conceptions, with less systematic use of scientific language and a weaker link between the experiments and the conceptual explanation. Numerous responses classified as common-sense knowledge remain, particularly in questions relating to what provides energy (question 2), what possesses energy (question 3), the conservation of energy (question 4) and the possibility of losing energy (question 6). In these questions, GC pupils tend to describe energy as a consumable or storable resource, associated mainly with food, technological objects and electricity. Furthermore, students make more limited use of the observed experiments as interpretative tools, and their descriptions are often descriptive and poorly reasoned, using language that is not fully formalised. This result indicates that the traditional methodology used did not allow for the active involvement of students in carrying out the experiments and, consequently, did not allow for a meaningful assimilation of the latter (Novak, 2012).

In the EG, however, there is a greater presence of responses classified as partially scientific knowledge and scientific knowledge. Students more frequently refer to the experiments conducted during the TLS, using them as a basis for explaining the phenomena analysed. In particular, in questions relating to the conservation and loss of energy, they more often attempt to justify their answers by referring to the concepts of energy transmission and transformation, moving beyond the idea of a simple ‘loss’ linked to use or effort (Etkina et al., 2023).
The EG’s answers are, overall, more articulate and characterised by a more accurate use of scientific terminology. The students demonstrate a greater ability to link experimental observations to the theoretical concepts addressed. These results suggest that the inquiry-based learning process typical of ISLE has enabled a meaningful understanding of the practical activities carried out and a modification of the students’ cognitive structures (Novak, 2012; Etkina, 2015).

The differences observed between the two groups are consistent with what has been reported in the literature regarding the role of active teaching methodologies in helping to overcome misconceptions (Novak, 2012; Bybee, 2009; Grandrath et al., 2021). These previous studies have highlighted that mere exposure to theoretical content or everyday examples is insufficient to promote a profound restructuring of students' conceptual models, as they tend to retain intuitive interpretations of energy as a substance, resource or intrinsic property of objects. Conversely, the ISLE methodology adopted in the EG appears to have fostered more active student engagement, promoting deeper processes of knowledge construction and restructuring compared to the traditional methodology used in the GC.

9.5 The SE-IS questionnaire: analysis methodology

The third version of the SE-IS questionnaire (Appendix A), developed at the conclusion of Study 3 (see Chapter 7), was administered to students at the start and end of the 12-hour TLS on the topic of energy. The aim of the instrument is to analyse students' Science Self-Efficacy (SSE) and to identify any gender-based differences before and after the TLS. Through exploratory factor analysis (see Chapter 7), eight factors (Table 7) were identified within the questionnaire.

Table 7. Factors extracted via EFA in the SE-IS

Factor	Name
F1	Specific self-efficacy in physics and chemistry
F2	Specific self-efficacy in human biology
F3	Specific self-efficacy in plant and animal biology
F4	Self-efficacy in scientific tasks
F5	Mastery Experience
F6	Emotional State
F7	Verbal Persuasion
F8	Vicarious Experience

Given the longitudinal design of the study (pre/post) and the presence of repeated measures on the same participants, the analysis was conducted using Linear Mixed Models (LMM), employing the JASP software. This approach allows for the simultaneous modelling of the effects of time (pre- instruction vs post- instruction), group (Control Group vs Experimental Group) and gender (males vs females), as well as their interactions, whilst accounting for individual variability among students (West et al., 2022). The use of Linear Mixed Models is particularly suitable in longitudinal studies with repeated measures, as it allows for the handling of the dependency between observations from the same subject and provides a more accurate estimation of the effects of experimental factors compared to traditional comparisons using t-tests or ANOVA (Field, 2018; West et al., 2022).

To analyse the trends of the eight factors in the questionnaire, eight separate Linear Mixed Models were estimated, one for each factor of the SE-IS (Table 7).

In all models, Time (Pre vs. Post), Group (Experimental vs. Control) and Gender (F vs. M) were included as fixed effects. Interactions between the factors (Time × Group, Time × Gender, Group × Gender, Time × Group × Gender) were also considered, in order to verify any differential effect of TLS across the different groups and between genders. The participant ID was included as a random effect to account for the dependency between the two repeated observations on the same subject. The models were estimated using maximum likelihood, and the significance of the effects was assessed using Type III likelihood ratio tests.

Due to the data structure (only two time points), it was not possible to estimate random slopes; therefore, the final models include only a random intercept per participant. The interpretation of the results is based primarily on significance tests of the fixed-effect s and on estimates of marginal means, which are particularly useful in the presence of interactions.

9.6 Results of the SE-IS questionnaire

Descriptive analyses confirmed the suitability of the dataset for the application of mixed-effects linear models. The sample consisted of 71 students assessed at two time points (pre-instruction and post- instruction), for a total of 142 observations. No missing data were detected and the distributions of the self-efficacy dimensions were acceptable.

Table 8 shows the p-values corresponding to the three dependent variables (Time, Group, Gender) and their interactions for each factor.

Table 8. Results of the analysis using Linear Mixed Models (LMM): p-values

Factor	**Time**	**Group**	**Gender**	**Time × Group**	**Time × Gender**	**Group × Genre**	**Time × Group × Gender**
F1	**< .001**	.705	**< .001**	**.002**	**.003**	.610	.085
F2	.215	.199	.807	.440	.480	.985	.654
F3	.128	.438	.972	.202	.751	.831	.628
F4	**< 0.001**	.746	**< .001**	.112	**.007**	.791	.665
F5	**< .001**	.957	**< 0.001**	**.004**	**< 0.001**	.509	.087
F6	**< .001**	.522	**< 0.001**	**.006**	**.002**	.502	.098

F7	**.009**	.919	.138	**.028**	**.026**	.725	.236
F8	.927	.377	.169	.756	.981	.971	.970

Note. Statistically significant results ($p < .05$) are highlighted in bold.

The analysis of skewness values indicated that the distributions of self-efficacy scores were generally acceptable for mixed-methods linear modelling, with skewness values ranging approximately between −1.19 and 0.66. Only a small number of potential outliers were detected, and their frequency was sufficiently low not to influence the analyses.

Comparisons with independent pre-instruction samples showed no statistically significant differences between the control and experimental groups on any factor, indicating that the two groups were comparable prior to TLS.

Effects of fixed variables (Time, Group, Gender)

The results show that the Time effect is significant in five of the eight factors considered: F1 – Specific self-efficacy in physics and chemistry (p < .001), F4 – Self-efficacy in scientific tasks (p < .001), F5 – Mastery Experience (p < .001), F6 - Emotional State (p < .001), F7 - Verbal Persuasion (p = .009). This indicates that, regardless of the group and the methodology used, self-efficacy scores in these dimensions showed a significant change between the pre- instruction and post-instruction. This is particularly evident in dimensions F1 and F5, where the increase from pre-instruction to post- instruction is marked and statistically very robust.

The main effect of Group is not significant in any model, indicating the absence of overall mean differences between the experimental group and the control group across the entire time period considered. This suggests that the differing effect of TLS can be attributed not to a static difference between groups, but to a difference in the trajectory of change.

The main effect of Gender is significant in four factors: F1 (p < .001), F4 (p < .001), F5 (p < .001), F6 (p < .001). Differences between males and females are present in both groups, but not uniformly across all factors.

Effects of interactions

In interpreting the results, particular attention was paid to significant interactions, as these provide a more comprehensive description of the dynamics of change between the variables under consideration.

The key effect for assessing TLS is the Time × Group interaction, which allows us to verify whether the change from pre- to post- instruction differs between the experimental and control groups.

This interaction is significant in three factors: F1 (p = .002), F5 (p = .004) and F6 (p = .006). In these, the EG shows a different trend compared to the CG. In particular, students in the EG show a greater increase in F1 (Fig. 1) and F5 (Fig. 5) in the post- instruction compared to students in the CG. In F6, however, an examination of the marginal means shows that the EG experienced a decrease in score, indicating that negative emotional states associated with science have diminished (Fig. 6).

In the case of F7, the Time × Group interaction is significant (p = .028), but its interpretation requires caution, as the analysis reports a singularity warning, indicating estimation problems in the model's random structure. For this reason, the result relating to F7 cannot be considered with the same degree of reliability as the effects observed in F1, F5 and F6.

The Time × Gender interaction is significant in five factors: F1 (p = .003), F4 (p = .007), F5 (p < .001), F6 (p = .002) and F7 (p = .026). This finding shows that gender affects not only average levels of self-efficacy but also the way in which it changes over time. Males and females did not change their perception of self-efficacy from pre- instruction to post-instruction in the same way. In some factors both genders showed an improvement, although it was more marked in one of them; in F6, the change mainly concerns one of the two genders (females, Fig. 6).

The Group × Gender interaction is not significant in any factor. This suggests that the differences between males and females do not vary depending on whether they belong to the experimental or control group.

To examine whether TLS had a different impact on male and female students, the three-way interaction Time × Group × Gender was analysed; again, no significant evidence was found for any factor. Therefore, although gender is significant both as a main effect and as an interaction with time, it does not moderate the effectiveness of the TLS. This indicates that the TLS is not more effective for one gender than the other: it produced similar effects for both males and females.

In summary, the results highlighted statistically significant differences between males and females in certain dimensions of the SEE, in both the EG and the GC; several of these underwent a significant change at the end of the TLS. Secondly, the ISLE methodology produced observable effects in certain factors (F1, F5 and F6). Gender emerged as an important factor both in average levels and in the change in self-efficacy over time. Finally, there is no evidence that the effect of TLS depends on gender.

The estimated marginal means are reported below for each individual factor, analysing pre/post, gender and group.

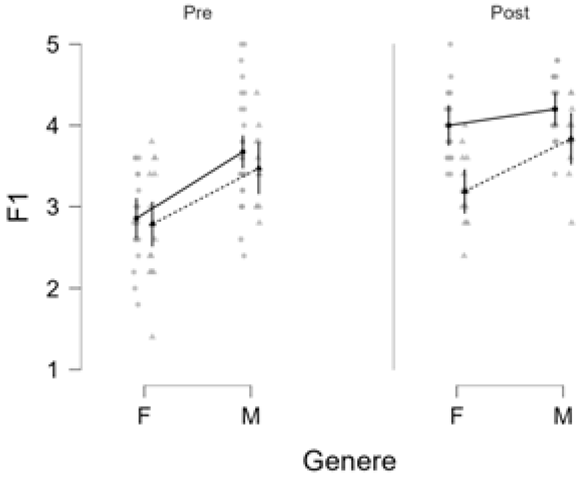

Fig. 1 F1 results (Specific self-efficacy in physics and chemistry)
Solid line: EG; Dotted line: GC

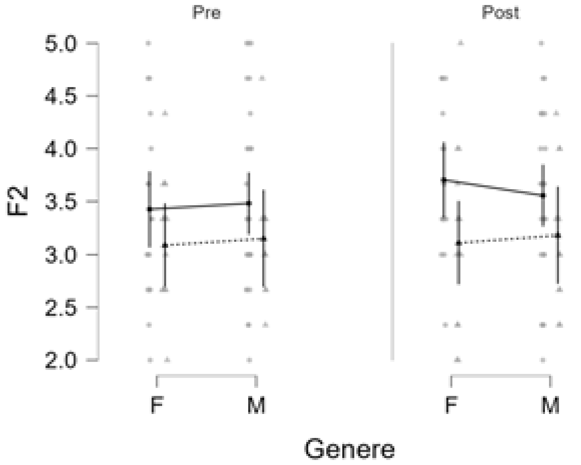

Fig. 2 Results F2 (Specific self-efficacy in human biology)
Solid line: EG; Dotted line: GC

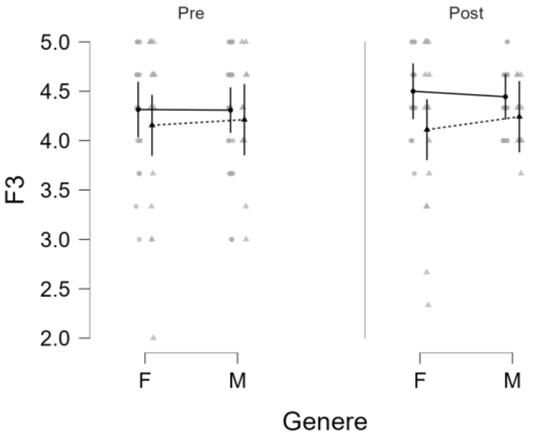

Fig. 3 Results F3 (Specific self-efficacy in plant and animal biology)
Solid line: EG; Dotted line: GC

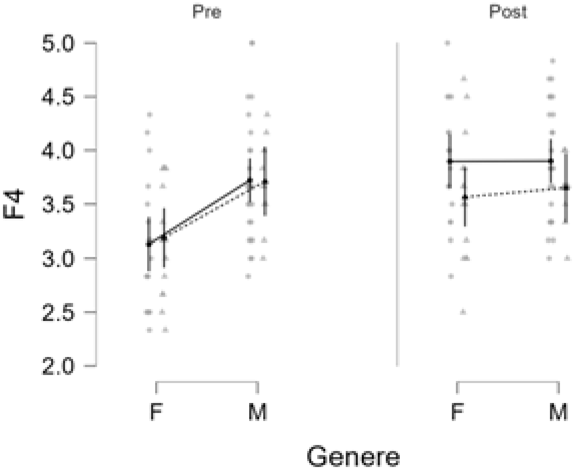

Fig. 4 Results F4 (Self-efficacy in scientific tasks)
Solid line: EG; Dotted line: GC

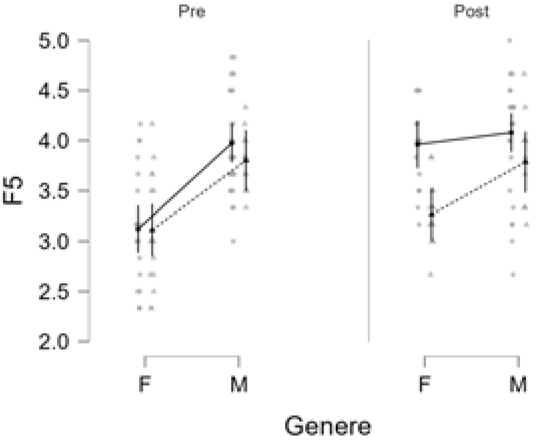

Fig. 5 Results for F5 (Mastery experience)
Solid line: EG; Dotted line: GC

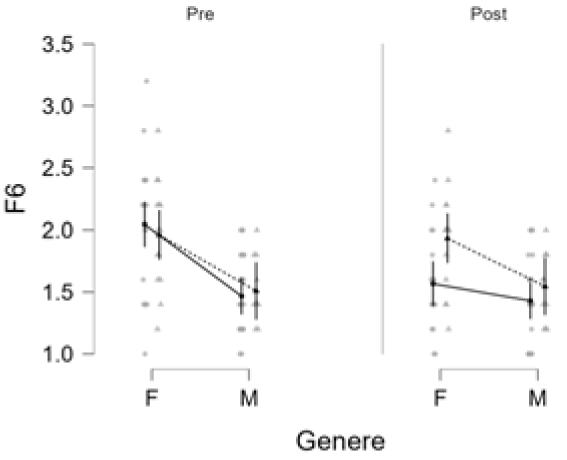

Fig. 6 Results for F6 (Emotional state)
Solid line: EG; Dotted line: GC

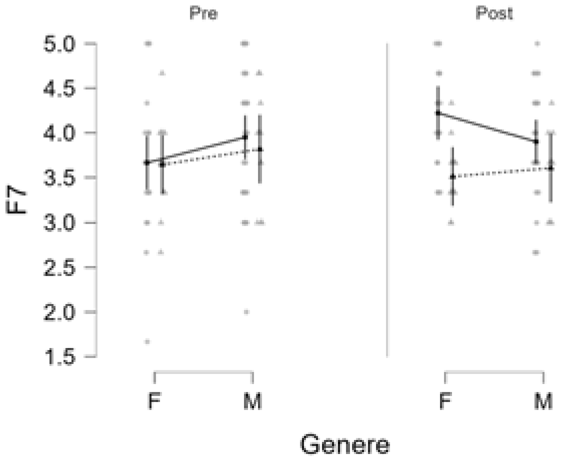

Fig. 7 Results for F7 (Verbal Persuasion)
Solid line: EG; Dotted line: GC

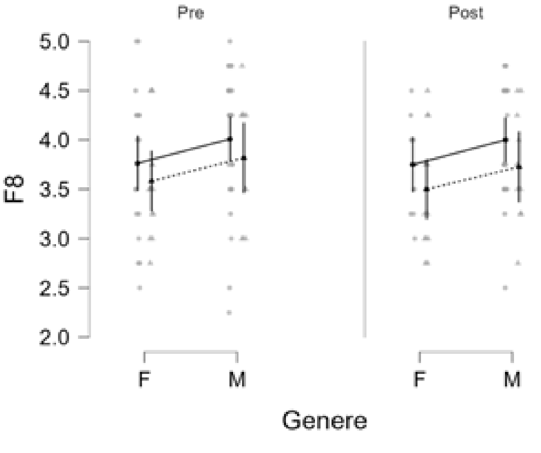

Fig. 8 Results for F8 (Vicarious experience)
Solid line: EG; Dotted line: GC

9.7 Discussion of results – self-efficacy questionnaire

One of the objectives of the research was to investigate the effects of a TLS on scientific self-efficacy, adopting a multidimensional perspective and explicitly considering the role of gender. The differences observed were analysed by comparing the control group (CG), in which a traditional methodology was adopted, with the experimental group (EG), in which the ISLE (Investigative Science Learning Environment) methodology was used.

Effects of TLS and changes over time

Firstly, the main effects of the Group did not reveal any statistically significant differences between the CG and the EG. This result shows that the two groups do not differ in their mean levels and suggests that the effect of TLS should be interpreted not as a static difference between the two groups, but as a change due to the methodology used.

The significant effects of the Time variable (pre/post) show that, in both CG and EG students, changes in the perception of scientific self-efficacy are observed. This suggests that part of the change may depend on general learning processes, familiarisation with subject content or, more generally, the school experience gained during the TLS, regardless of the teaching methodology adopted. This is particularly evident in F1 (Specific self-efficacy in physics and chemistry) and F5 (Mastery experience), where the increase from the pre-instruction to the post- instruction is marked and statistically very robust. The result for F1 is consistent with the topic addressed (energy), as it represents scientific content of a physical nature. The result obtained in F5 confirms Bandura's (1997) theory that the Experience of Mastery is the strongest source of scientific self-efficacy and the one most subject to change.

At the same time, the significant Time × Group interactions show that change over time differs between the CG and the EG. In particular, students in the EG show a greater increase in self-efficacy scores in F1 and F5, and a more marked reduction in negative emotional states compared to the CG.

These results are, in general, consistent with Bandura's (1996) socio-cognitive perspective and with research findings on the effectiveness of active learning methodologies. According to Bandura, beliefs in one's efficacy are formed and modified primarily through concrete experiences of mastery. The activities carried out with ISLE involve exploration, hypothesis formulation, data interpretation and decision-making; consequently, they can be considered contexts rich in experiences of mastery that have a more direct impact on the dimensions of self-efficacy most closely linked to scientific practice, whilst more general or stable dimensions require longer periods of time to change (Etkina et al., 2019; Brookes et al., 2020).

Gender effects and trajectories of self-efficacy development

The most significant finding concerns the role of gender, which is not merely an incidental factor but a variable that significantly influences scientific self-efficacy.

The analyses show that males and females differ in their average levels of scientific self-efficacy across certain factors, confirming the need to adopt a multidimensional perspective and avoid treating scientific self-efficacy as a single, homogeneous indicator. This finding is consistent with existing studies in the literature that have highlighted gender differences in STEM subjects as early as the initial stages of education (OECD, 2019; Toma et al., 2019; Master, 2021; 2025).

In particular, the effect of gender is significant in four factors: F1, F4 (Self-efficacy in scientific tasks), F5, F6. The data indicate a greater initial perception of competence among male students in dimensions related to scientific content and successful experiences, whilst among female students there is a stronger association between scientific learning and negative emotional states, such as anxiety or insecurity, which may hinder the development of robust self-efficacy. This finding is also consistent with studies in the literature (Else-Quest et al., 2010; Devine et al., 2012; OECD, 2019), which highlight how female students tend to experience greater anxiety and stress regarding scientific tasks.

However, the significant Time × Gender interactions show that these differences are not static but evolve over time. During the TLS, boys and girls interpreted and transformed the learning experience in different ways. In particular, for factors F1, F5 and F6, the Time × Gender plots show different trajectories: female students achieved a greater increase than their male peers in specific self-efficacy in physics and chemistry and in the Experience of Mastery. Conversely, the average score for Emotional State decreased, indicating that, particularly among girls, negative emotional states linked to anxiety were reduced. This finding suggests that the educational experience had a particularly significant impact on the development of female self-efficacy, helping to reduce, at least in part, the initial differences.

These findings indicate that male and female students, despite sharing the same school experience, attribute different meanings to it or face different social expectations (Eccles & Wigfield, 2002; Master et al., 2016). This confirms that gender differences in STEM are strongly mediated by cultural, relational and contextual factors (Nosek et al., 2009). In this sense, the role of educational intervention can be fundamental, as it can act to consolidate, reduce or reshape such differences.

Despite the important role of gender, the results show that it does not moderate the effect of TLS. The absence of a significant Time × Group × Gender interaction indicates that the ISLE methodology is not more effective for one gender than the other, but rather proves equally effective for males and females.

This suggests that this methodology, at least in the context of this study, can be considered a balanced and inclusive practice: not only does it promote the development of scientific self-efficacy, but it does so equitably, without amplifying gender differences. At the same time, the data seem to indicate a possible compensatory effect, particularly in favour of female students, highlighting the potential of the ISLE methodology to contribute to reducing gender differences in scientific disciplines.

Overall, the results appear to confirm that ISLE is a useful methodology for promoting scientific self-efficacy from primary school onwards. The emphasis on direct experience, problem-solving and the active involvement of students appears to foster not only the acquisition of knowledge but also the strengthening of beliefs in personal efficacy, acting in an integrated manner on the cognitive, motivational and emotional dimensions of the construct (Furtak et al., 2012; Hendrickson, 2021; Etkina et al., 2021).

9.8 Discussion of results

The analysis carried out through the administration of the pre-instruction and post-instruction of the knowledge questionnaire made it possible to investigate the students' prior knowledge of energy (RQ1) and to compare the evolution from common sense knowledge to scientific knowledge in both the EG and GC groups (RQ2).

The pre- instruction results show that the two groups have equivalent levels of knowledge, highlighting similar response categories among pupils in the GC and EG groups.

Thanks to the phenomenographic analysis conducted, we identified several categories at each level of knowledge (common-sense, partially scientific, scientific), and the results are consistent with those reported in the literature (Millar, 2005; Nordine et al., 2011; Colonnese et al., 2012; Opitz et al., 2015; Bezen et al., 2016; Detken & Brückmann, 2021; Detken, 2023).

Primary school pupils possess initial knowledge of energy, predominantly attributable to vitalistic and anthropocentric conceptions (Besson, 2015). The categories that emerged most frequently in the pre-instruction relate primarily to food, living beings, and the body and movement (Millar, 2005; Detken, 2023). There is marked confusion between the terms energy, force and motion, which are often used as synonyms (Besson, 2015). Pupils' prior knowledge is based on everyday life experiences; students frequently mention commonly used technological objects, such as TVs, tablets and phones, interpreted as sources or stores of energy. Energy is conceived as an almost material substance (Millar, 2005; Colonnese et al., 2012) and is not associated with immobile inanimate objects, with the exception of those explicitly designed to store and supply energy (Besson, 2015).

The concept of energy transformation features only marginally and is predominantly linked to everyday technological devices (Detken, 2023), such as battery chargers, batteries and lampposts; this highlights a significant confusion between the concepts of energy and electricity (Opitz et al., 2015; Bezen et al., 2016). In this sense, pupils imagine energy as a substance that flows from one object to another (Solomon, 1992; Colonnese et al., 2012). Several pupils highlighted a link between energy transformation and natural elements (wind, water, sun), demonstrating an initial, partial approach to the scientific model, albeit through imprecise and non-formalised language. Finally, the idea that food is converted into energy to enable the body to move is common (Millar, 2005; Nordine et al., 2018; Detken, 2023).

However, no coherent conceptions of the principle of conservation emerged; this principle is interpreted according to the literal meaning of the term 'conservation'. Only a minority of students demonstrated prior knowledge of renewable and non-renewable energy sources, which are often equated with natural and artificial elements respectively.

Based on this prior knowledge, the two groups underwent a TLS on energy: the CG using a traditional methodology; the EG through an approach based on the ISLE (Investigative Science Learning Environment).

At the end of the TLS, a significant improvement in scientific knowledge was recorded in both groups. All students used more appropriate language and described energy in terms that were more coherent and closer to the physical model, using practical examples to support their explanations. Despite this, the EG group showed a statistically greater improvement than the GC group, achieving higher levels of understanding and a greater frequency of responses attributable to scientific and partially scientific knowledge.

In the EG, in fact, there is a more marked shift from intuitive, everyday conceptions of energy to descriptions that highlight its nature as a physical quantity that can be transformed and manifested in different forms (RQ2). The post-instruction responses show a more appropriate use of scientific language and a more frequent use of cause-and-effect relationships and examples drawn from the experiments carried out in class. This suggests that the ISLE approach has facilitated not only the acquisition of new information but also a process of conceptual reorganisation, in which students were able to challenge their initial conceptions through direct observation of phenomena, hands-on experience and guided reflection (Etkina, 2015). Furthermore, the responses from the EG group that refer to the experimental activities carried out are often more accurate, well-contextualised and clearly articulated, clearly highlighting cause-and-effect relationships.

In the GC's responses, overall, a greater number of categories belonging to scientific and partially scientific knowledge emerged, with more accurate and coherent descriptions of energy compared to the pre-instruction. Although an improvement was recorded, conceptions attributable to common-senso knowledge persist to a greater extent, particularly in questions relating to the conservation and loss of energy. Furthermore, students make more limited use of the observed experiments as interpretative tools, and their descriptions are often merely descriptive and poorly reasoned, using language that is not fully formalised. They answered the more specific questions on energy consistently ("Can energy be transformed?" "What 'types' of energy do you know?") but showed greater difficulty in extending this knowledge to broader reasoning that considers energy as a quantity applicable to all systems and all bodies. The description of the observed experiments often remained tied to the single example and was neither transferred to similar situations nor generalised.
These results indicate that a predominantly transmissive approach may facilitate the learning of definitions or examples, but is less effective in helping students overcome deeply rooted misconceptions, such as the idea of energy as a substance that is consumed or depleted through use. This trend appears consistent with the literature, which suggests that the concept of energy exhibits a high resistance to conceptual change and requires teaching approaches that make the processes of transformation and conservation explicit (Millar, 2005; Grandrath et al., 2021; Abramovitch & Fortus, 2023).

In the EG, there is a greater ability to use experiments as interpretative tools, linking the observation of phenomena (such as the rise in water temperature or a light bulb coming on) to the concepts of energy transformation and transmission. This aspect represents one of the defining features of ISLE, which places empirical experience at the centre as the starting point for the construction of scientific meaning (Etkina et al., 2019). In the EG, students described the concept of transformation coherently and correctly; they progressively extended the concept of energy to all systems and all bodies, moving beyond its exclusive association with living beings, the human body or movement. Energy is thus described as a quantity that transforms and takes different forms. To support this, students frequently refer to the experiments and activities they carried out in cooperative learning, through hypotheses and concrete evidence.

However, even in the Investigative Science Learning Environment (ISLE), a significant proportion of students continue to interpret energy conservation in intuitive terms, confirming the complexity of this conceptual issue.

Overall, the data suggest that the Investigative Science Learning Environment fosters a more profound development of pupils' conceptions compared to a traditional approach, as it promotes the integration of experience, scientific language and conceptual explanation (Etkina et al., 2019; Brookes et al., 2020). The opportunity to reflect, formulate hypotheses and test their own ideas through investigative activities has enabled students to achieve meaningful learning (Novak, 2010); the new knowledge acquired has been integrated with pre-existing cognitive structures in an active and conscious manner (Vosniadou, 2013). This process is evident in the ability, demonstrated by many students, to identify cause-and-effect relationships from specific situations and to transfer them to different contexts (Bransford et al., 2000; Perkins, 1992).

These results are consistent with previous studies showing that inquiry-based and guided discussion approaches are more effective in countering substantialist conceptions of energy and in promoting interpretative models closer to scientific ones (Etkina et al., 2019; Abramovitch & Fortus, 2023).

With regard to the final research question (RQ3), it was possible to analyse gender differences between males and females in scientific self-efficacy using the SE-IS questionnaire. The analysis revealed that, in the sample analysed, there are statistically significant differences between the two genders in certain dimensions of self-efficacy and that these underwent changes during the TLS programme. In this sense, gender should not be considered an incidental variable but a dynamic factor in development (Eccles, 2007; Cech et al., 2011).

Both the traditional methodology and the ISLE methodology led to improvements in self-efficacy factors related to subject-specific content and the experience of mastery. At the same time, the results showed that TLS conducted using ISLE was more effective than the traditional methodology in fostering the development of scientific self-efficacy in certain specific factors. In particular, the increase in self-efficacy was found mainly in dimensions related to the experience of mastery, emotional state and specific self-efficacy in physics/chemistry; this appears consistent with the characteristics of discovery-based teaching, which promotes active, exploration-centred learning (National Research Council, 2000; Etkina et al., 2019). This result is also in line with the structure of the ISLE methodology, which explicitly integrates the affective dimension into its educational objectives, positing that the learning process should not only facilitate the construction of knowledge but also promote student well-being, motivation, a sense of belonging and confidence in one’s own abilities (Etkina, 2015; 2021).

Although the female students initially showed lower levels of self-efficacy, the results indicate that males and females interpreted their experiences differently, revealing distinct trajectories of change. It appears that the female students benefited more from the ISLE methodology than their male peers, thereby helping to reduce the gender gap.

The reduction in negative emotional states observed in the data suggests that ISLE helped to reduce anxiety and insecurity, factors which the literature indicates are more prevalent among female students in science (Else-Quest et al., 2010; Devine et al., 2012). In this sense, the ISLE methodology appears to have fostered a more supportive and inclusive learning environment, in which female students had the opportunity to experiment actively without fear of error or negative judgement, thereby progressively increasing their confidence in their own abilities.

9.9 Conclusion

The overall results of the research highlight how the TLS has contributed to promoting a significant evolution both in students’ knowledge of the concept of energy and in their levels of perceived self-efficacy in science.

The qualitative and quantitative analysis shows a general improvement in both groups, but more pronounced in the experimental group, where the Investigative Science Learning Environment approach fostered a greater restructuring of initial conceptions and a more informed use of scientific language. In particular, students in the experimental group demonstrated a greater ability to interpret phenomena in terms of energy transformation and forms, as well as to link experimental experiences to theoretical models, indicating more meaningful and lasting learning.

At the same time, the results regarding scientific self-efficacy show statistically significant differences between males and females. However, by the end of the TLS, these differences are significantly reduced, particularly in the experimental group. Female students, in fact, show a more marked improvement in both knowledge and levels of self-efficacy, suggesting that an active teaching approach, based on inquiry and direct experience, can help counter implicit stereotypes and promote greater participation and confidence in scientific disciplines. This suggests that active involvement in investigative processes, the opportunity to formulate hypotheses and test them empirically, and direct reference to experimental experiences have helped to strengthen students' confidence in their own abilities. In this sense, the ISLE approach emerges not only as an effective tool for conceptual learning, but also as a context conducive to the development of fundamental motivational dimensions.

Overall, the results support the effectiveness of the ISLE methodology in fostering not only the acquisition of more structured scientific knowledge, but also the development of self-efficacy and the reduction of gender inequalities. This evidence highlights the importance of designing inclusive STEM programmes, based on experimental activities, conceptual reflection and active participation, in order to promote deep, lasting learning that is accessible to all students.

The design used in this research, namely the quasi-experimental design with two equivalent groups, is very commonly used in educational research (Benvenuto, 2015), due to the fact that it is more complex to randomise participants in schools.

The results of this study are not intended to be generalised to the entire primary school population, mainly because of the limited number of students involved. Nevertheless, the intervention made it possible to explore the issue of gender differences in science self-efficacy within a real classroom context, providing concrete and meaningful indications regarding the use of the ISLE approach and its potential benefits for both conceptual improvement and students' science self-efficacy. Future research should involve larger and more diverse samples in order to further investigate the robustness and transferability of these findings. Moreover, future studies should not rely exclusively on the direct presence of a single researcher during the implementation phase. Rather, it would be important to promote specific teacher training, so that classroom teachers can autonomously conduct the teaching-learning sequences planned within the research design and developed according to the ISLE approach.

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CHAPTER 10

Conclusion

This research stems from a specific research problem: the under-representation of women in certain areas of STEM disciplines. In particular, the study began with an analysis of the role of gender stereotypes and the socio-cultural context in shaping students' interests, expectations and perceptions of competence regarding scientific disciplines. In the school setting, in fact, lower scientific self-efficacy among female students can emerge as early as the initial stages of education; this perception can negatively influence motivation, participation in scientific activities and, more generally, their relationship with STEM subjects (Britner & Pajares, 2006; Master et al., 2025).

Against this background, the doctoral research was structured around two integrated lines of inquiry. The first concerns the development and validation of the Self-Efficacy in Science questionnaire (SE-IS), designed to investigate science self-efficacy among primary school pupils. The second concerns the design, implementation, and evaluation of teaching interventions on energy based on the ISLE (Investigative Science Learning Environment) approach (Etkina et al., 2019). Within these interventions, the SE-IS was used to analyse changes in pupils' science self-efficacy, together with a questionnaire aimed at assessing conceptual change.

The development of the SE-IS questionnaire represents an innovative aspect of the research, as the instrument was specifically developed and validated to analyse the science self-efficacy of primary school children in a specific Italian context. It is a multidimensional instrument, designed to assess various aspects of scientific self-efficacy and potentially useful in teaching practice as well. Through the SE-IS, in fact, teachers can obtain useful insights into how students perceive their own abilities in science, identify any gender differences, and design activities aimed at promoting greater confidence in their own skills. The SE-IS questionnaire was subsequently used within two different Teaching-Learning Sequences (TLS) on energy, each lasting 12 hours. The choice of this topic was motivated by its relevance within science education: energy is, in fact, one of the key concepts in science, but it is at the same time a complex subject, often characterised by intuitive conceptions and difficulties in understanding on the part of students (National Research Council, 2012). Furthermore, the topic of energy is particularly topical today, in relation to climate change, environmental sustainability and the growing focus on renewable energy sources.

The TLS studies conducted enabled an analysis of the effects of the ISLE teaching approach, based on inquiry, observation, experimentation and the progressive construction of scientific explanations. In particular, we investigated students' common conceptions of the concept of energy and their gradual transition towards forms of knowledge closer to scientific understanding (Nordine, 2016). In parallel, through the administration of the SE-IS, changes in scientific self-efficacy and any gender differences were analysed, assessing whether and to what extent the teaching programme could contribute to improving students' perception of their competence.

Overall, the process of developing and validating the SE-IS questionnaire has resulted in a suitable tool for analysing scientific self-efficacy in primary schools. The ISLE-based TLS, on the other hand, made it possible to integrate the cognitive and affective-motivational dimensions of scientific learning, demonstrating how an active, workshop-based teaching approach centred on meaning-making can foster not only conceptual change but also the strengthening of students' confidence in their own scientific abilities (Buggé & Etkina, 2020). In this sense, the research has sought to contribute both to theoretical reflection on scientific self-efficacy and gender differences, and to the design of teaching tools and pathways useful for promoting a more informed, inclusive and motivating engagement with scientific disciplines.

10.1 Gender differences, scientific self-efficacy and the school context

According to cultural stereotypes that remain widespread, women continue to be strongly associated with their maternal and caregiving roles. For this reason, women who excel and build high-level careers in the scientific world are often viewed with great admiration and seen as exceptions (Schmader, 2023). Statistics confirm this trend, highlighting that it is much more difficult for women to hold positions of prestige and power, particularly in certain scientific fields (European Commission, 2025).

Eradicating cultural representations that have become entrenched over time is a complex process, but not an impossible one. Girls grow up with fewer female role models, with toys and social expectations that are often stereotypical, within a context that tends to associate femininity with personal care, education and the humanities. Their journey is more arduous because they must contend with implicit biases that can gradually shape their beliefs about themselves, their interests and their abilities (Master et al., 2025). It is precisely in this context that the concept of self-efficacy takes on particular significance (Bandura, 1997). The cultural context, in fact, influences the perception individuals have of themselves. In the scientific field, girls may come to perceive themselves as less suited, less interested or less capable in disciplines such as physics, engineering and computer science (Schmader, 2023). The under-representation of women in these sectors cannot be attributed to women having fewer abilities or skills, but rather to a set of socio-cultural factors that influence expectations, interests and educational choices. In particular, traditional gender stereotypes tend to associate women with the humanities and care work, whilst men are more frequently linked to mathematics, technology and the so-called ‘hard’ sciences. Such representations can affect the development of scientific self-efficacy, fueling greater anxiety towards science and a lower perception of competence among female students (Starr et al., 2023; Master et al., 2025).

Science self-efficacy (SSE) is a key factor in learning processes, as it is closely linked to motivation, participation, perseverance and academic success. It influences academic choices, the strategies students employ, and their ability to manage stress and anxiety whilst performing a task (Britner & Pajares, 2006). A lower perception of efficacy can therefore affect interest, engagement and persistence in scientific activities, contributing over time to many female students being deterred from STEM pathways. Studies in this field highlight that, as early as primary school, female students may report lower levels of self-efficacy, interest and confidence in their scientific abilities, even in the absence of significant differences in performance. These differences may subsequently affect educational, university and career choices, contributing to horizontal and vertical segregation (Tang et al., 2024).

For this reason, it is essential to promote scientific self-efficacy from primary school onwards, a stage at which differences between boys and girls are not yet fully established and perceptions of self-efficacy remain highly malleable. Indeed, school provides a key setting for fostering the development of self-efficacy through active teaching methods that promote inclusion, experimentation, collaboration and peer interaction. At this stage, pupils begin to form their first self-perceptions as competent or less competent in various subject areas. Early intervention therefore helps to counter gender stereotypes and supports a more

informed and motivated participation of female pupils in scientific activities (Gunderson et al., 2012; Master & Meltzoff, 2020).
The measurement of scientific self-efficacy in primary school therefore has not only a descriptive function but can also have educational value, as it allows for the identification of any weaknesses and the design of teaching programmes capable of supporting pupils' confidence in their own scientific abilities.

In this sense, the development of the SE-IS questionnaire is part of a broader perspective that views scientific learning not only as the acquisition of knowledge, but also as the development of attitudes, beliefs and dispositions favourable towards science. Having a specific tool to assess scientific self-efficacy in primary school allows for the analysis of gender differences, offering useful insights for both research and teaching practice. The ability to monitor these dimensions makes it possible to design teaching activities that are more informed, inclusive and attentive not only to conceptual change but also to the development of a positive self-perception as students capable of learning and engaging in science.

10.2 Development and validation of the SE-IS

As highlighted, the first line of research focused on the development and validation of a tool suitable for measuring scientific self-efficacy in primary schools.
The SE-IS questionnaire therefore stems from a practical need and the necessity to analyse a dynamic construct that is fundamental to students' development. It was developed based on existing studies in the literature and has been adapted to both the Italian context and the target age group (OECD, 2019; Carroll et al., 2024). As highlighted by Bandura, instruments designed to measure self-efficacy must be specific to a particular domain and context (Bandura, 2006).
The items were progressively adapted and modified over the course of the four studies, which enabled the psychometric properties of the questionnaire to be improved.

In particular, the pilot study represented an initial phase of exploration and application of the questionnaire in schools, allowing for the testing of item comprehensibility, the observation of the preliminary functioning of the scales, and the collection of useful feedback for revising the instrument. At this stage, the questionnaire initially included broader dimensions, relating not only to scientific self-efficacy but also to related constructs, such as attitude towards science, general self-efficacy in certain school subjects, and aspects linked to motivation to learn. However, the results suggested the need to progressively narrow the scope of the instrument to dimensions more closely related to scientific self-efficacy.

Studies 2 and 3 therefore played a fundamental role in the process of refining the questionnaire. Through exploratory factor analyses, conducted on independent samples, it was possible to examine the internal structure of the instrument, identify the items least consistent with the expected theoretical factors, and proceed with modifications, eliminations and reformulations. This process allowed for the progressive improvement of the SE-IS's theoretical and psychometric consistency, making the instrument more focused on the specific dimensions of scientific self-efficacy. The transition from a broader and more complex version to a more defined structure thus represented an essential phase of the validation process, as it allowed for the selection of only those items most relevant to the construct under investigation.

Confirmatory factor analysis was conducted during Study 4. This phase helped to consolidate the evidence of the instrument's validity, confirming the adequacy of the theoretical model and the multidimensional structure of the questionnaire. The validation process thus took the form of a sequential and iterative procedure, in which each study contributed to refining the instrument and defining its final version.

In its final version, the SE-IS consists of 31 items divided into 3 scales, with responses given on a 5-point Likert scale. Its structure reflects a multifaceted perspective of self-efficacy, understood as a complex affective variable comprising various facets. The questionnaire allows for the analysis of students' perceived competence regarding specific scientific content and various tasks, whilst integrating the four sources of self-efficacy identified by Bandura (1997). This enables the construction of a comprehensive and detailed picture of the student's science self-efficacy.

10.3 The ISLE methodology and the role of TLS

The second line of research focused on the development, implementation and evaluation of two teaching-learning sequences (TLS) on energy in primary school. Both were developed with the aim of promoting conceptual change in students and analysing any changes in the perception of scientific self-efficacy.

The first TLS served as the pilot study, conducted to test the research hypotheses, the feasibility of the intervention, the methodological design, and the procedures and tools used. It enabled us to verify the consistency between the planned teaching activities and the set objectives, providing useful guidance for the subsequent refinement of the programme.

The second TLS, on the other hand, constituted the main trial, conducted using a quasi-experimental design with a control group (CG) and an experimental group (EG). In both TLSs, the Investigative Science Learning Environment (ISLE) methodology was adopted, with the aim of analysing its effectiveness in terms of conceptual change regarding energy and the development of scientific self-efficacy, in comparison with a traditional teaching methodology.

ISLE is a teaching approach based on a constructivist perspective on learning, widely used in science education and, in particular, in physics education (Etkina, 2015). This approach rejects the notion of learning as the mere transmission of knowledge and instead assigns a central role to the student's active, collaborative and reflective participation.

The use of ISLE in this research is consistent with the two main aspects under investigation: on the one hand, the development of conceptual learning; on the other, the emotional-psychological dimension of learning. Starting with an analysis of students' common conceptions of the concept of energy, the ISLE approach allows for the design of cyclical activities in which pupils are encouraged to reason, discuss, experiment and revise their explanations in ways that closely resemble scientific research. These characteristics are consistent with the research objectives, as they promote active learning based on inquiry, observation, experimentation and shared reflection (Brookes et al., 2020). At the same time, the affective dimension plays a central role. The activities proposed within ISLE can indeed offer students concrete opportunities to feel capable of tackling scientific tasks, collaborating with peers, using materials, formulating explanations and participating in the construction of knowledge (Hazari et al., 2013; Gupta et al., 2018). In this sense, the methodology does not act solely on a cognitive level but can also contribute to the development of a sense of mastery, the reduction of anxiety towards science, and the strengthening of the perception of competence.

Thanks to the study on common knowledge of energy and the use of ISLE, the TLS sessions were not merely a sequence of lessons, but structured pathways designed to lead students to revise their initial conceptions through hands-on activities and guided discussions. Active participation, collaboration, and practical and laboratory activities enabled all students to experiment in an inclusive and non-stereotypical context, fostering the development of their scientific skills.

10.4 Results of the Teaching-Learning Sequences

As described above, the pilot study served a preliminary purpose: it allowed us to test the first version of SE-IS questionnaire (Appendix A), observe initial conceptual shifts and gather useful insights for improving the TLS. The results obtained provided initial evidence regarding the tool's functionality and its suitability for the objective of measuring science self-efficacy among primary school pupils.

In addition, an open-ended questionnaire on energy was administered (Colonnese et al., 2012). The responses were analysed using descriptive statistical methods and through a phenomenographic analysis (Marton, 1981), which enabled the creation of a detailed picture of children's common knowledge of energy, in line with what has been highlighted in the literature.

Statistically significant differences emerged between boys and girls in scientific self-efficacy, although these were not particularly marked. These differences were particularly evident in the management of emotions related to science: girls reported feeling greater anxiety than their male peers. Overall, the results of the pilot study were encouraging and provided favourable preliminary indications regarding the use of ISLE in promoting scientific knowledge and improving scientific self-efficacy, particularly among female students.

In the main trial, the participating students were divided into GS and GC groups. The activities proposed during the TLS were partially revised considering the results obtained from the pilot study, to make the programme more consistent with the research objectives and with the initial conceptions that had emerged among the students. In this phase too, two instruments were administered as pre-tests and post-tests: the third version of the SE-IS (Appendix C) and the questionnaire on energy-related knowledge. The analysis of the responses was conducted using a phenomenographic analysis and Linear Mixed Models (LMM) to compare the effects of the different variables (time, group, gender) as well as their interactions. This methodological choice allowed for a more robust analysis of the intervention's effects, considering the structure of the quasi-experimental design (West et al., 2022).

Furthermore, compared to the pilot study, the comparison between the EG and the CG allowed for an assessment of the effectiveness of ISLE relative to traditional teaching methods.

In the initial analysis, the responses provided on energy were categorised as common sense, partially scientific and scientific. The categories that emerged reflect the studies in the literature and represent a systematic and coherent way of analysing students' different ideas about energy (Millar, 2005; Nordine, 2016). These were initially based on everyday life, on the idea of energy as a quasi-material substance, linked to the body, movement and living beings. The categorisation carried out allowed for a rigorous analysis of the transition from common knowledge to scientific knowledge in both groups.

At the same time, an analysis was conducted of the responses provided to the SE-IS questionnaire. Here too, statistically significant differences emerged between boys and girls, confirming the presence of differences in scientific self-efficacy as early as primary school and in line with findings in the literature (Webb-Williams, 2018; Carroll et al., 2024).

The ISLE methodology proved to be more effective than the traditional methodology in both aspects investigated. Although both the CG and the EG showed improvements in conceptual change and the promotion of scientific self-efficacy, the experimental group demonstrated more substantial improvements.

ISLE enabled students to actively construct their own knowledge, starting from their common ideas about energy. These were discussed and gradually revised from a more scientific perspective through observation, experimentation and shared analysis. The practical research activities engaged and motivated the students, who played an active role by questioning their own initial explanations. During the proposed experiments, the pupils exchanged views, formulated hypotheses and discussed different solutions, in a process that gradually led them towards scientific conceptions. The conceptual change was not imposed from outside but constructed through a process of comparing common knowledge with experimental evidence.

ISLE also fostered better outcomes because it created a collaborative and inclusive learning environment (Etkina, 2015). Peer discussion, group work and the sharing of hypotheses enabled students to participate actively, to compare different points of view and to value their own contribution. This aspect is particularly relevant in terms of scientific self-efficacy:

feeling involved in practical activities, being able to formulate explanations, using materials, observing phenomena and contributing to the solution of a problem provide opportunities to experience mastery. Such experiences constitute one of the most important sources of self-efficacy, as they allow students to perceive themselves as capable of understanding and tackling scientific tasks (Hazari et al., 2013; Gupta, 2018).

Overall, the pilot study and the experimental study demonstrated that a TLS designed using the ISLE methodology can represent an effective teaching strategy for promoting both conceptual learning and the perception of competence in the scientific domain. Compared to traditional teaching, the approach based on inquiry, practical activity, discussion and shared reflection appears to have encouraged more active student participation, whilst also helping to strengthen confidence in their own abilities to learn and engage with science.

10.5 Strengths and contributions of the research

The research conducted is characterised by several strengths and innovative aspects, relating to both the theoretical and the methodological and pedagogical dimensions.
The study sought to link various aspects within a coherent research design: theoretical reflection on gender differences in STEM, the study of scientific self-efficacy, and the design of TLS aimed at conceptual change. In this sense, the research did not consider the cognitive and affective-motivational dimensions of learning separately but sought to analyse their interaction within a structured teaching programme.

Firstly, focusing on gender differences at an early stage of schooling is particularly relevant, as it confirms the importance of intervening early on perceptions of competence, before any gender-related differences become entrenched in subsequent educational pathways. Gender stereotypes and differences in the perception of self-efficacy can begin to take shape at an early age, influencing interests, motivation and educational choices over time (Cvencek et al. 2011; Master et al., 2017). Furthermore, as highlighted by Bandura (1997), differences in self-efficacy are not universal but vary according to context, domain and age group. The research has therefore made it possible to investigate this variable within the specific Italian context of primary school, identifying gender differences as early as in 10-year-old boys and girls.

The analysis of self-efficacy perceptions was made possible by the Self-Efficacy In Science questionnaire. The development and validation of a tool specifically designed for primary schools constitute one of the innovative aspects of this research. In the Italian context, in fact, tools specifically designed to investigate scientific self-efficacy in primary school pupils remain limited, despite international literature emphasising the need for domain-specific tools adapted to the students' age (Webb-Williams, 2018; Carroll et al., 2024; Luo et al., 2021). The SE-IS addresses this need, presenting itself as a multidimensional tool capable of measuring various aspects of science self-efficacy, including the perception of competence in specific scientific content, the ability to perform scientific tasks, and the sources of self-efficacy identified by Bandura (1997). The questionnaire represents a significant initial methodological contribution to the study of the affective and motivational dimensions of scientific learning: it can offer teachers a useful tool for monitoring students' perceptions of competence, identifying any gender differences, and designing teaching interventions more specifically aimed at strengthening scientific self-efficacy.

A further strength of this research lies in its combined focus on conceptual learning and self-efficacy. From this perspective, learning has been viewed not merely as pure cognitive development but as a complex, multifactorial process. Psychological and pedagogical studies demonstrate that the socio-affective aspect is indispensable and decisive in learning processes (Pekrun et al., 2012): in this sense, scientific self-efficacy can be considered a central variable in science education (Bandura, 1997). This approach allows for a more comprehensive view of the educational process: it is not only important to understand whether students learn a particular concept, but also whether, through the teaching experience, they develop greater confidence in their own abilities to understand, discuss and carry out scientific activities.

The TLSs developed integrated both the conceptual aspect and that relating to self-efficacy, demonstrating that these are two closely interlinked dimensions. The use of the ISLE methodology has highlighted that it is possible to design TLS that produce positive effects both on the acquisition of new scientific knowledge and on the perception of self-efficacy. In particular, it is noteworthy that, initially, gender differences were observed in the perception of scientific self-efficacy; however, at the end of the TLS, female students showed more substantial improvements. This result underscores the need to promote science self-efficacy from primary school onwards, through educational programmes capable of strengthening students' perception of their own abilities in science and countering any gender-related differences at an early stage (Master et al., 2025). Furthermore, a central and complex scientific theme was identified: energy. This concept represents a fundamental cornerstone of science education but is often characterised by intuitive conceptions that are difficult to change.

Finally, the use of both qualitative and quantitative analytical methodologies has enabled the phenomenon to be analysed from different perspectives, enhancing the interpretative richness of the results. The integration of phenomenographic analysis, psychometric tools and statistical models has allowed us to examine not only the evolution of students' conceptions but also changes in their perceptions of scientific competence.

Overall, this research forms part of the scientific literature dedicated to the analysis of gender differences in STEM, contributing to the debate on the role of primary school in promoting scientific self-efficacy. It has integrated conceptual and socio-affective aspects of learning within TLS designed according to the ISLE approach, using an active, inquiry-centred methodology, which has led to significant improvements compared to traditional teaching. The main contribution of the research lies in having integrated the development of a measurement tool, the analysis of gender differences and the design of TLS within a single coherent framework. This integration allows scientific learning to be viewed as a complex process in which knowledge, emotions, perceptions of competence and the educational context interact deeply.

The research therefore offers both a theoretical and an operational contribution: on the one hand, it explores the role of scientific self-efficacy in primary school; on the other, it proposes tools and approaches useful for promoting a more inclusive, active and informed approach to science teaching.

10.6 Limitations of the research and future prospects

The research conducted has certain limitations that must be considered for a correct interpretation of the results and which, at the same time, open up possibilities for future developments.

Firstly, the process of constructing and validating the SE-IS questionnaire has resulted in a psychometrically sound instrument. However, further studies need to be conducted on larger, more diverse and representative samples from different regions of Italy to further strengthen its generalisability. At this stage, the SE-IS is still limited to specific school and regional contexts; therefore, whilst demonstrating good psychometric properties and a structure consistent with the theoretical construct under investigation, it requires further testing in more heterogeneous populations.

A second limitation concerns the size of the samples involved in the two TLSs. Although the number of pupils is adequate given the exploratory and applied nature of the intervention, the samples are limited and do not allow the results obtained to be generalised to the entire population of primary school pupils. The pupils involved belong to specific schools and geographical contexts; consequently, the characteristics of the classes, teachers, schools and the socio-cultural context may have influenced the results obtained.

Furthermore, from a methodological perspective, the study was conducted using a quasi-experimental design, with an EG and a CG, but not a fully randomised experimental design. This aspect represents a limitation, as it does not allow for complete control of all variables that may have influenced the results, such as the initial characteristics of the classes, the teacher's role, the classroom atmosphere, or the students' prior experience with active teaching methods. However, the design adopted is consistent with the real-world school context in which the research was conducted and has nevertheless allowed for a systematic comparison of the effects of the ISLE approach compared to traditional teaching.

The educational sessions lasted 12 hours, which was sufficient to observe initial changes in the students' conceptions of energy and their perception of scientific self-efficacy, but not long enough to assess more stable and lasting effects. Furthermore, it was not possible to conduct a follow-up study with the students involved in the project; consequently, it is not possible to determine whether the improvements observed have been sustained over time.

The limited duration of the intervention may also have influenced the results for both boys and girls, reducing the possibility of observing more profound and consolidated changes.

For these reasons, the research cannot be considered concluded, but opens various future avenues aimed at expanding, consolidating and deepening the results obtained.

Firstly, it appears necessary to carry out further validations of the SE-IS questionnaire in schools located in different geographical areas and within diverse socio-cultural contexts, to verify the stability of the factor structure and the reliability of the instrument in more heterogeneous populations.

Subsequently, it would be advisable to design longer TLS programmes, capable of guiding students through a broader process of scientific knowledge construction. In this regard, future studies could also include follow-up assessments at a later stage, to verify whether the improvements observed in conceptual learning and scientific self-efficacy are sustained over time.

Additionally, the TLS was designed around three interconnected qualitative aspects of energy—energy as a property associated with the state of a system, manifestations/forms of energy, and energy transfers and transformations—with the aim of supporting the progressive construction of a coherent and unitary conceptual model. However, the present analysis did not directly assess whether pupils developed a unified view of energy across the different contexts addressed in the TLS.

Future studies should investigate this issue more systematically by examining whether pupils are able to coordinate these three qualitative aspects across different phenomena, rather than referring separately to energy forms, sources, or particular everyday situations. In particular, future analyses could include coding categories aimed at identifying whether students recognise energy as a single conserved quantity whose manifestations, transfers, and transformations can be used to interpret changes in different systems.

A further area for future development concerns a more in-depth examination of gender differences. The results suggest the presence of differences in the perception of scientific self-efficacy as early as primary school and, at the same time, show particularly significant improvements among female students at the end of the TLS. However, this evidence should be further verified on larger samples, so as to better understand which dimensions of self-efficacy are most sensitive to gender and which characteristics of the teaching intervention can contribute most effectively to reducing any gaps. It would also be useful to integrate quantitative and qualitative tools, such as interviews, classroom observations or analyses of peer interactions, to gain a deeper understanding of how girls and boys experience scientific activities and construct their own perception of competence.

Overall, the limitations identified do not diminish the value of the programme implemented but clarify its scope of validity and point to future directions for further research. The research has provided an initial contribution to the development of teaching tools and programmes aimed at promoting scientific self-efficacy in primary schools but requires further development to consolidate the results obtained. Expanding the sample sizes, diversifying the contexts, extending the duration of the interventions and exploring the role of gender in greater depth are fundamental steps towards strengthening the research's contribution and promoting science teaching that is increasingly inclusive, informed and capable of supporting pupils' confidence in their own scientific abilities.

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Appendix A

SE-IS Version in the Pilot Study

General Information
Gender
Age
School
Class

Scale A	**How much do you agree with these statements?**	**Not at all**	**A little**	**Somewhat**	**Very much**	**Totally**
1	I am a very curious person					
2	I like learning new things					
3	I think learning new things is boring					
4	When tasks get difficult, I stop					
5	There are people who do badly in science, no matter how much they study					
6	I am very creative					
7	I can think quickly					

Scale B	**How well could you learn...**	**Terribly**	**Badly**	**Neither badly nor well**	**Well**	**Perfectly**
8	Italian					
9	Mathematics					
10	Science					
11	English					

Scale C	**How would you answer questions about these science topics?**	**Terribly**	**Badly**	**Neither badly nor well**	**Well**	**Perfectly**
12	Plants					
13	Animals					
14	States of matter					
15	Heat and temperature					
16	The human body					
17	Liquids					
18	Solutions and mixtures					
19	Energy					
20	The water cycle					
21	Forces					
22	The Universe and the Solar System					

23	Electricity					
24	Magnets					

Scale D	**How much do you agree with these statements?**	**Completely disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Completely agree**
25	Science is one of my favorite subjects					
26	I get excellent grades in science					
27	I enjoy learning new science topics					
28	I can't wait to do science					
29	I lose interest during science lessons					
30	Science is easy for me					
31	I am interested in learning science topics					
32	Even when I try hard in science, I do badly					
33	When science topics are explained to me, I understand the concepts very well.					
34	When I see a classmate doing a science experiment, I want to do it too					
35	I am always successful in science					
36	I like science homework					
37	I usually do well in science tests and oral assessments.					
38	I can't think clearly when I have to do science homework.					
39	I learn science topics quickly					
40	I can even do the most difficult science homework					
41	I feel very tense when I have to do science					
42	When I see my teacher doing science experiments, I imagine doing them too					

43	My teacher tells me that I am very good at science					
44	My classmates like working with me during science lessons because they think I am good					
25	Science is one of my favorite subjects					
26	I get excellent grades in science					
27	I enjoy learning new science topics					

Scale E	**How much do you agree with these statements?**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
45	Making connections between science topics											
46	Explain science topics to my classmates if they haven't understood something											
47	Work together with my classmates to better understand science topics.											
48	Writing down the activities we do in science.											
49	Using materials during experiments											
50	Encouraging classmates to participate in discussions											
51	Doing science experiments using hands-on materials											

Appendix B

SE-IS Version in Study 2

General Information
Gender
Age
School
Class

Scale A	**For each science topic, indicate how true this sentence is for you: “I feel capable when we study…”**	**Not at all true for me**	**A little true for me**	**Somewhat true for me**	**Very true for me**	**Completely true for me**
1	Plants					
2	Animals					
3	States of matter					
4	Heat and temperature					
5	The human body					
6	Forces					
7	Solutions and mixtures					
8	Energy					
9	The water cycle					
10	Electricity					
11	The Universe and the Solar System					
12	Magnets					

Scale B	**For each activity, indicate how true this sentence is for you: “I can…”**	**Not at all true for me**	**A little true for me**	**Somewhat true for me**	**Very true for me**	**Completely true for me**
13	Make connections between science topics					
14	Explain science topics to my classmates if they haven't understood something					
15	Work together with my classmates to better understand science topics					
16	Write down the activities we do in science					
17	Use materials during experiments					
18	Encourage classmates to participate in discussions					

19	Do science experiments using hands-on materials					

Scale C	For each statement, indicate how true it is for you.	Not at all true for me	A little true for me	Somewhat true for me	Very true for me	Completely true for me
20	I do even the most difficult science homework well					
21	I get excellent grades in science					
22	When science topics are explained to me, I understand the concepts very well					
23	I am always successful in science					
24	Science is easy for me					
25	I learn science topics quickly					
26	When I think about science homework, I feel confused					
27	When I think about science tests, I feel nervous					
28	Even when I try hard in science, I do badly					
29	My teacher tells me that I am very good at science					
30	My parents tell me that I am very good at science					
31	When I see my teacher doing science experiments, I imagine doing them myself					
32	When I see a classmate doing a science experiment, I want to do it too					
33	My classmates like working with me during science lessons because they think I am good at it					

Appendix C

SE-IS Version in Study 3

General Information
Gender
Age
School
Class

Scale A	**For each science topic, indicate how true this sentence is for you: "I feel capable when we study…"**	**Not at all true for me**	**A little true for me**	**Somewhat true for me**	**Very true for me**	**Completely true for me**
1	Plants					
2	Animals and their classification					
3	Leaves					
4	The cell					
5	The digestive system					
6	The skeletal system					
7	Solutions and mixtures					
8	Energy					
9	Forces					
10	Electricity					
11	Magnets					

Scale B	**For each activity, indicate how true this sentence is for you: "I can…"**	**Not at all true for me**	**A little true for me**	**Somewhat true for me**	**Very true for me**	**Completely true for me**
12	Make connection between science topics					
13	Explain science topics to my classmates if they haven't understood something					
14	Work together with my classmates to better understand science topics					
15	Encourage classmates to participate in discussions					
16	Do science experiments using hands-on materials					

Scale C	For each statement, indicate how true it is for you.	Not at all true for me	A little true for me	Somewhat true for me	Very true for me	Completely true for me
17	I do even the most difficult science homework well					
18	I get excellent grades in science					
19	When science topics are explained to me, I understand the concepts very well					
20	I am always successful in science					
21	Science is easy for me					
22	I learn science topics quickly					
23	When I think about science homework, I feel confused					
24	When I think about science tests, I feel nervous					
25	Even when I try hard in science, I do badly					
26	I feel worried when I have to answer science questions					
27	My teacher tells me that I am very good at science					
28	My parents tell me that I am very good at science					
29	My classmates tell me that I am good at science					
30	When I see my teacher doing science experiments, I imagine doing them too					
31	When I see a classmate doing a science experiment, I want to do it too					
32	Watching my classmates use scientific materials helps me understand what to do					
33	When I watch a cartoon or film about scientists, I imagine myself as the main character					

Appendix D

SE-IS Final version

General Information
Gender
Age
School
Class

Scale A	For each science topic, indicate how true this sentence is for you: "I feel capable when we study…"	Not at all true for me	A little true for me	Somewhat true for me	Very true for me	Completely true for me
1	Plants					
2	Animals and their classification					
3	Leaves					
4	The cell					
5	The digestive system					
6	The skeletal system					
7	Solutions and mixtures					
8	Energy					
9	Forces					
10	Magnets					

Scale B	For each activity, indicate how true this sentence is for you: "I can…"	Not at all true for me	A little true for me	Somewhat true for me	Very true for me	Completely true for me
11	Explain science topics to my classmates if they haven't understood something					
12	Work together with my classmates to better understand science topics					
13	Encourage classmates to participate in discussions					
14	Do science experiments using hands-on materials					

Scale C	For each statement, indicate how true it is for you.	Not at all true for me	A little true for me	Somewhat true for me	Very true for me	Completely true for me
15	I do even the most difficult science homework well					
16	I get excellent grades in science					
17	When science topics are explained to me, I understand the concepts very well					
18	I am always successful in science					
19	Science is easy for me					
20	I learn science topics quickly					
21	When I think about science homework, I feel confused					
22	When I think about science tests, I feel nervous					
23	Even when I try hard in science, I do badly					
24	I feel worried when I have to answer science questions					
25	My teacher tells me that I am very good at science					
26	My parents tell me that I am very good at science					
27	My classmates tell me that I am good at science					
28	When I see my teacher doing science experiments, I imagine doing them too					
29	When I see a classmate doing a science experiment, I want to do it too					
30	Watching my classmates use scientific materials helps me understand what to do					
31	When I watch a cartoon or a film about scientists, I imagine myself as the main character					