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PhD Thesis

An EARLY PHYSICS approach to improve students' scientific attitudes. The role of teachers' habits.

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Abstract

One of the Key Competences for Lifelong Learning recommended by the Council of the European Union is the "Mathematical Competence and Basic Competences in Science, Technology, Engineering". In Science, this competence refers to the ability and willingness to explain the natural world by making use of a large body of knowledge and methodologies, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions. As connotative of this competence, there is also the ability to use logical and rational thought to test a hypothesis and the readiness to discard one's convictions when they contradict new experimental findings.

This Recommendation underlines the need to motivate young people, especially girls and young women, to engage in STEM (Science, Technology, Engineering and Mathematics) related careers through the use of an inquiry-based pedagogy at all levels of education, training and learning pathways. The enhancement of scientific competences is also consistent with the UN Sustainable Development Goals (SDG), in particular within the SDG4 and SDG5, into education, training and learning.

The aim of our research is to explore new teaching approaches and methodologies in order to help students develop positive attitudes.

First, we investigated the educational approach adopted in Italian High-School Physics Instruction to develop scientific competences. This overview gave us a detailed picture of students' attitudes towards Physics, intercepted some conceptual difficulties and focused on their skill for argumentation as

the key point to their adoption and use of a scientific language. Concerning teachers, we monitored their PCK (Pedagogical Content Knowledge) mainly related to Math/Phys Interplay and Argumentation Framework. In this way, we could identify some students' and teachers' conceptions that need to be changed to better fulfil the Recommendation's goals.

Then, we focused on Physics instruction in the first years of curricular studies, which is different according to the type of high-schools and curriculum. We pursued our research along two main directions, featuring an *Early Physics* approach and developing teachers' habits to adopt it in their classrooms.

The conceptual and theoretical framework for an *Early Physics* grounds its foundation by the use of tools for reasoning and conceptual building as Multiple Representations and promoting inquiry-based learning. Based on research in cognitive science, scientific epistemology, and teacher perspectives, we hypothesised that the Investigative Science Learning Environment (ISLE) approach should be recommended at the beginning of Physics studies in Italian Secondary Schools. This approach fully aligns with the European Council Recommendation.

With this working hypothesis, we conducted our study towards developing teachers' habits in the *Early Physics* scenario, trying to address the need to change. We engaged teachers in cognitive apprenticeship through monitoring, coaching, tutoring and reflecting phases and in a community of in-service learning teachers. They worked in their classrooms continuously sharing ideas, problems, trials, and materials with each other. During the implementation of the activities, we collected many data: teaching artifacts (notes, teaching sequence log, teachers' diary, written tests for assessments and materials for lessons), relevant conversions, audio/video recording lessons. We analysed these data collected through a mixed-method design, mainly focusing on how teachers changed their dispositions, their knowledge, and their skills, and to what extent these changes were related to students' knowledge and attitudes.

In this study we described our attempt to start a process of developing teachers' habits (Etkina et al., 2017): this process is still ongoing, but we can already witness an initial change and a teachers' community growing. We are confident that this goes in the direction of improving the scientific education of future European citizens.

Dedication

To Physics teachers: it's ever time to change.

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Chapter 1

Introduction

The aim of this research project comes from a dream.

As a Maths and Sciences teacher in middle school, I spent most of my time thinking, reflecting and reviewing my teaching strategies and methodologies. All could be necessary for my students to change their attitude towards the disciplines they considered far away. Working with 6^{th} to 8^{th} grades students requires many skills, but, according to my experience, the most important is engaging learners in active processes. This was the mainstream of my teaching, and it featured all my education activities in the classroom, both during Maths and Sciences hours (Bologna, 2008). This skill was supported by the disposition to ensure learning success for my students. If their assessments were not good, my first thought was how I had to change the requirements to allow students to have positive feedback. Their negative score was my teaching problem because it would mean something went wrong in the process I had activated. This disposition influenced my knowledge, referring mainly to content knowledge and the knowledge I needed to help my students develop conceptual understanding of physics.

In the last twenty years, I have been attending in-service teacher training programs to become more skilled, reinforce my disposition, and to develop the needed knowledge. I preferred the ones that gave me tools for developing the habits of mind, practice and improvement in agreement with my dispositions, knowledge and skills (Etkina et al., 2017) described above and to reinforce them.

I could recognise a meaningful change in my teaching practice during the 2007-2008 academic year when I started a training program in the ArAl project (Navarra, 2019). The acronym ArAl stands for a syncopate name of *E-**Ar**-ly **Al**-gebra*. The project was a part of innovative research in Maths Education (D. W. Carraher and Schliemann, 2018; Kaput et al., 2008) at its beginnings. The *Early Algebra* approach is well-defined by the words of one of its theoretical founders, David Carraher (D. Carraher and Schliemann, 2007; Kaput et al., 2008):

> *Early Algebra is not the same as Algebra Early [...]*
> *We will use the expression Early Algebra to encompass algebraic reasoning and algebra-related instruction among young learners loosely.*

Defining *Early Algebra* did not mean anticipating Algebra courses in curricular instruction. It would define a new Maths teaching area based on representative and relational activities. Students are gradually guided to recognising analogies, meanings, structures, relationships, and whatever they need to move from arithmetic to algebraic thinking, from general to particular and vice-versa, in a coherent conceptual framework, where all the activities are built upon Piaget's theory of cognitive development and Vygotsky's ideas of the role of cultural tools and social interaction (D. W. Carraher and Schliemann, 2018; D. Carraher and Schliemann, 2007; Vygotsky, 1987).

This conceptual coherence fascinated me: I was looking for a new theoretical framework to overcome the procedural and computation constraints that Maths textbooks induced (through exercises, explanations and content-topic-specific organisation). As a Maths teacher and a researcher in action (actively involved in the ArAl Project), I began testing this new approach in all my classes. And I was persuaded that this approach worked to promote conceptual change from arithmetic to algebraic reasoning.

Each activity in this new learning environment was developed to evoke students' views about a problem involving relations among sets of quantities and gradually introduce new mathematical representations, conventions, and tools (Kaput et al., 2008). Upon my experience in classroom, I could report that *Early Algebra* successfully works for students, both those skilled in Maths and those with learning difficulties.

In the meantime, as a Sciences teacher (and as a Physicist, too), I started to dream: if there exists an *Early Algebra* approach, why does not an *Early Physics* one exist?

Transposing exactly Carraher's words to Physics, it'll become:

> *Early Physics is not the same as Physics Early.*
> *We will use the expression Early Physics to encompass Physics reasoning and Physics-related instruction among young learners loosely.*

So, *Early Physics* would define a Physics teaching domain based on representational, relational and experimental activities. Students are gradually guided to recognise analogies, meanings, structures, relationships, and whatever they need to pass from qualitative to quantitative conceptualisation in a coherent conceptual framework.

In this new context, in my classes, I tried to make my first steps with clinical practices and trials, collaborating with the Physics Department of the University of Trieste through undergraduate Physics students' apprenticeship (Bologna, 2014, 2017; Bologna et al., 2021; Bologna and Miniussi, 2018; Leban et al., 2020).

But, it was not enough. I needed more time to study the results and outcomes of Physics Education Research (PER) to outline an *Early Physics* approach in a correct theoretical framework. For this reason, in 2019, I presented a research project to the PhD board committee of the Physics Department of the University of Trieste, and it was selected. So I could start my PhD with extraordinary leave from my teaching position.

This dissertation presents the research I could develop during these last three years.

* * *

According to a very recent study by the Italian Physics Teaching Association (AIF, Associazione per l'Insegnamento della Fisica), 80% of Italian Physics teachers would like to improve their teaching methods using innovative strategies and preparing compelling lessons (Magliarditi et al., 2020). This study aimed to investigate the teachers' professional needs and their desired in-service training goals. Three main domains of the investigation were the disciplinary competencies (in terms of subject matter content knowledge), the use of experimental activities, and the exploration of educational-interdisciplinary activities, such as the Maths/Phys interaction, the interchange between Philosophy and Physics, and the History of Physics. Teachers' responses indicated they would like to know Quantum Mechanics and Modern Physics better, how to use Smartphones in classroom activities, and how to be skilled in all labs activities (including simulation-based ones). The average score value of the survey items was relatively high (mostly above three on a 4-point scale), indicating the teachers' need to change.

Many stakeholders also advocate for a change in Science education: the Council of the European Union stated this need in the last Recommendations for developing Key Competences for Lifelong Learning (European Council, 2018). An inquiry-based pedagogy would endorse the change at all levels of education to engage students in STEM (Science, Technology, Engineering and Mathematics) careers.

Also, the Italian National Guidelines for high schools encourage Physics teachers to develop students' skills to understand and evaluate the scientific and technological choices that affect the society in which they live (MIUR, 2010). Both suggest a way of changing: promoting an approach to scientific discovery through experimentation and reasoning.

> Is this goal the same that the Italian Physics teachers are looking for?

The goal partly seems the same, but the changes that the teachers have to implement to achieve it is harder and deeper than what emerged through the survey. The changes have to become a teachers' need of change, specifically referring to their dispositions towards teaching and learning Physics, to their knowledge, especially the knowledge related to teaching Physics. The changes also involve teachers' experimental skills (Etkina et al., 2017). Teachers' formative needs are the starting point for developing an in-service training program (based on cognitive apprenticeship, A. Collins and Kapur, 2014; Etkina et al., 2017) towards adopting an innovative approach.

Developing in-service teacher training and outlining an approach to target Key Competencies are the aims of this research. They are built together because there is no change in learning if there is no change in teaching (Bao and Koenig, 2019). Change is not easy and usually not immediately observable, occurring in the long term.

Furthermore, the change must come as a direct response to the investigation of actual classroom practices. This evidence-based method ensures that we respond to questions from our students and teachers. The questions arise analysing their conceptions towards knowledge, learning, teaching, and instruction. This way, the overview becomes the tool we gained to ground the motivation for enhancing teachers' need to change. Understanding students' and teachers' conceptions also provided insights and motivation for our research questions. (Chapter 2).

To describe an approach, we kept in mind the requirements to foster the learning goals for the 21^{st} Century: an approach designed as learner-centered and tailored to their needs and characteristics. At the same time, it should facilitate knowledge integration to promote deep conceptual understanding in physics and inquiry learning to foster scientific reasoning (Bao and Koenig, 2019). The focus on learners should be taken into account also by referring to students' cognitive development during secondary schooling. Acknowledging this developmental feature of processing and changing their scientific thinking, we would refer to this approach as denominating it *Early Physics*.

As a conceptual and theoretical framework, we started accounting for the *Early Algebra* approach in teaching/learning algebraic thinking and reasoning (D. W. Carraher and Schliemann, 2018; D. Carraher and Schliemann, 2007; Kaput et al., 2008; Navarra, 2019, 2022). Using natural language (referring to the language naturally spoken by students) as a semantic facilitator (Navarra, 2022) between other disciplinary languages (such as mathematical/symbolical, graphical, and pictorial) led us to explore the use of Multiple Representations in Physics Education as a tool for reasoning (Ainsworth, 1999; Bologna and Leban, 2022; P. B. Kohl and Finkelstein, 2017; Munfaridah et al., 2021; Opfermann et al., 2017; Van Heuvelen, 2001) and scientific talk (Lemke, 1990). Multiple Representations undoubtedly promote conceptual understanding (Munfaridah et al., 2021), make physics more accessible to learners (Brookes et al., 2020) and support the use of Maths in Physics (Pospiech et al., 2019; E. F. Redish, 2021e). Coordinating Multiple Representations activates a way for doing Physics (Brookes et al., 2020; Van Heuvelen, 1991). This shapes the difference between *Early Algebra* and *Early Physics*: an epistemological perspective. This perspective allows students to underpin other learning skills: to think like scientists (Sin, 2014) and to improve critical thinking (Etkina and Planinšič, 2015).

Inside the epistemological perspective to develop learning skills, an *Early*

Physics approach needs to be defined as inquiry-based. Learning by inquiry is a learning environment that, in practice, should enact the building of epistemological beliefs (Cairns, 2019). It is also a possible strategy to integrate the activation of cognitive areas besides the frontal cortex into the learning process (Kuhn et al., 2000), operating, for example, with sensor-motor input, which is a functional part of conceptual knowledge (Yee, 2019). Secondary students often have difficulty elaborating on the information because they still grow their cognitive abstraction ability (Dumontheil, 2014). For this reason, students need to be engaged in active learning fostering the use of all their brain's cognitive areas in the so-called complete learning cycle (Zull, 2004).

In Physics Education, there are many examples of inquiry-based (Martin-Hansen, 2002) and active learning approaches (Meltzer and Thornton, 2012).

We identified the Investigative Science Learning Environment (ISLE - Etkina and Van Heuleven, 2007; Etkina, 2015a) as the matching one (Bologna and Longo, 2022) to foster the learning goals for 21^{st} Century and students' scientific abilities (Buggé and Etkina, 2020), designed as learner-centered, and enhancing to all the learners' cognitive need (Etkina, Brookes, et al., 2019) also in the secondary schooling (Buggé and Etkina, 2016).

Promoting the adoption of the ISLE approach in Italian context of secondary instruction required us to bear as cultural (from a schooling point of view) and linguistic (from English to Italian) facilitator (Chapter 3).

With a skecthed *Early Physics* scenario, we pursued the aim of developing in-service teacher training. We embraced the framework of the Development of Habits through Apprenticeship in a Community (DHAC, Etkina et al., 2017; L. Shulman and Sherin, 2004) and expanded its application in the context of in-service training teachers.

Working with in-service teachers and guiding them towards adopting a new approach would mean not properly developing habits of mind and practice (Etkina et al., 2017) but, more precisely, changing or starting a change process (responding to teachers' needs). We engaged in our research project some teachers belonging to different high schools of Trieste. Teachers were involved in cognitive apprenticeship (A. Collins and Kapur, 2014) through monitoring, coaching, tutoring and reflecting phases, sharing ideas in a community of professional peers. They performed in their classrooms for two schooling years, testing learning paths, changing assessments, and promoting labs. We studied and analysed all data collected using a multi-phase mixed-method research design (Creswell and Clark, 2017; Johnson et al., 2007; Sawyer, 2014). We tried to focus on how teachers changed their dispositions, knowledge and skills by adopting a new teaching approach and redefining their habits of mind, practice and improvements (Chapter 4).

Finally, we measured if the adoption of this approach influenced students' attitudes towards Physics with a scale adequately designed and developed (Bologna and Peressi, 2021a, 2021b) for Italian Physics high school students (Discussion and Conclusions).

The research questions are presented in Chapter 2, based on the evidence we collected trying to depict Italian students' and teachers' conceptions towards knowledge, learning, and teaching.

Chapter 2

Learning and Teaching Physics: Italian Overview

There are many differences between countries' instruction system and schooling: what schooling means and what it is for depends greatly on a country's history and culture.

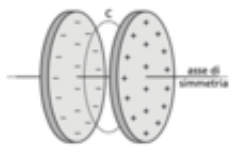
Italian public instruction is an old institution. The first reform, which was designed, dates back to 1859-61 (Riforma Casati, 1861; Dal Passo and Laurenti, 2017). In this first reform, high school instruction provided Physics teaching and the requirement to become a teacher was to attend University courses at the Faculty of Science, Maths and Physics.

Through its long history, Physics teaching based its pillars on the transmission of knowledge. Despite many reforms that wanted (and want) to introduce innovation, new methodologies and new technologies and implement laboratory activities, physics lessons in Italian schools are largely conducted in a traditional manner with the teacher lecturing at the front of the classroom and the students passively listening (Minister's Act of Guidance; P. Bianchi, 2021 p.6).

The national final tests (the National Exam) at the end of secondary education require a bag of knowledge defined by national guidelines, which ask students to know a great number of content topics specific to be successful on the examination (Fig. 1)[1].

PROBLEM 2

A flat capacitor consists of two circular plates of radius R, placed at distance d, where R and d are expressed in meters (m). A potential difference, that varies over time and with initial null value, is applied to the plates.



Inside the capacitor, the presence of a magnetic field $\vec{B}$ is detected. Neglecting the edge effects, at a distance r from the axis of symmetry of the capacitor, the intensity of $\vec{B}$, expressed in tesla (T), varies according to the law:

$$\left|\vec{B}\right| = \frac{kt}{\sqrt{(t^2+a^2)^3}}\, r \quad \text{con } r \leq R$$

Where a and k are positive constants and t is the elapsed time from the initial instant, expressed in seconds (s).

- After determining the units of a and k, explain why there is a magnetic field in the capacitor even in the absence of magnets and conducting currents. What is the relationship between the directions of $\vec{B}$ and the electric field $\vec{E}$ at the points inside the capacitor?
- Consider, between the plates, a perpendicular plane to the axis of symmetry. On this plane, let C be the circumference having center on the axis and radius r. Determine the circulation of $\vec{B}$ along C and derive from it that the flow of E, through the circular surface delimited by C, is given by:

$$\Phi(\vec{E}) = \frac{2k\pi r^2}{\mu_0 \varepsilon_0}\left(\frac{-1}{\sqrt{t^2+a^2}} + \frac{1}{a}\right).$$

Calculate the potential difference between the plates of the capacitor.
What value does $\left|\vec{B}\right|$ tend to as time passes? Justify the answer from a physical point of view.

Figure 1: Translated extract of an exercise by the national final Maths/Phys examination test (2019) for high school for scientific studies.

On the teachers' side, the Italian recruitment policy has been continu-

[1]This was the last national test examination before the pandemic spread out. After 2019, the final examination was temporarily changed and reduced because of the health emergency.

ously changing in the last two decades. Before the new century, to become a Physics teacher, it was necessary to have a Master's Degree in Maths, Physics or Engineering and to have passed successfully a public admission test (written and oral based on subject matter knowledge). Lacking a pre-service training program, the teachers with more than 20 years of a career (around one-half of the total teachers) had never received higher education in pedagogy or teaching methodology before starting the profession (Dal Passo and Laurenti, 2017). The others have followed specific pre-service training after their degrees (Dal Passo and Laurenti, 2017, p. 269).

Instead, nowadays, those who want to become teachers are waiting for the application of the amendments of a recent new law. The pre-service training will consist of a three-year preparation, including an apprenticeship, clinical practices, courses in pedagogy and Physics Education, and also technology and even more. This reform follows the trend of the last decades, and it will overcome the limitations of the admission tests if they are definitively abandoned (this is still not clear in the new law).

This very brief insight into the Italian system of instruction helps us to describe the context in which students and teachers live. The context undoubtedly affects students' and teachers' conceptions of Physics learning and teaching.

In the next sections, we will try to describe some aspects of these conceptions and how they are related to our research questions.

2.1 Overview of Students' Conceptions

The following overview tries to describe the main features of Italian high school students' conceptions. We could analyse these conceptions as a way to understand the learning process in a specific learning context (Eklund-Myrskog, 1998; Marton et al., 1997), strictly correlated to the learning environment (Entwistle and Peterson, 2004; Lowyck et al., 2004).

There are at least two main types of individual conceptions, conceptions of knowledge and conceptions of learning (Entwistle and Peterson, 2004; Perry, 1970), and one type of environmental conception, which is the instructional one (Lowyck et al., 2004; Marton et al., 1997). They all describe the developmental trends in students' learning based on their experiential setting (Perry, 1970) and the link with their experienced teaching (Trigwell et al., 1999). Their joint inter-relations build students' learning orientation concerning attitudes, behaviour and motivation (Entwistle and Peterson, 2004).

To explore students' conceptions in the Italian high school context, we investigated some descriptive categories which examine their learning outcomes and impacts in terms of:

- profiling attitudes (conception of knowledge, learning and instruction);
- building knowledge (conception of knowledge and learning);
- developing skills (conception of learning and knowledge).

2.1.1 Attitudes towards Science

Many factors are responsible for students' attitudes towards a specific school discipline. In Science, they are related to students' perceptions, teachers' quality and learning environments (Haladyna et al., 1983; Cahill et al., 2018). Negative attitudes are also specifically caused by teaching effects, such as a teacher-dominated classroom, incompetent teachers or poor teaching methodology (McDermott, 2001; J. Osborne et al., 2003; Kaur and Zhao, 2017). The research shows there are many difficulties in how to find a unique definition for attitudes (J. Osborne et al., 2003), but they can be measured (Lovelace and Brickman, 2013; Thurstone, 1928). In fact, the factors belonging to attitudes run between emotional to cognitive, passing through behavioural aspects (P. L. Gardner, 1975;B. Fraser, 1981; P. L. Gardner, 1995; J. Osborne et al., 2003). The concept itself of attitude is poorly articulated (P. L. Gardner, 1975; J. Osborne et al., 2003) and misinterpreted due to its complex construct (Reid and Skryabina, 2006; Kaur and Zhao, 2017). However, a way to overcome the difficulties of building a scale to measure attitudes is to satisfy two conditions: unidimensionality and internal consistency (Rosenberg et al., 1960; P. L. Gardner, 1995).

2.1.1.1 Brief Literature Review

During the last three decades, Physics Education Research (PER) has devoted many efforts to define scales and measure attitudes and beliefs towards Physics with a focus on college students (Adams et al., 2006; E. F. Redish et al., 1998; I. Halloun, 1997; Otero and Gray, 2008; Gray et al., 2008; Kurnaz and Yiğit, 2010; Guido, 2013; Madsen et al., 2015; Wilcox and Lewandowski, 2016; Wilcox and Lewandowski, 2017 Kaur and Zhao, 2017; Kapucu, 2017; Madsen et al., 2020; Gürler and Baykara, 2020). More recently, some scales have been developed for high school students (Kaya and Büyük, 2011; Cermik and Izzet, 2020; Stefan and Ciomoş, 2010; Tekbiyik and Akdeniz, 2010; Testa et al., 2022). A list of the validated and most frequently used tools in the American context to support educational innovations is illustrated in Table 1.

All of them are available online (AAPT, 2011) and also in many foreign languages, but none has yet been translated into Italian. In Table 2, one can find some of the scales developed in other school contexts at an international level (many others are referred here Kurnaz and Yiğit, 2010; Stefan and Ciomoş, 2010; Tekbiyik and Akdeniz, 2010; Kaya and Büyük, 2011; Pehlivan and Köseoğlu, 2011; Gürler and Baykara, 2020; Selçuk, 2010), not available in Italian too. These research-based surveys are tools for faculty members and for teachers to assess what students believe learning physics is all about (Madsen et al., 2020, p. 90).

In Italy, researchers recognise the important role of these surveys to underpin the adoption of active learning strategies (Pizzolato et al., 2014; Testa et al., 2021; Fazio et al., 2021), or investigating the students' views of physics through a socio-cultural psychological model (Testa et al., 2022) and exploring the advantages/difficulties of remote teaching during COVID-19 pandemic (Marzoli et al., 2021; Mazzola et al., 2022).

Italian-translated surveys could help faculty members and teachers to improve how they measure, for example, the effect of the impact of different

Table 1: *Attitudes' surveys examples, developed and validated in the American school context, and also used in other countries (Madsen et al., 2019).*

Title	**Intended population**	**Purpose**
CLASS - Colorado Learning About Science Survey (Adams et al., 2006)	Upper-level, intermediate, intro college, high school	Measure students' beliefs about physics and learning physics and distinguish the beliefs of experts from those of novices.
E-CLASS - Colorado Learning About Science Survey for Experimental Physics (Wilcox and Lewandowski, 2016)	Upper-level, intermediate, intro college	Measure students' epistemologies and expectations around experimental physics.
MPEX - Maryland Physics Expectations Surveys (E. F. Redish et al., 1998)	Upper-level, intermediate, intro college, high school	Probe some aspects of student expectations in physics courses and measure the distribution of student views at the beginning and end of the course.
VASS - Views About Science Survey (I. Halloun and Hestenes, 1998)	Intro college, high school	Characterize student views about knowing and learning science and assess the relation of these views to achievement in science courses.
EBAPS - Epistemological Beliefs About Physics Survey (Elby, 2001)	Intro college, high school	Probe the epistemological stances of students in introductory physics, chemistry and physical science.

teaching practices on students' beliefs and attitudes by studying the changes in these beliefs and attitudes during introductory college courses or high school instruction (Gray et al., 2008; Guido, 2013; Madsen et al., 2020).

Curriculum differences and instruction methods could affect the outcomes in terms of coherence depicting the Italian school system. For instance, the

Table 2: *Attitudes scales mainly designed for high schools developed and validated more recently in other countries' school contexts.*

Title	**Intended population**	**Purpose**
Attitudes towards Physics (Reid and Skryabina, 2002)	Intro college, high school	Identifying aspects of the Physics curriculum that hinder learning and a positive attitude towards the discipline.
Attitude Scale for Physics Course (Pehlivan and Köseoğlu, 2011)	High School for Scientific Studies	Investigation of attitudes according to the three-dimensional model investigating the cognitive, affective/emotional and behavioural components.
PAS - Physics Attitude Scale (Kaur and Zhao, 2017)	Intro college, high school	Measurement students' attitudes by identifying aspects of their learning and orientation to the study of Physics.
PCAS - Physics Course Attitude Scale (Cermik and Izzet, 2020)	High school	Identifies students' interest or lack of interest in physics and their predisposition/need to continue studying it.

strong mathematization in Italian Physics studies influences students' beliefs and attitudes(Meltzer, 2002; Veloo et al., 2015; Kapucu, 2017). Students are not often engaged in experimental activities because these are poorly integrated into teaching practices.

Administering attitudes survey is more common in Math Education, even at an early stage of Italian instruction (Di Martino and Zan, 2011; Villani, 2012; Ursini, 2019), with a deep coherence with the system, the curriculum and the goals of National Recommendations (Indicazioni Nazionali - MIUR, 2012).

A cross-analysis between Maths Italian scales and Physics foreign scales could give researchers and teachers an insight helping develop a new scale. This new scale might include instruction peculiarities, cultural context, learning goals and skills. The new scale also might clearly identify what the main target of the attitude measurement is in a well-defined theoretical framework (J. Osborne et al., 2003; Watson, 2020), limiting -or better-avoiding interference of - social-psychological observations (Likert, 1932; Goleman, 2009).

There are two stumbling blocks in assessing and administering attitudes surveys. The first stumbling block "towards assessing the significance and importance of attitudes is that they are essentially a measure of the subject's expressed preferences and feelings towards an object" (J. Osborne et al., 2003, p. 1054). The second stumbling block "for research into attitudes towards science is that such attitudes do not consist of a single unitary construct, but rather consist of a large number of sub-constructs all of which contribute in varying proportions towards an individual's attitudes towards science"(J. Osborne et al., 2003, p. 1054). This means multi-dimensionality in a scale which has to maintain internal consistency (P. L. Gardner, 1995; Reid and Skryabina, 2006).

One of the possible choices for building a scale is the use of the tripartite model or the three-dimensional model (Rosenberg et al., 1960). This is not unique and scientifically accepted; this model has been adopted in some scales we took into account. They were examples in Math Education (Di Martino and Zan, 2011; Ruiz and Ursini, 2010; Ursini and Ruiz, 2019;) also used in the Italian context.

This model allows for the exploration of students' attitudes at different levels, some of which are highly dependent on the teacher's efforts, while others are intrinsic to the epistemological structure of the discipline (Rosenberg et al., 1960), and still, others relate to the affective-dependent domain in which learning occurs (Table 3).

Table 3: *Attitudes' features according to the three-dimensional model (Rosenberg et al., 1960; Ursini et al., 2004; Ursini and Ruiz, 2019).*

Component	**Description**
Affective/Emotional	This component concerns the feelings, evaluation and emotions one feels towards the object of attitude.
Cognitive	This component is related to the set of beliefs, opinions, and thoughts in general that one has about the object of attitude and the knowledge one has about it.
Behavioural	This component regards both one's behaviour in the face of the object of attitude and one's behavioural dispositions and intentions.

These features highlight the choice for use in developing a scale for measuring attitudes towards physics. They take care of the two main interacting domains: teaching and learning. Teaching looks to the epistemological framework; learning looks to the difficulties arising during physics studies.

The measure's "snapshot" is also a way to pinpoint how scientific abilities (Etkina, Heuvelen, et al., 2006) and soft skills (Boyce et al., 2001; European Council, 2018) are involved in the non-automatic student-building process. This process strictly depends on the activation of cognitive, emotional and behavioural components (Salomon and Perkins, 1989).

Furthermore, the three-dimensional model could be considered age-independent, working as a longitudinal scale through the learning process.

The tested experiences in Maths Education in the Italian context(Di Martino and Zan, 2011; Ursini, 2019) and the lack of a translated scale to measure attitudes towards physics inspired the development of a new scale for attitudes towards Physics specifically tailored to the Italian high-school students. This new scale would also illuminate students' learning difficulties (relative to the cognitive component), teaching strategies adopted (enacting the behavioural component) and students' learning engagement (affording affective/emotional component).

2.1.1.2 Developing a Scale for Attitudes' Measure

Most of the literature's examples that have been examined in both Physics (Adams et al., 2006; Cermik and Izzet, 2020; I. Halloun and Hestenes, 1998; Kaur and Zhao, 2017; Pehlivan and Köseoğlu, 2011; E. F. Redish et al., 1998; Reid and Skryabina, 2002) and in Mathematics (Di Martino and Zan, 2011; Palladino, 2020; Ursini, 2019; Ursini and Ruiz, 2019) present a survey based on a five-point agreement/disagreement scale, known as a Likert scale (Likert, 1932). In a survey based on the Likert scale, "respondents are remarkably honest and consistent in their responses" (Reid and Skryabina, 2006, p. 9).

According to the Likert scale, the measurement assigns a numerical value to each possible option; furthermore, it is possible to reverse the attribution of the score if one considers that the question (called reversal questions, Kaur and Zhao, 2017) investigates a negative attitude rather than a positive one (*reverse-score*). We also included the neutral point of view to frame a broader spectrum of opinions, whether this is indicative of a neutral or indifferent/irrelevant attitude in a not entirely positive connotation (Table 4). The neutral option provides spatial uniformity (Reid and Skryabina, 2003)

Table 4: Five points Likert scale (Likert, 1932) for attitudes' measure.

Agreement Rank	**Positive Question Score**	**Negative Question Score**
Strong agree	5	1
Agree	4	2
Neither agree or disagree	3	3
Disagree	2	4
Strongly disagree	1	5

between the scale's options[2], even if those tendencies also depend on the items' type and their wording[3]. In this kind of scale, there are two different types of processing the acquired information (expert and peer). These infer the way of reading and interpreting the data collected in the experts-context or the peers-context frame (Madsen et al., 2020; Palladino, 2020).

In the framework of experts, it could be more important to identify epistemological beliefs (Adams et al., 2006; I. Halloun and Hestenes, 1998; E. F. Redish et al., 1998). In the framework of peers, it could be interesting to compare data between age groups, years of Physics studies, and types of

[2]The neutral option resides in the middle of the scale for mirroring the meaning in the reversion scoring. This position allows us to underline better the different tendencies between positive and negative mean scores.

[3]There are some problems associated with using scales like the Likert scale, even though it is among the most widely and extensively used in surveys in many disciplinary and psychological fields in the detection above all of the attitudes. In particular, attention must be drawn to the correlation links of a statistical nature and the implication of the relationship between the questions and the attitude they individuate (Reid and Skryabina, 2003).

curriculum.

In the second case, the mean score measures the attitudes' trend (Table 5) by category of data and/or significant groupings of the statistical sample. The mean score is a measure to underpin the trend in single items, groups of items, and items defining components of attitudes. The mean score could also hint at the whole trend for each student by averaging all the items, providing an indication of the attitudes towards the discipline.

Table 5: Mean score and attitudes' trend correlation (Ursini, 2019; Ursini et al., 2004).

Mean Score (m)	**Attitudes' Trend**
$1,00 \leq m \leq 1,49$	Negative
$1,50 \leq m \leq 2,49$	Towards Negative
$2,50 \leq m \leq 3,49$	Neutral
$3,50 \leq m \leq 4,49$	Towards Positive
$4,50 \leq m \leq 5,00$	Positive

2.1.1.3 Design and Methodology

We tried to measure attitudes towards Physics of Italian high-school students by developing a homogeneity and consistent scale based on a three-dimensional model, defining items for affective/emotional, cognitive and behavioural components. Our multi-components tool polled students through agree/disagree Likert scale. In the following, we in detail describe the scale we developed and its validation.

The affective/emotional component regards feelings of like or dislike towards physics. The items are built on contrasting feelings, and they involve students in answering questions such as "you like/you dislike", "you are fun/you are bored", and "You are anxious/you are not anxious" (Table 6).

Table 6: Affective/emotional component's items (the item with "∗" is marked for *reverse-scoring*).

#	**Item**
1	Physics is my favourite subject
2	I enjoy doing physics experiments
3	I get bored during physics classes ∗
4	Physics is fun
5	I like physics more when the teacher provides real, everyday examples
6	I do not feel confident while doing experimental/labs activities ∗
7	I like physics more when the teacher uses formulas to describe a phenomenon
8	I am anxious when I am asked to solve a physics problem ∗
9	I like doing physics in the lab

The cognitive component enhances the difficulties and other related aspects of the building process of concepts, ideas and knowledge (Rosenberg et al., 1960). It highlights how a specific learning process enacts cognitive abilities and skills (Table 7).

The behavioural component describes students' actions implemented as learning outcomes. They also intend to emphasise the need for behaviours to improve one's learning (as a self-reflection aim) - Table 8.

Some items could belong to more than one component. We suggested this grouping for mapping students' attitudes to recognisable features of their emotional, cognitive, and behavioural facets. The survey presents the items by mixing components, and grouping by domains of experience, such as:

Table 7: Cognitive component items.

#	**Item**
1	Learning physics is important
2	Physics is difficult ∗
3	It is easy for me to solve physics problems before others do
4	I have difficulties in translating a physics problem into mathematical language ∗
5	I face difficulty in expressing my reasoning by words resolving a physical problem∗
6	I am able to ask questions during the teacher's explanation
7	It is difficult for me to understand a phenomenon through graphical representations ∗
8	It is easy for me to represent a physics problem graphically
9	It is easier to understand and describe a physical phenomenon during experimental/labs activities in groups
10	I learn physics better by solving many problems
11	It is difficult for me to solve physics problems in groups ∗

Table 8: Behavioural component items.

#	**Item**
1	I would like to learn physics through experimental activities
2	I don't usually take part in physics lessons because I don't understand ∗
3	I can always explain 'how and why' I solve a physics problem
4	I will try many times until I can solve a physics problem
5	I get involved in physics lessons, often by asking for explanations/details
6	I comment on experimental activities/workshops with peers
7	If I were a physics teacher, I would teach using experimental activities/labs
8	I study physics only before assessments∗

- Physics is a subject matter
- The way students experience how Physics is taught
- The way students experience how they learn Physics.

We administered the survey online for its validation to the student population of Liceo Scientifico Guglielmo Oberdan in Trieste (Italy) during the school year 2019-2020.

This is a five-year high school for scientific studies with three different curricula: Traditional Scientific curriculum (TS), Applied-Sciences curriculum (AS) and Sports-Scientific curriculum (SS) (Table 9).

Table 9: Sample features for attitude scale validation (TS = traditional scientific curriculum, AS = applied-sciences curriculum, SS = sports-scientific curriculum.

Year Classes	**# Students**	**M**	**F**	**TS**	**AS**	**SS**
FIRST YEAR	134	80	54	32%	49 %	19%
SECOND YEAR	46	22	24	52%	43,5%	0,5%
THIRD YEAR	101	45	56	48%	51 %	1%
FOURTH YEAR	74	39	35	62%	35 %	3%
FIFTH YEAR	112	66	46	40%	38 %	22%
TOTAL	467	252	215	45%	43 %	11%

The distribution of the students who took part in the survey is compatible with the population of the entire institute. Therefore the statistical analysis of the data collected provides a coherent and realistic insight into this high school, both in clustering by gender and by curricula.

We validated the scale developed for attitudes' measurements defining its internal consistency, its statistical unidimensionality and its reliability (Cronbach, 1951; P. L. Gardner, 1975; J. Osborne et al., 2003; Reid and

Skryabina, 2002).

The internal consistency is statistically defined through Cronbach α coefficient (Cortina, 1993; Cronbach, 1951). However, while uni-dimensional scales will certainly be internally consistent (since they all measure the same construct - P. L. Gardner, 1975), it does not follow that internally consistent scales are uni-dimensional.
This is because a scale can be composed of several groups of elements, measuring distinct facets. If each element correlates statistically well with the other elements, it will still result in a high Cronbach's alpha coefficient (J. Osborne et al., 2003), indicating its reliability.

To bring out the level of items' correlation through Cronbach's coefficient (and to attempt defining its uni-dimensionality [4], the value of the coefficient was calculated according to two different definitions (Dunn, 1992; Falk and Savalei, 2011) to have a comparison to support the validation:

- *standardized Cronbach's alpha*, based on correlation matrix;
- *unstandardized Cronbach's alpha*, based on covariance matrix.

These procedures are differently used according to the data collected: if all the items have the same number of answers, the *unstandardized Cronbach's alpha* is recommended. If the items have a different number of answers, the *standardized Cronbach's alpha* is to be preferred (Falk and Savalei, 2011).

[4] To estimate the uni-dimensionality of the scale it would be necessary to use *Confirmatory Factor Analysis Technique* (Costello and Osborne, 2005; Field, 2009; Miles, 2005). We only estimated the *Sample Adequacy Measure* (MRA), computing the *Kaiser-Meyer-Okin* (KMO) coefficient (Kaiser, 1974). For the data collected, we obtained a KMO = 0.989, which is an "excellent value of adequacy" - according to the reference scale defined by Kaiser, 1974 -, useful for employing a factor analysis test (Field, 2009; Kaiser, 1974; J. Osborne et al., 2003). For our intent, we decided to consider this kind of analysis a second time.

According to the features of our sample, all the items had the same length measure (number of answers collected), so we adopted the *unstandardized Cronbach's alpha* procedure. We used the *standardized Cronbach's alpha* as a control test (Falk and Savalei, 2011).

Internal consistency reliability refers to the extent to which different items in a test measure the same construct (Kaur and Zhao, 2017). So, the Cronbach α value depends on the items' number, inter-items correlation, and the dimensionality of the survey or a part thereof. The α coefficient ranks between 0 and 1. This value specifically corresponds to the scale internal consistency according to the following thumb rule (Table 10, Field, 2009; Streiner, 2003).

Table 10: Cronbach α coefficient reference values for reliability.

α **value**	**Reliability**
$\alpha \geq 0.9$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

We obtained a quite "Excellent" α value ($\alpha = 0,89$) to the whole scale (the *unstandardized* and *standardized* Cronbach's alpha procedures differed by coefficient values to the thousandth).

For a more detailed statistically defined validation of the scale, we investigated (Field, 2009; J. Osborne et al., 2003):

- *Item Statistics*: to provide items coherence through the mean and the standard deviation analysis;
- *Inter-Item Correlation Statistics*: to examine the items' correlation matrix;
- *Item-Total Statistics*: to remove items with low correlations, defining a corrected correlation (*Corrected Item-Total Correlation*) and the corresponding *R-squared multiple correlations*; lastly, to re-value the Cronbach's alpha coefficient for increasing reliability (*Item-Total Statistics*).

We presented the final version of the scale in table 6, table 7, and table 8 for the three components. After statistical validation, we removed either two items, one for redundancy and the other for lack of statistical information (because the same agreement value was expressed in 88% of the answers).

2.1.1.4 Data Analysis and Findings

We completed a first descriptive statistical analysis of the data collected in the scientific high school based on *Item Statistics*. This simple analysis pins out some interesting trends in individuating students' attitudes towards Physics. The descriptive statistical analysis focuses on the items' mean score (Table 5).

We divided the sample into clusters (and sub-categories) to provide clear insight. Clusters are based on students' groups by year or by grouping years (the first two years period and the second three years period). Inside these clusters, we also divided data by gender (Bologna and Peressi, 2021a, 2021b).

Detailing by clusters, we obtained a clearer picture of students' trends. If we consider the whole sample, we observed that an attitude among students tending towards the positive (46%, 44% with $3,5 \leq m \leq 4,49$ and 2% with $4,5 \leq m \leq 5$) contrasted with a more neutral predominant attitude (50%), as seen in Figure 2).

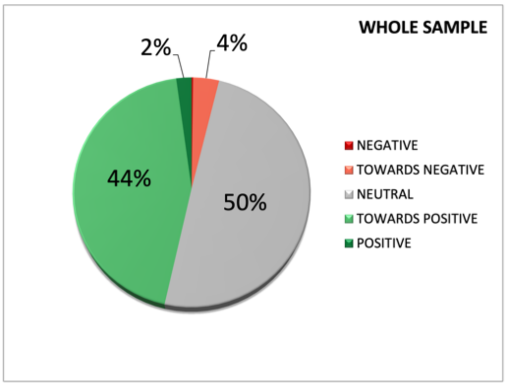


Figure 2: Attitudes towards Physics for the whole sample.

This is quite different if we consider the gender sub-categories (Figure 3). We clearly notice the neutral prevalence for the female group. All the female

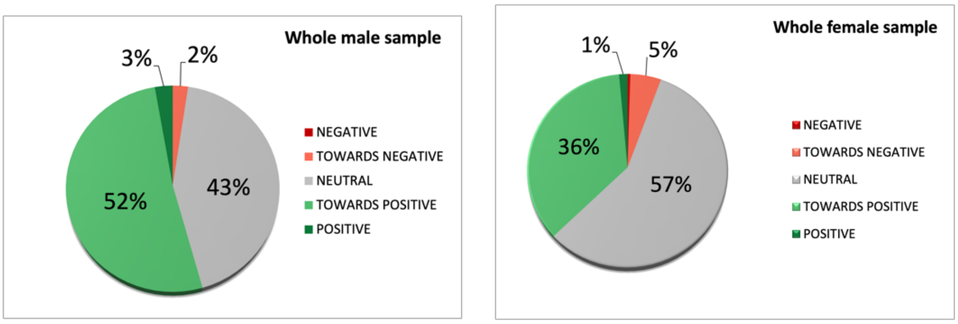


Figure 3: Compared attitudes between male and female samples.

mean scores were lower than the corresponding male. In both samples, the positive attitudes are mainly due to the items referring to experimental/labs activities and real-everyday phenomena (listed in Table 11).

It is interesting to notice the change during the school years (the first and the last one, the fifth), between the whole sample (Fig. 4) and between genders (male sample Fig. 5, and female sample Fig. 6). The increasing

Table 11: Items referred to experimental aspects.

#	**Affective/emotional component (Table 6)**
2	I have fun doing physics experiments
5	I like physics more when the teacher provides real, everyday examples
#	**Cognitive component (Table 7)**
9	It is easier to understand and describe a physical phenomenon during experimental/labs activities in groups
#	**Behavioural component (Table 6)**
1	I would like to learn physics through experimental activities
7	If I were a physics teacher, I would teach using experimental activities/labs

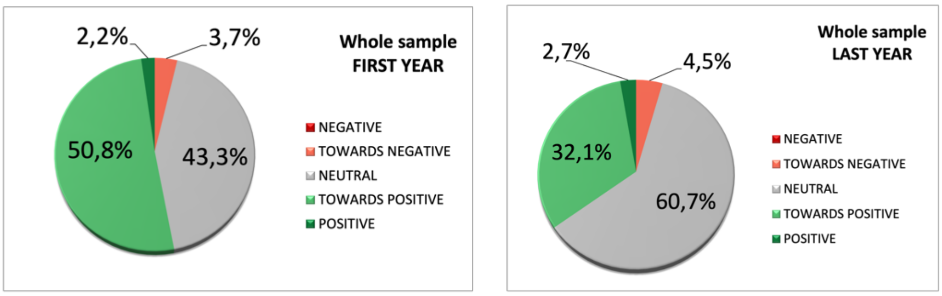


Figure 4: Compared attitudes between first and last year for the whole sample.

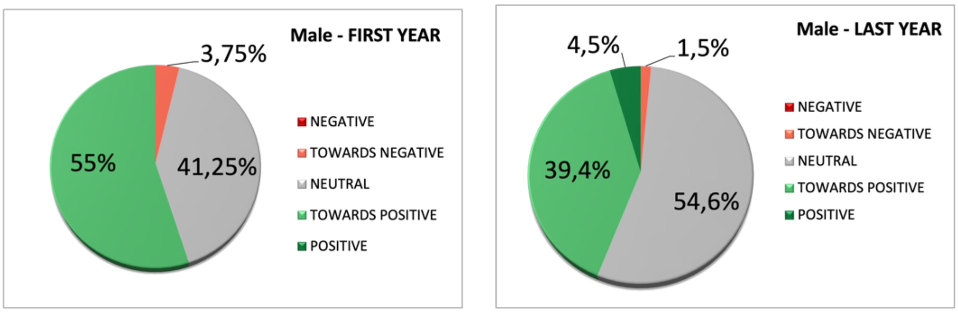


Figure 5: Compared attitudes between first and last year for male sample.

disaffection towards the discipline is considerably evident in the "towards positive" mean score value decreasing. This value is the lowest in the female sample in the last year of the scientific high school. It is the lowest consid-

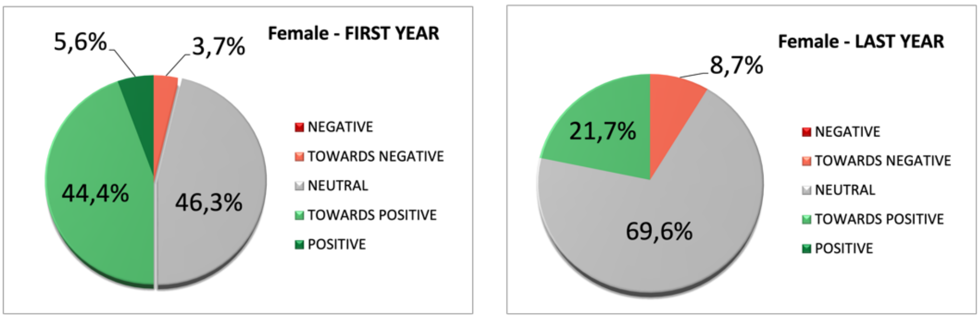


Figure 6: Compared attitudes between first and last year for female sample.

ering all the possible analyses by clustering data between years or genders. This cluster (last year, female sample) also features the highest percentage "towards negative". What we did not expect was the growth of a prevalent neutral position.

It is tough to deeply understand the reasons for this trend, mainly pinpointed at the end of this cycle of studies. The Italian scientific high school has a curriculum strongly based on Maths, Physics, and Sciences subject matters (quite one-half of the weekly lessons planning). So, we observed that increasing knowledge in the disciplines does not correspond to a growing attitude towards them. And this clearly happens to female students more than to male ones.

The observed trend is also present by comparing the data between clusters by years (Fig. 7). This comparison is particularly interesting for three main reasons: firstly, the first two year courses are mandatory schooling. Secondly, the Physics teachers in the first two years are not the same as in the last three. Then, there is a change in students' learning disposition during their intellectual growth (Trumper, 2006).

Examining mean scores, we identified other interesting information. The

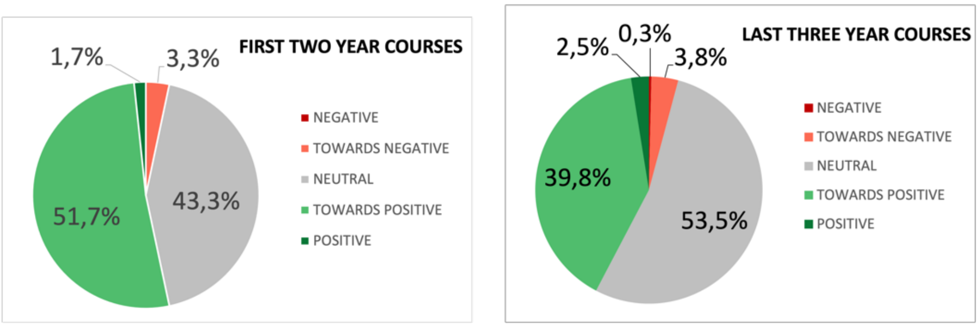


Figure 7: Compared attitudes between the first two year courses and the last three.

first comes from the lowest item mean value. It regards the item "Physics is difficult". Its value confirms the students' perception of Physics itself as difficult to study and understand.

The second concern is the item with the highest mean value, $m \geq 4.4$. This item is "If I were a physics teacher, I would teach using experimental activities/labs". This result is more than a mere suggestion. It is a direct invitation to teachers to adopt experimental practices in their Physics teaching. All the other items with a higher mean score value ($m \geq 4$) reinforce this invitation:

- It's important to learn Physics ($m \approx 4.2$, cognitive component);
- I would like to learn Physics through experimental activities ($m \approx 4.4$, behavioural component);
- I like Physics more when the teacher provides real, everyday examples ($m \approx 4.3$, affective/emotional component);
- I do not feel confident performing experimental/labs activities (with reverse scoring) - ($m \approx 4.1$, affective/emotional component);
- I like doing Physics in the lab ($m \approx 4.3$, affective/emotional component).

Observing this list, we investigated another interesting finding, summarised in the table 12. We recognised that the "towards positive" trend is mainly enacted by items describing the affective/emotional component (P. Gardner, 1985). The male sample differs from the others for the same contribution to the "towards positive" trend coming from the emotive and cognitive components. This also could be recognised as a gender effect (Trumper, 2006).

Table 12: Number of items for each component with a high mean score ($m \geq 3.50$).

Sample	**n. emotional items**	**n. cognitive items**	**n. behavioural items**
Whole	4	2	3
Male	5	5	2
Female	4	3	2

Finally, we analysed the items with a mean score value $m \leq 2.5$, which means a "towards negative" tendency. There are four items belonging to this statistical group, and two of them belong to the cognitive component:

- Physics is difficult (cognitive component);
- It is simple for me to solve Physics problems before others (low mean score value indicates disagreement) - (cognitive component);
- Studying Physics only before assessment (with reverse scoring, low mean score value indicates agreement) - (behavioural component);
- Physics is my favourite subject (emotional component)

Then, one last item caught our attention: "Physics is fun". This item did not reach the mean score value to overcome the neutral tendency, even if the 45% of the responses indicates a positive score (33% Agree; 12% Strongly Agree).

We could expect this result for the main sample feature (the students attend a scientific high school). Still, if we look at gender groups, we noted a great difference between male and female students: in the male cluster, 41% of students are "Agree", and 13% "Strongly Agree". In the female one, only 24% are "Agree", and 11% are "Strongly Agree".

2.1.1.5 Brief Discussion

Our descriptive statistical analysis goes in the same direction as other recent studies (Kaya and Büyük, 2011; Reid and Skryabina, 2006; Trumper, 2006). There are two main facets which influence and determine students' disaffection towards Physics:

- the role of experimental/labs activities (Kaya and Büyük, 2011);
- the gender differences (Reid and Skryabina, 2006; Trumper, 2006).

To describe an *Early Physics* approach, we need to consider these two facets.

We developed this scale for measuring attitudes to have a tool that better fits Italian high schools' features. The data collected are representative only of students belonging to scientific high schools. In fact, a scientific high school is very different from the others: it differs by student population, students' disposition towards scientific studies, students' orientation towards sciences, and students' disposition for learning and studying. When we administered the scale, we could not involve all the schools we engaged in our research study, but only the Liceo Scientifico Guglielmo Oberdan; this happened because we administered the survey during the spread of COVID-19 infection and thus faced the resulting restrictions and school re-organisations. Furthermore, we realised that the scale developed was unsuitable for all secondary schools. We adopted a reduced version with fewer items for technical-professional secondary schools, trying to match the schools' physics curriculum.

The scale developed and validated could also be used as pre-post test monitoring if adopting a new teaching/learning approach influences students' attitudes.

We faced the limitations of its use because we could not administer the survey to all schools engaged in our research project.

2.1.2 Describing Conceptual Knowledge

A possible way to measure students' learning is using a Concept Inventory (CI). CIs are research-based assessment instruments for examining how a physics concept is understood. They do not measure the process of knowledge development but the efficacy of the building process knowledge concerning particular topics or related content topics (Fazio et al., 2021; Madsen et al., 2017). They also can focus on students' conceptual coherence in assessing the state of students' knowledge, observing its context dependence (Bao and Redish, 2006). We used CI with this specific aim.

We administered a concept inventory at the beginning of college studies to young Physics and Engineering freshmen during the Academic Year 2021-2022. We wanted to spotlight if the context of instruction affected the Physics knowledge that the students developed. To investigate conceptual coherence, we analysed the responses in the two following ways:

- exploring if the knowledge was acquired in a fragmented way that means partial knowledge correctly used only in some responses;
- trying to individuate those responses which persistently show wrong ideas or missing concepts, indicating a lack of conceptual change (diSessa, 1993, 2014; Vosniadou, 1994).

For this reason, we administered the CI referring to force and motion, two mutually nested and connected concepts. The connection among variables, relations, and conceptual ideas is explained in Fig. 8. This figure describes the conceptual framework of force and motion and the distinguished pathways between expert and novice knowledge structures (Nie et al., 2019)[5].

Student difficulties in developing these concepts are well known (Bao and Redish, 2006; diSessa et al., 2004; I. A. Halloun and Hestenes, 1985; Nie et al., 2019; Thornton and Sokoloff, 1998). In this framework, conceptual

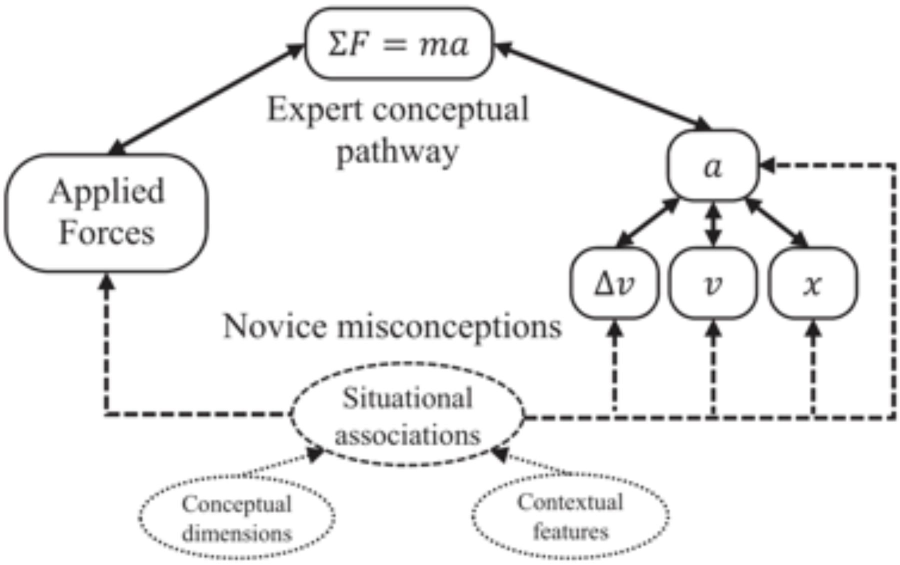


Figure 8: Conceptual framework of force and motion (Nie et al., 2019).

coherence means recognising the expert conceptual pathway in the students and testing them through a specific concept inventory. At the same time, we could identify conceptual incoherence if the possible pathways of connections differ from a correct conceptual physical description.

2.1.2.1 FMCE Concept Inventory

The Force and Motion Conceptual Evaluation (FMCE) is a research-based multiple-choice assessment instrument developed in the late Nineties

[5]The figure is used by courtesy of the authors. The two-way arrows indicate possible pathways of connections within a learner's knowledge structure. The solid lines represent experts' conceptual pathways, while the dashed lines represent novices' possible pathways.

(Thornton and Sokoloff, 1998). The questions on this CI were developed based on student interviews, responses to open-ended versions of the questions and expert review. It has been validated through statistical analyses of reliability and consistency between the test and re-test.

FMCE was constructed to assess students' understanding of Newtonian mechanics in one dimension. The original concept inventory contained 43 items (Thornton and Sokoloff, 1998); a revised instrument added 4 items to measure the understanding of energy. Each item has a minimum of six possible responses, with some items having nine responses. All items include a "none of the above" response. This response is not the correct answer for any item which may serve to limit its negative effects (Yang et al., 2019). The instrument groups items into 8 blocks where all items in each block refer to a common stem. Only one item is not included in a problem or conceptual block.

The questions have also been clustered in different groups, according to the kind of statistical analysis conducted (Bao and Redish, 2006; Richardson et al., 2021; T. I. Smith and Wittmann, 2008; Thornton and Sokoloff, 1998). These groups could describe a physicist's view of equivalent content areas and students' responses could be evaluated based on their agreement with a physicist's viewpoint without regard for why students might choose incorrect answers. FMCE has also been used to compare the effectiveness of many different teaching methods (Von Korff et al., 2016). It has been administered to over 20,000 students in the English version, and all the data all available for researchers. It has also been translated into Japanese (Ishimoto, 2013) and Spanish versions.

We provided the Italian translation of the CI to administer it to freshmen. The translation from the original English FMCE was performed using a conceptual translation model. The translation had to remain faithful to the ideas and concepts being probed by the original FMCE. But, at the same time, it had to adopt words students usually used in daily conversation and in studying physics topics. We reviewed our translation in terms of semantics, grammar, and syntax based on comments given on the draft version by two Physics college teachers, three Physics high school teachers and an English high school teacher. This revised version was considered validated for use.

2.1.2.2 Methodology

Here we present a brief report of a more extensive work we are still ongoing and preparing for publication[6].

The FMCE - Italian version was administered through a Google Form: this method of collecting data helps us to create a database for the analysis, ready for use. The CI was proposed at the beginning of the Physics courses: during the first semester for Physics freshmen students and during the second semester for Engineering freshmen students. The two faculties differ in the academic plan of the Physics courses in the first year. Nevertheless, Engineering students did not attend any Physics course (or similar) during the first semester. So, they could be considered to have the same training as the Physics ones when they responded to the inventory.

[6] We presented the findings of this study at the MESE1 - MEasurement in Stem Education (1) Conference, held in Napoli (Italy) at the end of January 2023. Here, we report some preliminary results, with many thanks to Fabrizio Diaz Guerra - a Physics student - for his contribution to quantitative and Neural Network Analysis.

The sample consists of 159 students divided into three subset categories:

- by gender (Fig. 9);
- by past curriculum (Fig. 10);
- by present curriculum (Fig. 11).

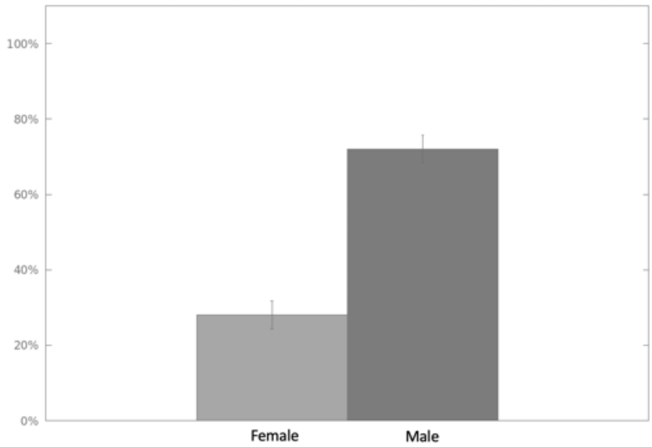


Figure 9: Gender sample distribution.

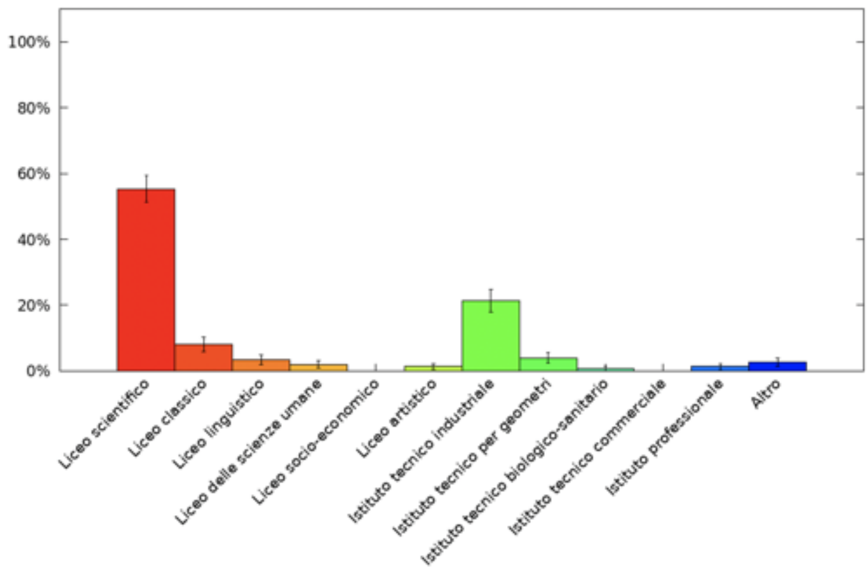


Figure 10: Past curriculum sample distribution (The school labels are not been translated: they are the specific Italian denomination for the corresponding high school types).

Our sample featured a prevalence of Engineering freshmen and a prevalence of male students (in agreement with the national standard trend value for this kind of study). Looking at the past curriculum distribution, we observed that many students attended scientific high schools. We could infer more detailed information by analysing the past curriculum distribution according to the year number of Physics studies as curricular subject matter (Fig. 11).

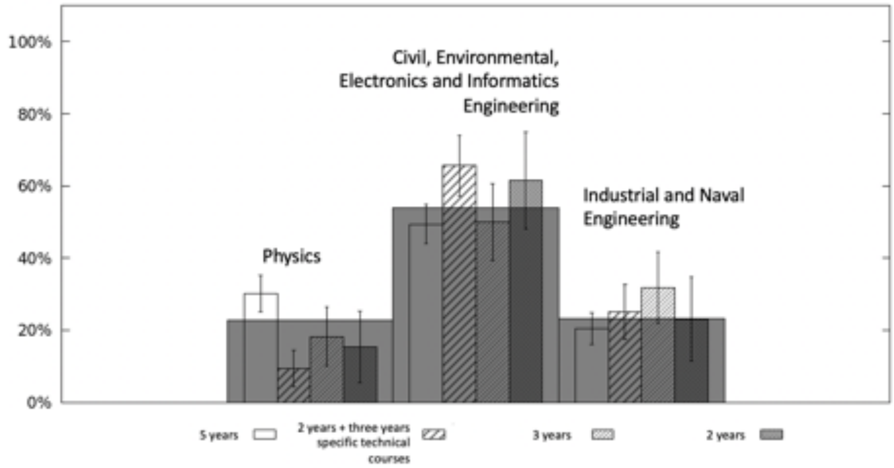


Figure 11: Present curriculum sample distribution and year number of past Physics studies.

The correspondence between the year number of physics studies and high school denomination is reported in Table 13.

The first analysis conducted was based on multivariate descriptive statistics. There are many kinds of clustering for FMCE questions (Richardson et al., 2021; T. I. Smith and Wittmann, 2008; Yang et al., 2019). Factor Analysis confirmed extensive blocking of items into groups with a common stem (Yang et al., 2019). We adopted conceptual blocking as a reference frame for our first statistical investigation, adding, if possible, a detailed de-

Table 13: Years number of Physics studies in Italian secondary instruction.

Years Number	**Italian High School Denomination**
5 years	Liceo Scientifico
First 2 years + Last 3 years of technical courses (Physics-based)	Istituto Tecnico Industriale
Last 3 years	Liceo Classico, Liceo Linguistico, Liceo delle Scienze Umane, Liceo Artistico
First 2 years	Istituto Tecnico per Geometri, Biologico-Sanitario, Turistico, Commerciale, Informatico, Nautico (...), Istituto Professionale

scription of the disciplinary language requested to answer in that particular block (Table 14).

We could also observe that some descriptions by words featuring the item responses clearly refer to external representations such as vectors (Ainsworth, 1999; Munfaridah et al., 2021):

- description referred to vector definition of forces, velocity and acceleration (in terms of magnitude and direction);
- description referred to vector sum of forces.

The data analysed are plotted according to correct answers in the following distributions:

1. whole sample (Fig. 12);
2. by gender (Fig. 13);
3. by past curriculum (Fig. 14);

Table 14: Items Blocks and Descriptive Language Response.

#	Items	Block	Descriptive Language Response
1	Q1-Q7	Force and Motion	Description by Words
2	Q8-Q13	Newtonian Mechanics Applications	Description by Words
3	Q14-Q21	Force and Motion	Description by Force-Time Graphs
4	Q22-Q26	Force and Motion	Description by Acceleration-Time Graphs
5	Q27-Q29	Kinematics Applications	Description by Words
6	Q30-Q39	Third Principle	Description by Words
7	Q40-Q43	Force and Motion	Description by Velocity-Time Graphs
8	Q44-Q47	Mechanical Energy Conservation	Description by Words

4. by present curriculum (Fig. 15).

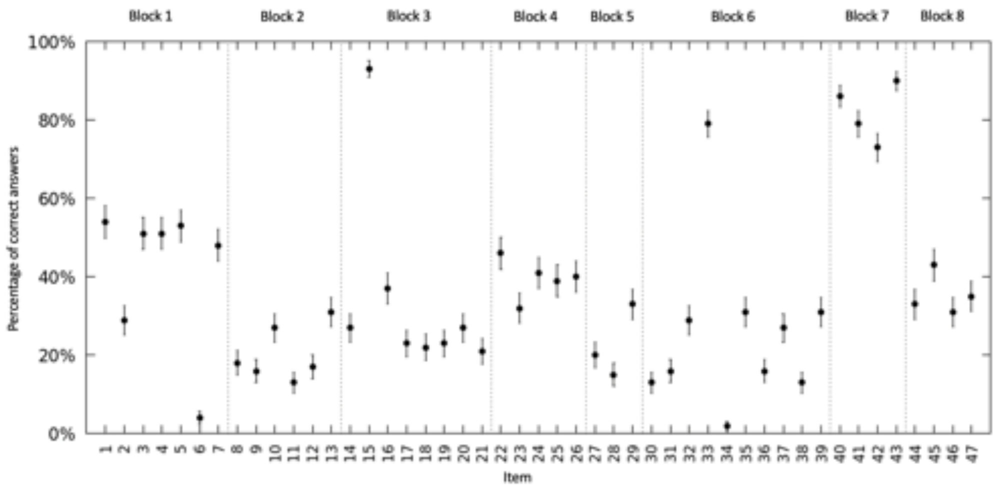


Figure 12: Whole sample distribution of correct answers.

The distributions disclose that is only one item block, i.e. the number 7 (see Table 14), where the percentage of correct answers gains greater than

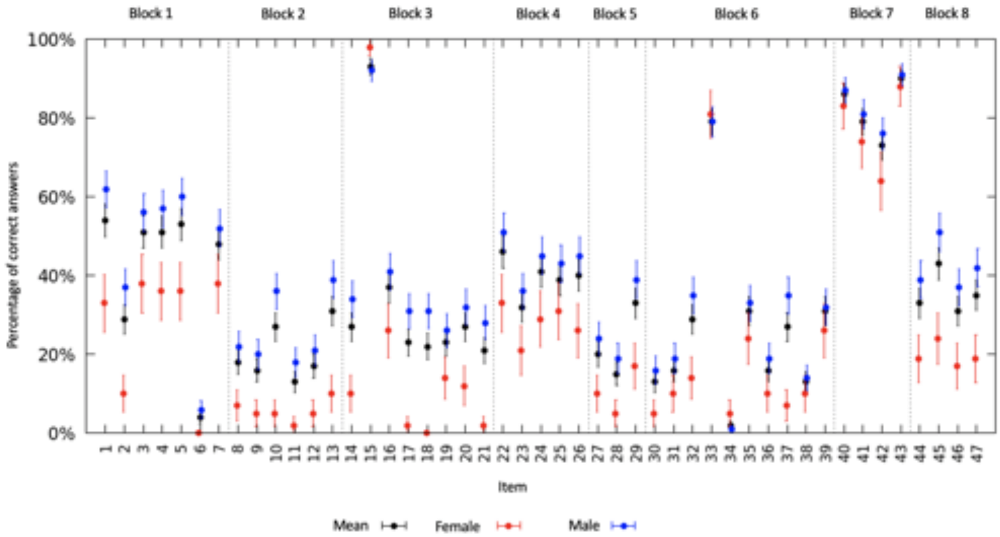


Figure 13: Sample distribution of correct answers by gender.

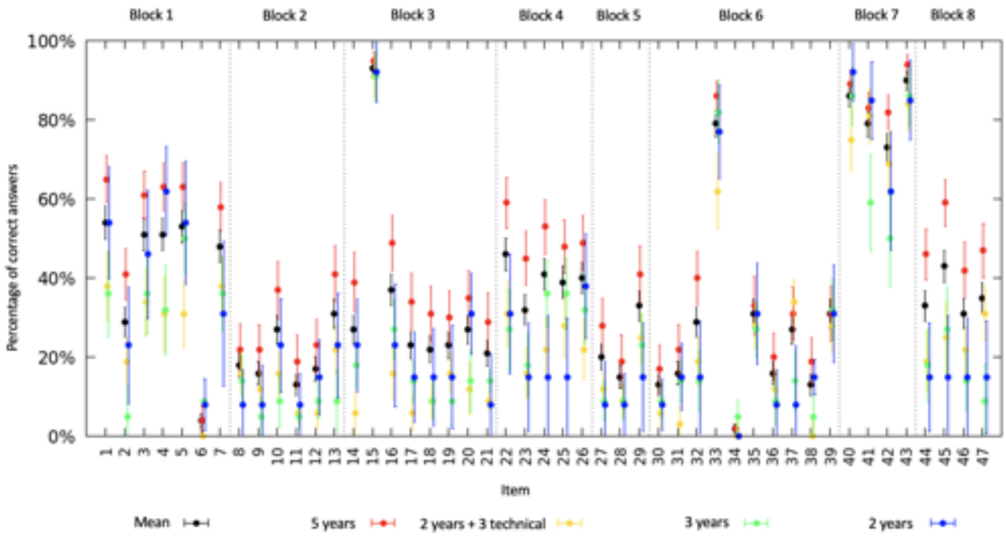


Figure 14: Sample distribution of correct answers by past curriculum.

60%. This block concerns the description in terms of velocity-time graphs of a specific physical situation.

The low percentage of the other items probed our data reading and required a deep insight into the data correlation and inter-relation.

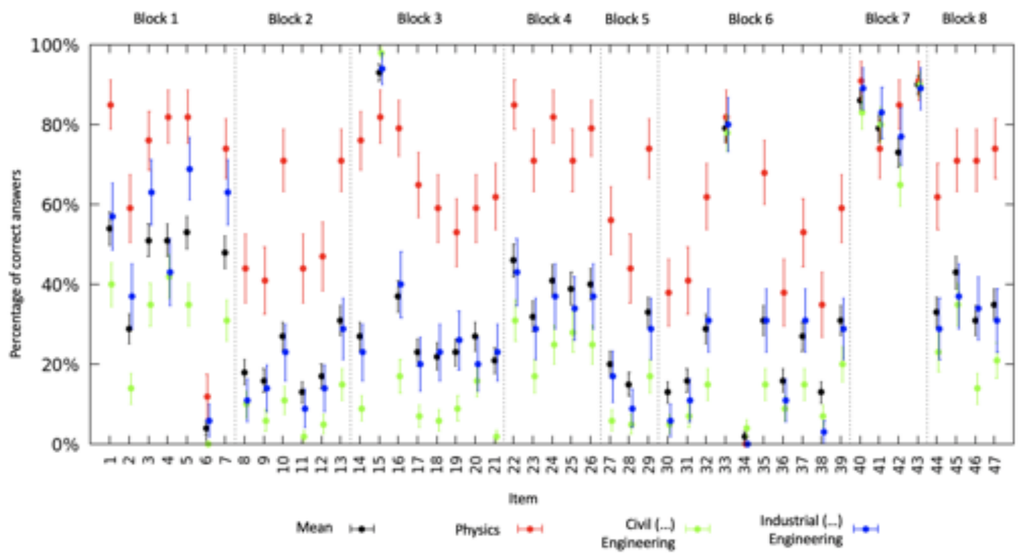


Figure 15: Sample distribution of correct answers by present curriculum.

Firstly we clustered the responses according to the physics they imply. The right response implies a correct physics relation between variables; a wrong response implies a wrong physics relation between variables, which could be referred to as a prior-primitive (diSessa, 1993), referring to this framework to describe students' knowledge thinking. For example, answers where the resultant force vector was proportional to the velocity vector, were classified as "$F \propto v$" (Ohm p-prims, diSessa, 1993). The list of all the possible responses and the physical/mathematical relationship - which students arise as causal relation in their reasoning process (diSessa, 1993) - are itemised in Table 15 with the correspondence with item blocks.

Clustering responses by blocks and classifying? correct and wrong answers according to the physical/mathematical relationship, we obtained the following histograms: on the left percentage of correct/wrong answers, and on the right percentage regarding each relationship spotted for each block

Table 15: Physical/mathematical relationship between variables and item block correspondence.

Kind of response	Meaning	Item Blocks
?	Not enough information is given to pick one of the answers above	All
x	None of these descriptions is correct, none of above	All
Wrong	Not relating to phys/math relationship	7
$F \propto \int x$	Force proportional to position integral	2, 3
$F \propto x$	Force proportional to position	1, 2, 3
$F \propto v$	Force proportional to velocity	1, 2, 3, 6
$F \propto a$	Force proportional to acceleration (*)	1, 2, 3
$F \propto j$	Force proportional to jerk	1, 2, 3
$F \propto s$	Force proportional to snap	1, 2, 3
$F \propto m$	Force proportional to mass	6
$F \propto \int\int x$	Force proportional to double integral of position	3
$F \propto \Delta m$	Force proportional to mass variation	6
$F \propto F_m$	Force proportional to motor force	6
$F = 0$	Null force	6
$F \propto 1/v$	Force proportional to the inverse velocity	6
$F \propto 1/m$	Force proportional to the inverse mass	6
$a \propto \int x$	Acceleration proportional to position integral	4, 5
$a \propto x$	Acceleration proportional to position	4, 5
$a \propto v$	Acceleration proportional to velocity	4, 5
$a \propto a$	Acceleration proportional to itself	4, 5
$a \propto j$	Acceleration proportional to jerk	4, 5
III	Third law	6
$v \propto x$	Velocity proportional to position	7, 8
$v \propto v$	Velocity proportional to itself	7
$v \propto a$	Velocity proportional to acceleration	7
$v \propto j$	Velocity proportional to jerk	7
$v \propto \Delta E$	Velocity proportional to energy variation	8
$v \propto \alpha$	Velocity proportional to slope angle	8
$K_f \propto \Delta E$	Final Kinetic Energy proportional to energy variation	8
$K_f = U_i$	Final Kinetic Energy equal to Initial potential energy	8

(Block 1 to Block 8, see Figures 16 to 23).

Looking at the block's screens we noticed the net prevalence in the chosen answers that directly referred to conceptual misunderstanding (Hammer,

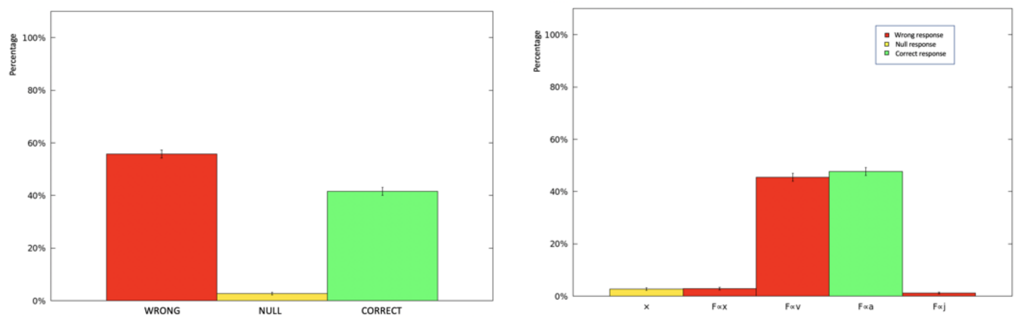


Figure 16: Answers distribution by correctness and by math/phys relationship refer to Block 1 questions (Q1-Q7).

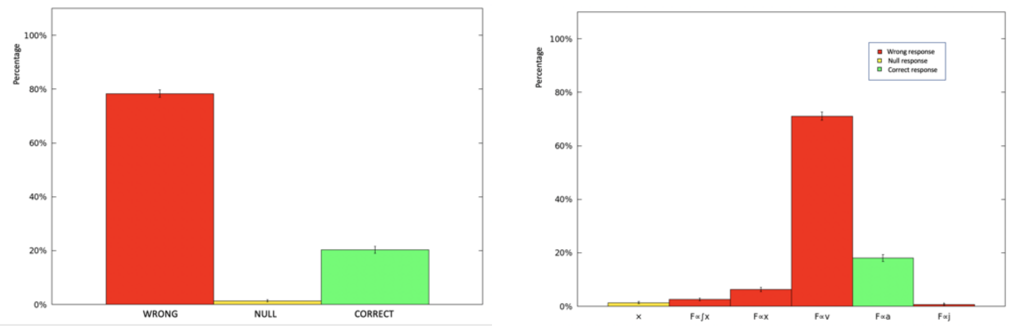


Figure 17: Answers distribution by correctness and by math/phys relationship refer to Block 2 questions (Q8-Q13).

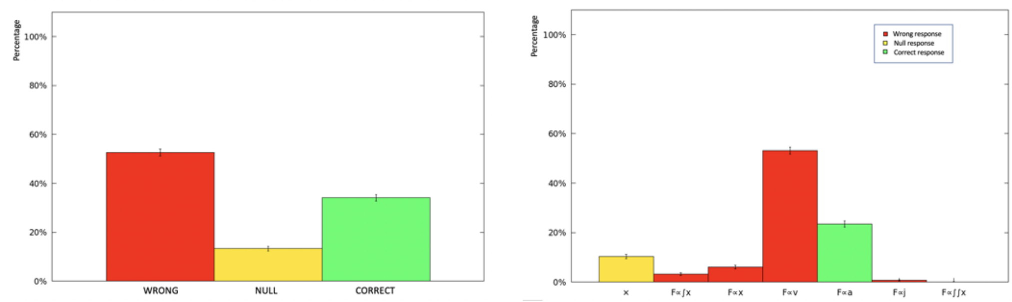


Figure 18: Answers distribution by correctness and by math/phys relationship refer to Block 3 questions (Q14-Q21).

1996). The prevalence of wrong answers is described by two main kinds of causal relationships between variables:

- $F \propto v$;
- $a \propto v$.

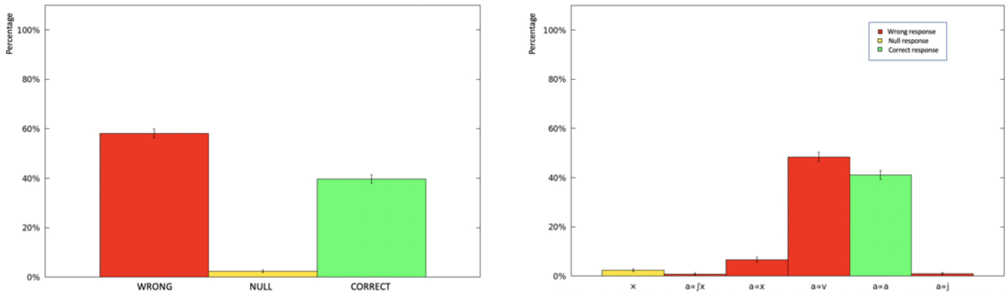


Figure 19: Answers distribution by correctness and by math/phys relationship refer to Block 4 questions (Q22-Q26).

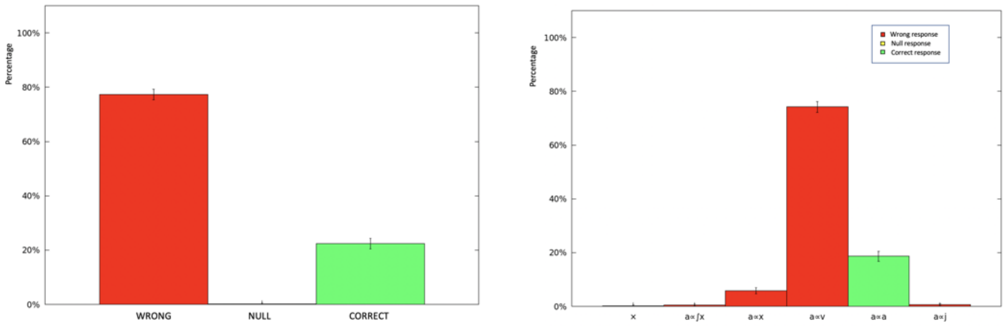


Figure 20: Answers distribution by correctness and by math/phys relationship refer to Block 5 questions (Q27-Q29).

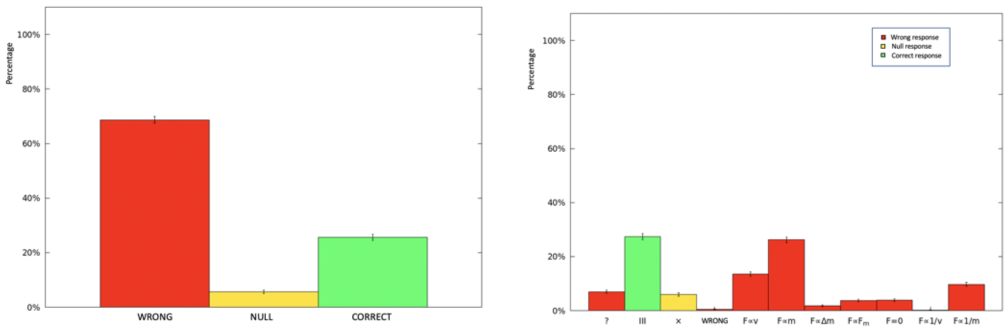


Figure 21: Answers distribution by correctness and by math/phys relationship refer to Block 6 questions (Q30-Q39).

They are concerned with the standard force and motion difficulty, namely, that a constant force was necessary to sustain constant rate motion (diSessa et al., 2004). Moreover, many questions require students' language disambiguation of force meaning. The difficulty which arises from analysing the

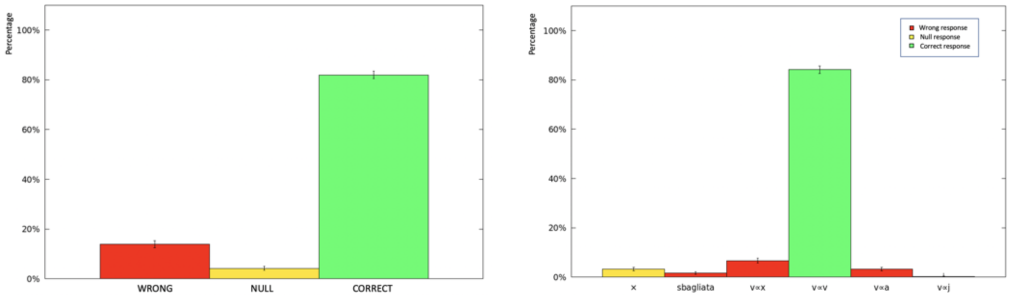


Figure 22: Answers distribution by correctness and by math/phys relationship refer to Block 7 questions (Q40-Q43).

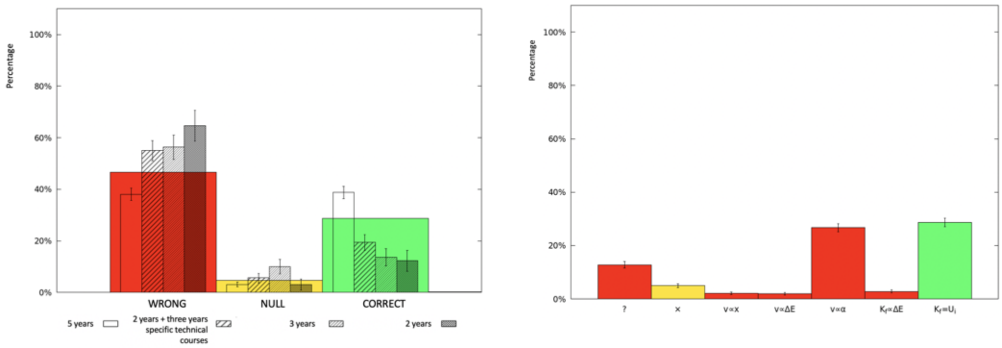


Figure 23: Answers distribution by correctness and by math/phys relationship refer to Block 8 questions (Q44-Q47). In this particular case, we stressed the past curriculum experience to notice the differences.

CI's answers suggests the lack of refinements in students' understanding of the physical meaning of the term "force" (Brookes and Etkina, 2009). By the descriptive analysis of blocks, it seems that blocks designed by "Words Description" present a greater percentage of errors than the others.

The other blocks with a low percentage of correct answers are the ones referred to the use of force-time and acceleration-time graphs, which claim physicist experience in recovering physical meaning in this kind of representation: if the meaning of force (and acceleration) is not conceptually well understood, any other physical representation implying them would not be used correctly.

To better investigate the correlation between blocks' answers we provided to adopt another statistical technique of data analysis.

In this way, we could uphold the finding of a lack of conceptual coherence at the beginning of College studies or the persistence of intuitive-naïve concepts even after secondary physics instruction.

We undertook this in-depth analysis based on the Artificial Neural Network (ANN) method (Lamb et al., 2014), a framework quite versatile (Amoo et al., 2018), which computes relationships based upon the interaction of multiply connected processing elements (Lamb et al., 2014; Pinkus, 1999). A key feature of ANN is that there is a strong connection between input elements and output elements (Lamb et al., 2014). Here we used ANN as a data analytical method. This use allows organising data in patterns (the neurons) based on statistical features maintaining the information along the network.

In PER this kind of analysis has only recently been performed to explore different levels of student interaction, or to explain academic performance (Amoo et al., 2018).

We adopted ANN technique to investigate possible statistical evidence of what descriptive analysis suggested. To achieve this goal, we organised data collected into a three-dimensional binary array $Q \times A \times N$. The first dimension represents the questions Q, the second A is the possible answers (categorised by causal relationship - Table 15), and the third N is the sample number of students indexed. Each cell can assume two logical values, reflecting if the answer to the question was selected by the student or not. Figure 24 displays the array for the first seven students and two students' answers examples.

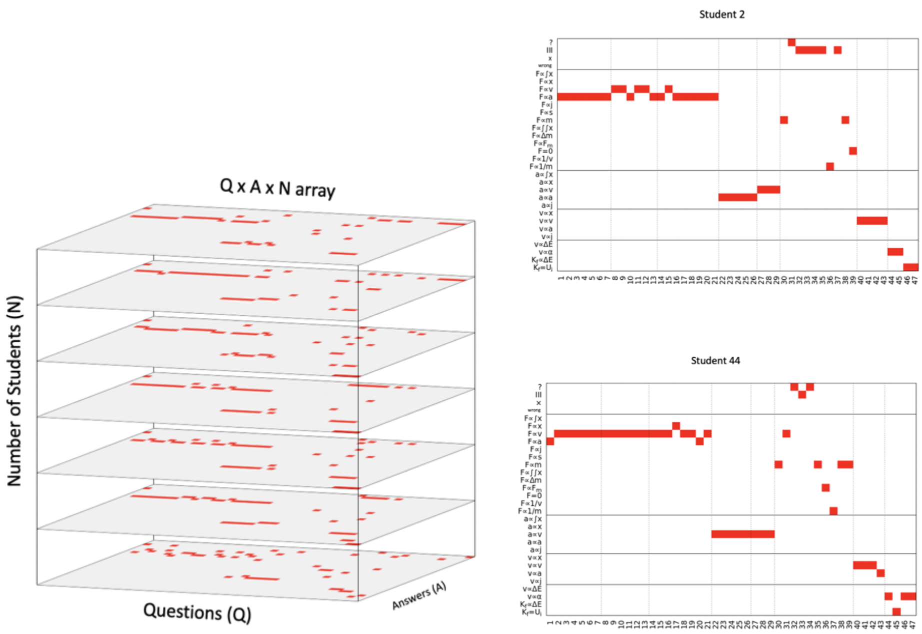


Figure 24: Array definition for ANN analysis.

To individuate recurring patterns in students' responses, we tried to find the principal components to which they were distributed. Principal Component Analysis aims to optimise the grouping of individual variables (in our case, the students' items responses) into a set of higher-order components (Dalka et al., 2022).

We adopted the Sanger rule, also known as Sequential Principal Components Analysis, which forces neurons to represent a well-ordered set of principal components of the data set (Sanger, 1989). So, every neuron finds the component, an already normalised eigenvector of the covariance matrix, which maximises the associated eigenvalues, and then subtracts it from the input before passing it to the next neuron (Fig. 25).

The first neuron of the chain finds the mean of the data set, as can be seen in Fig. 26. This first neuron does not inform more than descriptive

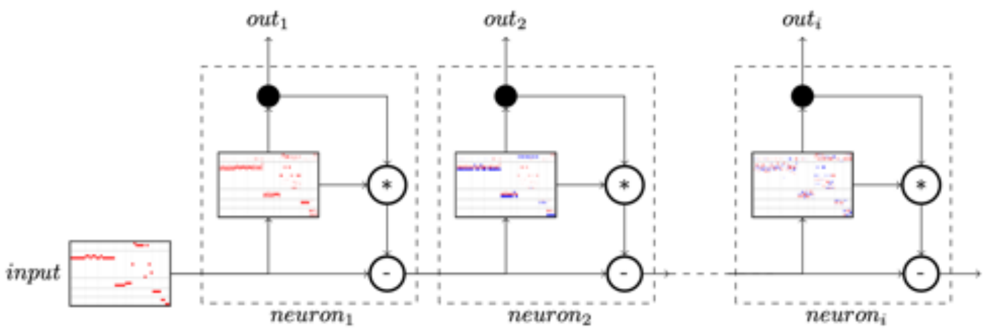


Figure 25: Illustration of the Sanger neural network applied to an FMCE response. We can see the principal components memorised in the neurons

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analysis, but it represents the first stage in building the network: this is the first principle component in the data set.

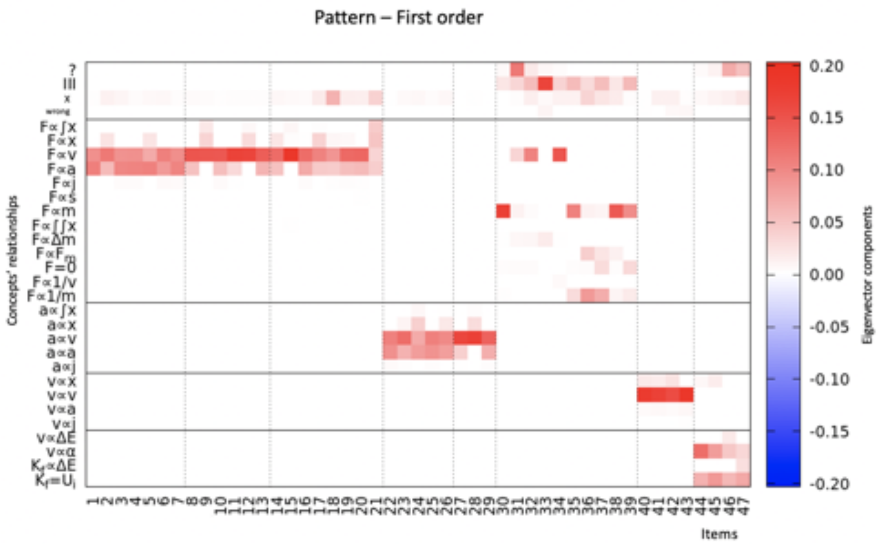


Figure 26: The first neuron which shows the data-set mean.

The second neuron collects the responses that most divide the opinions (since a multi-modal distribution has a higher total variance). The resulting pattern shows some interesting scenarios (Fig. 27). It is possible to recognise two main trends. One is constituted by red pixels, and the other is formed by blue pixels. Red and blue pixels indicate different clustering (distribution) of responses. The red trend corresponds to correct answers ($F \propto a$ and $a \propto a$), and the blue one to incorrect ($F \propto v$ and $a \propto v$). This leads to identifying the persistence of a featured student's knowledge, contrasting between a group with a clear meaning of force and motion conceptual description and one without (and this was exactly our goal).

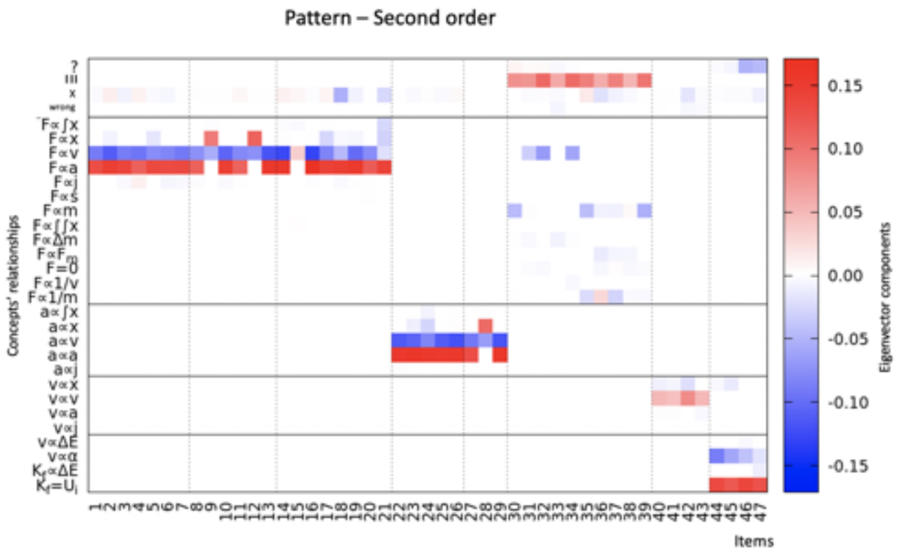


Figure 27: The second neuron shows the second principal component.

In the third and successive neurons, the components are built with decreasing dispersion (and even less structural information about inter-items correlation), as it can be shown in Fig. 28 and 29. In the third neuron, we could identify a direction in response distribution: students who gave wrong answers in the fourth and fifth blocks ($a \propto v$) were correct in the sixth one (III principle).

The higher order tries to include all the responses in the pattern without giving evidence of sample distribution or data-set grouping but only spread-

Figure 28: The third neuron with even recognisable structure.

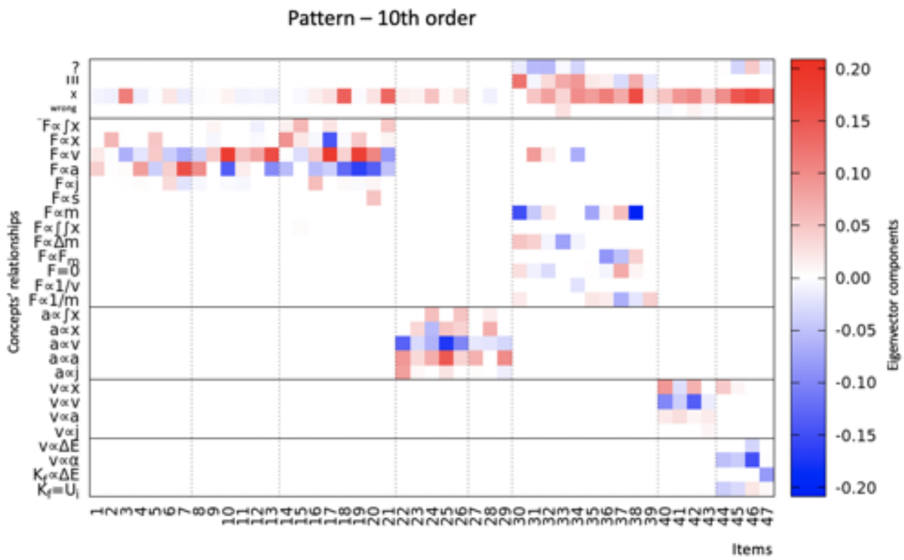


Figure 29: Higher neuron mainly described statistical noise (this is the 10^{th} order).

ing the statistical noise.

2.1.2.3 Findings

Artificial Neural Network analysis supplied a deeper insight into data-set statistical correlation. The second and the third neuron underpinned the conceptual distribution of responses. The statistical components individuated had a confirmatory value of the two trends that characterised students from our sample. First, most of them begin their College studies in Physics and Engineering, still knowing force and motion concepts intuitively or naïvely. Second, only a small group of students, mainly belonging to the Physics freshmen group, exhibit a strong conceptual understanding of force/motion phenomena. This Neural Network Analysis probes how different groupings of students follow the answers identified. Fig. 30 precisely provides the sub-clustering for the second order.

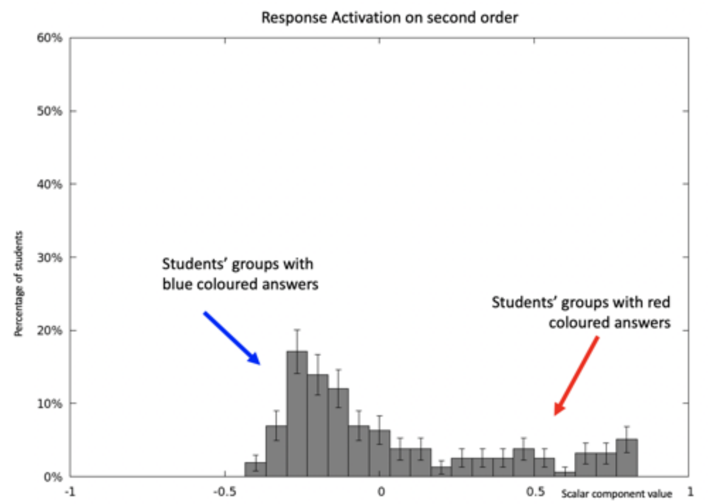


Figure 30: Second order response activation and corresponding students' clusters.

We confirmed what the descriptive analysis pointed out by plotting response activation by subset sample categories. By gender category, we underscored the difference between males and females (Fig. 31). We could suspect this trend by Fig. 17, but this analysis was a worst depiction than it could be hypothesised.

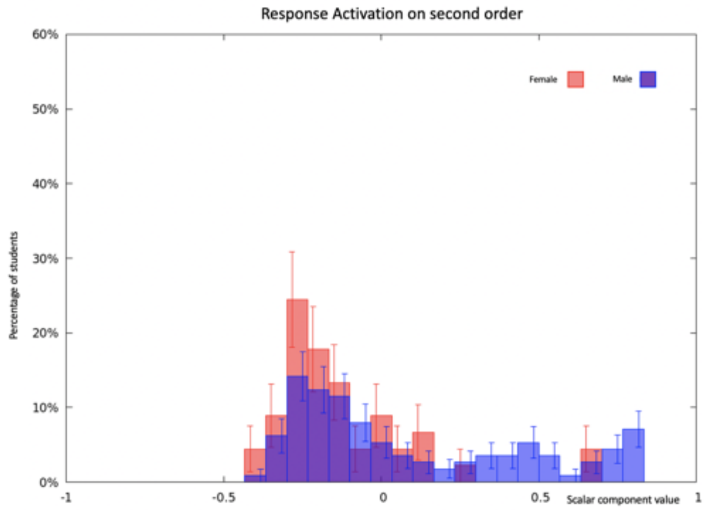


Figure 31: Response activation by gender.

By past curriculum, the differences between subcategories are a little more blending (Fig. 18). A long-exposure to physics curricular studies leads to a better conceptual understanding, as we would expect. An unexpected finding is a negative trend in students with a three-year past curriculum. Even if they experienced Physics studies at a heightened performance of cognitive development (mostly between 17-19 years old), they would suffer the lack of conceptual change in force/motion description (Fig. 32). The difficulties are steady in students with only early two-year exposition to Physics studies.

Finally, by present curriculum choice, we confirmed the differences between students' group affiliations (Fig.19). Students from the Civil, Environment, Electronic and Informatics Engineering group present more conceptual difficulties than the others. Physics freshmen consistently contribute to response activation in the correct area. Industrial and Naval future engineers

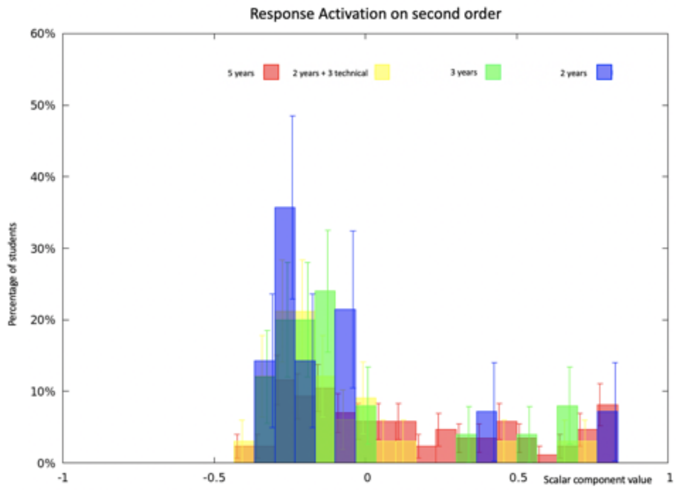


Figure 32: Response activation by past curriculum.

are spread between the two distributions (Fig. 33). The students' conceptual

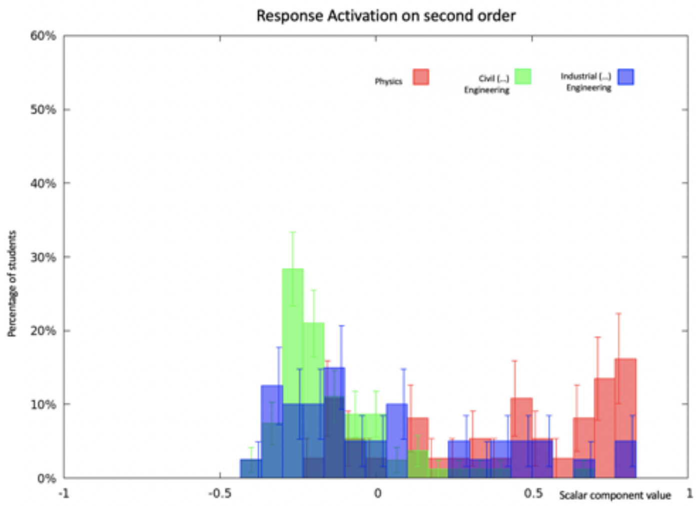


Figure 33: Response activation by present curriculum.

knowledge appears weak and strongly affected by prior primitives (diSessa, 1993). The Artificial Neural Network analysis validated what was depicted by descriptive statistical analysis. This gave us a noteworthy method to investigate the features of students' conceptual knowledge. Nevertheless, for more robust statistical inference, we will need to observe a greater sample.

2.1.2.4 Brief Discussion

The conceptual difficulties in force and motion are well known and well described by PER researchers (for instance, in Bao and Redish, 2006; Brookes and Etkina, 2009; diSessa et al., 2004). We would underline here the link between what we observed at the beginning of College studies and what happened in the learning process during secondary schooling. Deeper and more meaningful learning in secondary instruction allows students to obtain high-score, whereas shallow learning leads to low-score.

The investigated sample is not representative of all secondary students. It represents a very restricted category of students who were successful in Physics, Maths and Technical disciplines studies. These students are the ones who like these kinds of studying, presumably having gained high marks and satisfaction. We could infer their dispositions to scientific studies based on their college choice. So, we could also think they are well motivated to follow their desire to become physicists or engineers.

Even under these positive pre-conditions, administering FMCE inventory, we realised that something went wrong during the Physics learning process in secondary school. And if it went wrong for motivated students, it is a straightforward presumption to think that weaker students would have the same difficulty.

For the investigated sample, we noticed a possible absence of a coherent conceptual building during secondary schooling, strictly referring to force and motion topics. But these topics are indeed present in all the curricula named for Italian high schools (Table 13). And so, we could establish that this incoherence impacts the Physics learning process in secondary education.

Furthermore, the analysis stressed two subgroups of students most affected by this incoherence:

- the female students;
- the students with a short exposure to Physics secondary education (mainly 2-year or 3-year curriculum).

We must consider this evidence to describe an *Early Physics* approach.

In this brief discussion, we would remark on the following considerations which emerge from the FMCE response analysis. It could be interesting to investigate the relationship between student lack of conceptual coherence and the Italian curriculum design. In particular, in scientific high school, the curriculum design foresees a fragmentation in the conceptual building of force and motion, presenting topics in the sequence: Statics, Kinematics, and Dynamics (MIUR, 2010, p.26-27). The definition of the Force concept is presented before the definition of acceleration. And even there are many other examples of conceptual fragmenting (i.e. to describe circular motion).

This curricular organisation is supported by the idea that students lack mathematical tools to address the topics. In this curricular choice, it is clear that conceptual building has to pass through mathematization. This limitation could affect and restrain teaching practices, defining teachers' conceptions.

2.1.3 Students' Skill for Reasoning

Argument and argumentative practice is a core activity for scientists (a core epistemic practice - Bricker and Bell, 2008) and has to be included in science education (Driver et al., 2000; Kuhn and Crowell, 2011). For this reason, the development of argumentative reasoning skills is stated as a goal of science learning in the 21st century (Kuhn and Crowell, 2011; J. Osborne et al., 2004).

The skill of reasoning is also to be considered as a part of critical thinking skills or as constituting itself the domain of the development of critical thinking (Kuhn, 1991; Tippett, 2009). It could be identified and assessed precisely (Kuhn and Crowell, 2011), becoming a practice to nurture in classroom activities, even for its supporting in conceptual growth and conceptual change (Kuhn and Crowell, 2011; Mercer et al., 2004; Tippett, 2009). In classroom activities, it involves many aspects:

- classroom formative assessment (R. Dufresne and Gerace, 2004);
- classroom discourses (Cazden, 2001; Lemke, 1990) and dialogic interactions (Aguiar, 2016; Kuhn and Crowell, 2011).

Classroom formative assessment is commonly defined in teaching practices as using problem-solving exercises where students can test their reasoning skills (Kuhn and Udell, 2003). Whereas, the feature of classroom discourses, largely affected by the teacher-centred talks (Cazden, 2001; Lemke, 1990), could evolve to become a learning environment where students can learn to argue (J. Osborne et al., 2013).

Development dialogic interactions could not be considered a common teaching practice, basically for the lack of teachers' pedagogical skills in organising discourses (Driver et al., 2000).

Another distinguishable aspect in classroom discourses (comprehensive of all written and oral speech) is the interchangeable teachers' usage of the verb *Explaining* and the verb *Arguing*. There is a distinction between argumentation and other forms of discourse, such as explanation, elaboration, and clarification, and the distinction rests on the notion of standpoint (Bricker and Bell, 2008). However, the argumentative properties of explanation and the prominence of argumentation in many explanations could justify this mutual use in classroom discourses (Bricker and Bell, 2008) and formative assessment. Next, we will refer to teachers' requests for explanations as requests for argumentation and vice-versa, based on common lexical teaching (strictly referring to the Italian context). We will also refer to "explanation" as how students formulate their reasoning.

2.1.3.1 Italian Students' Overview

To get a picture of the reasoning skills of Italian students, we analysed three different facets of classroom activities. Firstly, we described skill development in the context of problem-solving. Secondly, we analysed the responses in classroom activities where there was mandatory to "explain why or how you reasoned". Finally, we analysed an audio-recorded lesson to feature students' discourses looking for their participation by counting the frame duration of their speeches and how many words they used. All of them could be considered as a single case study by which we could also identify features without any generalisation and research purpose, but only to highlight a standpoint or a starting point for following deep insight.

- **Analysis of problem-solving students' sheets**

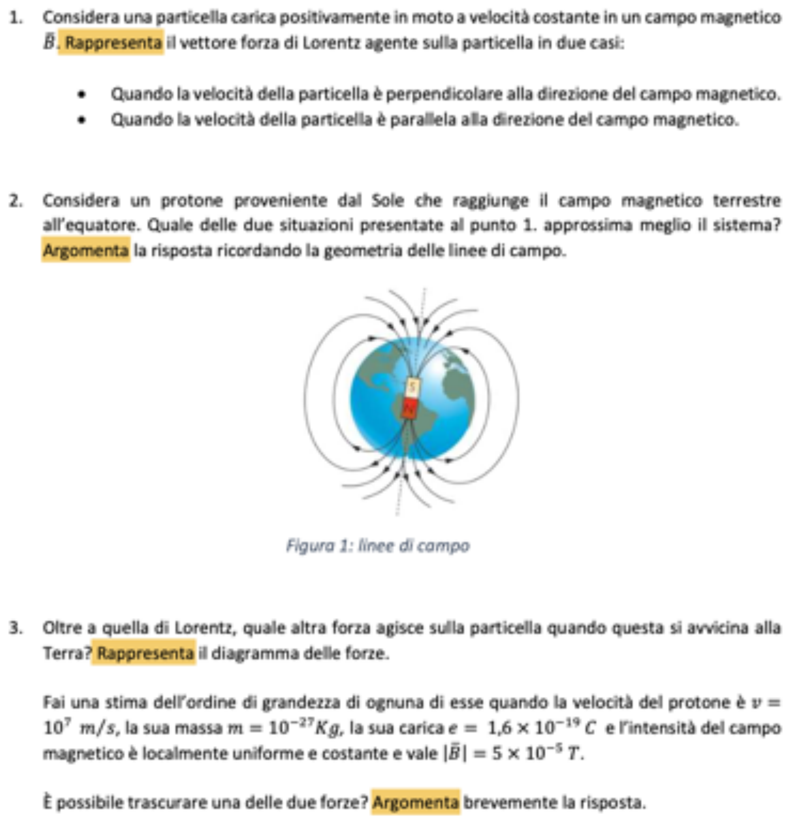
During the school year 2021-2022, we engaged two final classes of scientific secondary school (that means students eighteen years old, attending the fifth year of secondary high school instruction) in resolving two exercises administrated as problem-solving for consolidating knowledge about Lorentz's Force and Induction[7].

In agreement with the teachers, we did not assess students' conceptual knowledge of this topic. We focused on the disciplinary languages adopted to resolve a problem-solving task. To better recognise the reasoning skill, we set up students in working groups to foster discussion, which could activate discourses (J. Osborne et al., 2013).

The exercises in which students engaged were quite different from the ones at the end of the textbook chapter. We built them by trying to emphasise the role of requesting the use of sketching the situation and drawing a force diagram before using a mathematical representation (Fig. 34). Finally, we requested to explain what they obtained in their own words (we refer to it as described in *natural* language, which means *normally* or *naturally* spoken native language).

The deep insight into student groups' answers was accomplished by assigning a score point scale (Table 16) based on accuracy and correctness. The sample consisted of 6 groups of students for each class (about 40 students),

[7]The analysis has been conducted by the student Davide Gabrici as a part of his apprenticeship's activities in Physics Education for the Bachelor Degree with our supervision, in convention with Liceo Scientifico Guglielmo Oberdan (Trieste).



1. Considera una particella carica positivamente in moto a velocità costante in un campo magnetico $\bar{B}$. Rappresenta il vettore forza di Lorentz agente sulla particella in due casi:

   - Quando la velocità della particella è perpendicolare alla direzione del campo magnetico.
   - Quando la velocità della particella è parallela alla direzione del campo magnetico.

2. Considera un protone proveniente dal Sole che raggiunge il campo magnetico terrestre all'equatore. Quale delle due situazioni presentate al punto 1. approssima meglio il sistema? Argomenta la risposta ricordando la geometria delle linee di campo.

   Figura 1: linee di campo

3. Oltre a quella di Lorentz, quale altra forza agisce sulla particella quando questa si avvicina alla Terra? Rappresenta il diagramma delle forze.

   Fai una stima dell'ordine di grandezza di ognuna di esse quando la velocità del protone è $v = 10^7\ m/s$, la sua massa $m = 10^{-27} Kg$, la sua carica $e = 1{,}6 \times 10^{-19}\ C$ e l'intensità del campo magnetico è localmente uniforme e costante e vale $|\bar{B}| = 5 \times 10^{-5}\ T$.

   È possibile trascurare una delle due forze? Argomenta brevemente la risposta.

Figure 34: An extract of the exercises prepared for monitoring reasoning skills. The text is in the original language, but highlighted verbs are used for the requests: *Represent* and *Argue*.

Table 16: Accuracy/Correctness score value for responses' analysis.

Accuracy Score	**Value**
Correct use of representation or description or explanation	3
Partial correct use of representation or description or explanation	2
Not correct use of representation or description or explanation	1
No use or absence of representation, description or explanation	0

one with a Traditional Scientific curriculum and the other with an Applied Science curriculum. We plotted here the response analysis by each class and for the whole sample (Fig. 35).

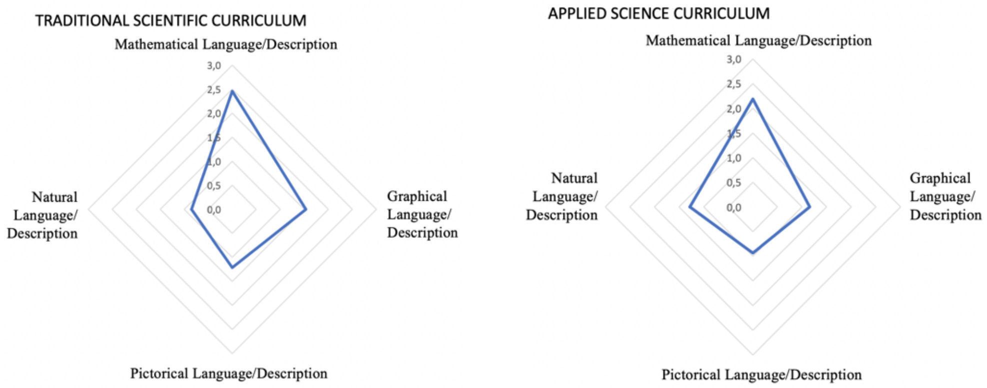


Figure 35: Comparison between answers' mean distribution score of the two classes focusing on each language/description.

After five years of Physics studies, these students disclosed their correct answers in applying formulas at the end of secondary instructions. The disciplinary language they are reinforced to use is the Mathematical one. The others are less defined or seem useless for describing a physical situation or problem-solving.

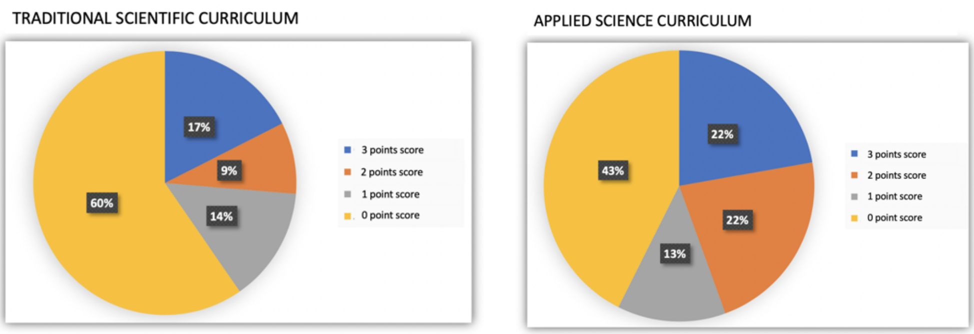


Figure 36: Comparison between natural language answers' mean distribution score value percentage of the two classes.

We could notice that the students were unaware of the use of natural language to account for the reason for what they describe in other representations (Fig. 36). The teachers stressed the same by reviewing the report analysis. They essentially agreed to underline the clear students' preference to resolve a problem by mathematical representation. Even in formative assessments, they noticed the lack of multiple representations usage and the difficulty reasoning by natural language.

The exercises administered were designed to highlight how students adopt all disciplinary languages in problem-solving. This analysis underscored students retaining a prevalent choice between disciplinary languages/descriptions.

In a deep reading into groups' sheets responses, we could also recognise a lack of coherence between the representations, as in the example selected (Fig. 37).

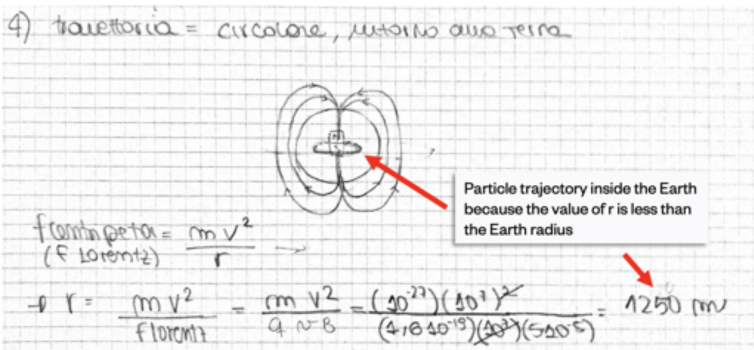


Figure 37: Example of conceptual incoherence between using different representations.

This specific case is an example of lack of reasoning switching between representations. There is no consistency between the mathematical result and the sketch, which had to depict the physical situation.

Teachers identified this inconsistency between representations as a distinctive aspect of students' exercise resolution, specifically evidencing their focus on the procedural mathematical application of formulas devoid of any physical meaning of their use. Students find a numerical value of what is requested, but this does not correspond to an in-depth understanding of what this value represents physically.

The teachers recalled this aspect in students' problem-solving process even in less structured exercises with fewer detailed requests for representations and explanations. By their teaching experience, what they recognised in the above analysis could be extended over all the secondary schooling years.

- **Analysis of students' responses in classroom activities**

The second insight is given by investigating students' written responses during classroom activities. The activities were thought and specifically designed to engage the students in reasoning activities.

During the pandemic restrictions, distance learning schooling allowed a wide use of different platforms to engage students in an active learning process (Bologna, 2021; Hoodge et al., 2020). By working face-to-face with teachers in different schools, we developed many online activities using the Desmos platform (Bologna et al., 2021; Bologna and Leban, 2022; Bologna, Leban, et al., 2022; DESMOS, 2022) and its activity builder (Fig. 38). The activity is built by a sequence of screens (eventually forced to be navigated by a given order), and each screen offers one or more interactive actions ("*Sketch, Graph, Multiple Choice, Free Response, Maths Response, Ordered List, Card Sort, Table...*" and many others).

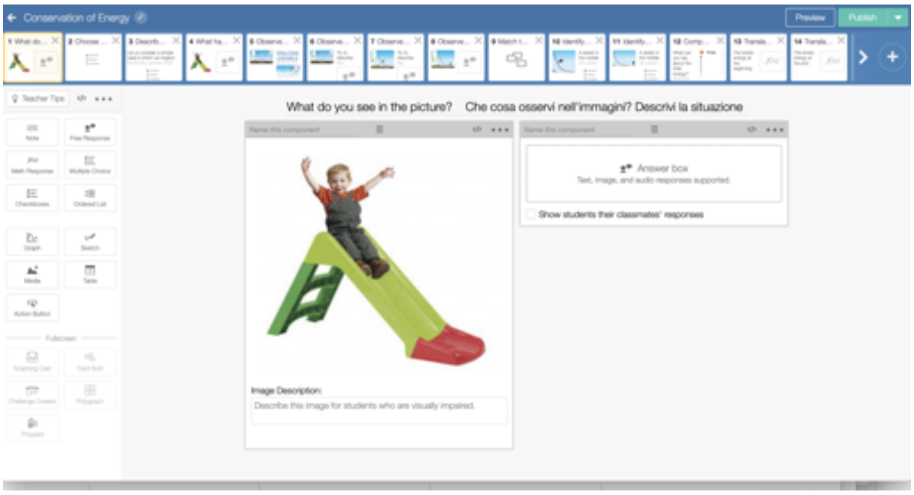


Figure 38: Desmos teacher's activity builder.

This platform allows synchronous and asynchronous interactivity between students and teachers. The teacher has a back-end dashboard (Fig. 39) tracking all the activities students perform on the front-end side (Fig. 40), collecting their answers, their sketches and whatever is allowed by the utilities (calculations, graphs, etc.).

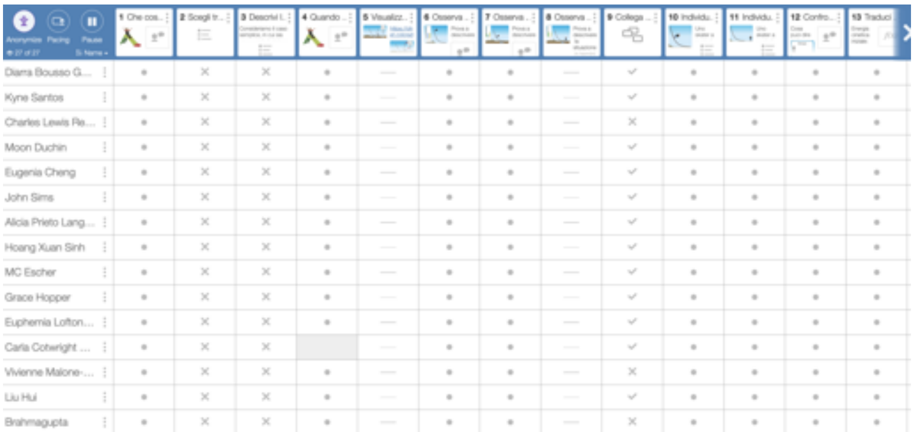


Figure 39: Desmos teacher's back-end dashboard.

In the synchronous mode, the teacher could follow step-by-step all the students, encouraging them to review their answers and preventing their

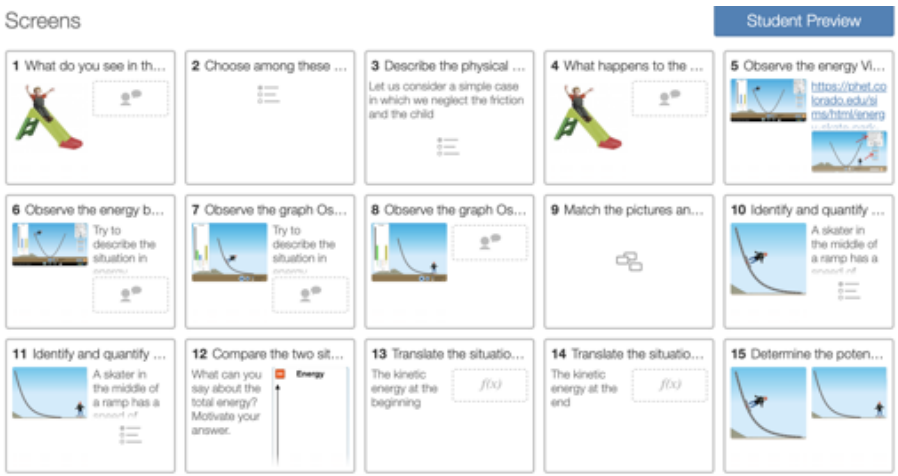


Figure 40: Desmos students' front-end.

difficulties in developing new content knowledge (Fig. 41).

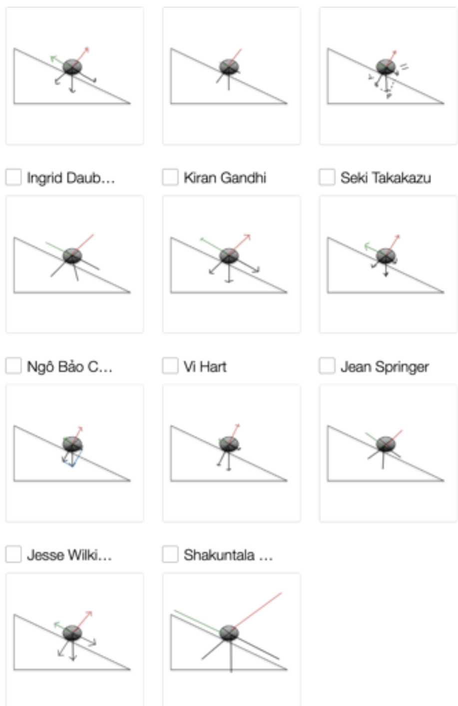


Figure 41: Example of Desmos students' responses about the force diagram representation of a ball moving down? an inclined plane (the students' names are anonymised).

Without going into detail about all the activities designed and performed during the online lessons, here we summarised the analysis of students' responses when the activity in the screens asks "*Explain your answer*" or "*Explain your thinking*" (Table 17). This analysis was conducted with teachers, and it first targeted the task of giving them a way to notice students' difficulties in reasoning.

Table 17: List of Desmos activities designed and performed during distance learning schooling (school years 2019/20 and 20/21).

Grade/School	# Students	**Contents topic**	**# screens with explain requests**	**Total screens**
Grade 10/LS[a]	25	Incline Plane	10	24
Grade 10/LS[a]	25	Kinematics - one dimension	15	34
Grade 11/LC[c] (Slo)[e]	8	Kinematics - one dimension	17	35
Grade 11/LL[b]	16	Kinematics - one dimension	16	32
Grade 11/LC[c]	20	Kinematics - one dimension	16	32
Grade 11/LC[c] (Slo)[e]	7	Circular motion	35	43
Grade 11/LSU[d] (Slo)[e]	16	Circular motion	35	43
Grade 11/LS[a]	23	Circular motion	11	23
Grade 12/LL[b]	38	Work and Energy	43	71

[a] LS: Liceo Scientifico - High School for Scientific Studies.
[b] LL: Liceo Linguistico - High School for Linguistic Studies.
[c] LC: Liceo Classico - High School for Classical Studies.
[d] LSU: Liceo Scienze Umane - High School for Humanities Sciences.
[e] (Slo): Slovenian spoken language.

Desmos platform allows following all the students synchronously while they perform the activity. It was an unusual teaching practice out of formative assessment practices to document the reasoning process of all classroom students (if the teacher requested this). Students also were engaged in something new with respect to their usual learning practices. Frequently asking "*Reason and Explain*" was uncommon in classroom discourses and written works and tasks (resolving exercises on the blackboard or their notebooks).

Here we choose to report only on a brief qualitative analysis of the responses collected and grouped based on a possible categorisation[8]. We defined the categorisation by using three parameters: one is the argumentation itself, the second is the sentence building, and the third is the correctness (Table 18). These three parameters are strictly related to the number of words used by students in the written sentences. These parameters allow us to identify how well the argumentation is built and give information about its soundness.

Table 18: Parameters for categorising students' argumentation responses.

Parameter	**Score Range**
Argumentation	No argument - Many arguments
Sentence Building	No sentence (few words) - Elaborated sentence
Correctness	No answer - Correct and complete answer

The most relevant remarks we collected by the analysis were the following:

- students minimise the number of words to use in argumentation tasks (incomplete sentences or lacking verbs or conclusions);
- students employ the formula for justifying their answer ("*it works so*

[8]We made a more detailed analysis in two Bachelor Thesis in Physics: "Experimentation of an educational pathway between Mathematics and Physics for environmental radioactivity measurements" - Fabrizio Diaz Guerra (March 2022) and "Development of teaching activities on kinematics aimed at studying the difficulties encountered by students and the argumentation skills related to the use of multiple representations" - Vasco Secomandi (October 2022); the thesis are in Italian.

because the formula is ..."); this also occurs as:

- students do not use words but the formula itself (as it contains all the information as an argument)
- students avoid connecting different representations for reasoning;
- students do not distinguish between description and argumentation;
- students do not activate a progression in argumentation through the content-building progression in the Desmos activity.

Even if many difficulties arose from the responses, students relished being interrogated about their reasoning. This disposition was shared by skilled and good students and less good ones. Therefore, we acknowledged that students wanted to provide argumentation but lacked the necessary skills.

- **Analysis of an audio-recorded lesson**

Finally, we report an example of the analysis of an audio-recorded lesson. We would remark it as representative among many others. We chose this one because it stresses some features in Physics classroom discourses (already observed and reported in the literature - Cazden, 2001; Doran, 2018; Kuhn and Crowell, 2011; Lemke, 1990; J. Osborne et al., 2013). This analysis regards students' discourses. In this section, we would emphasise students' point of view, while in section 2.2, we will refer to it to analyse the teacher's one.

We started our analysis by dividing the entire discourse into frames. Each frame is defined by one speaker. The frame changes when the speaker does. Then, we identified and coloured each frame, distinguishing between the teacher and students. The same colour means the same speaker (Fig. 42, 43). Lastly, we determined the frame time duration, that is, how long each frame speech was (Table 19).

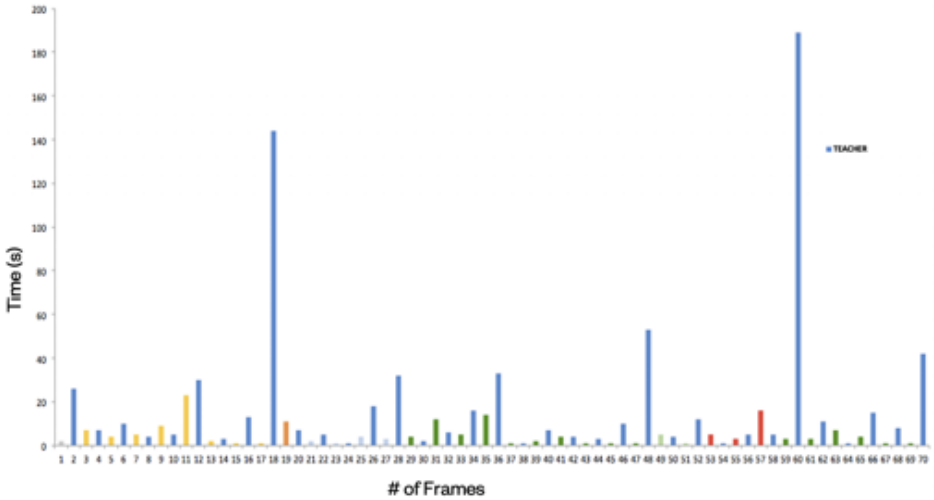


Figure 42: Time frames evolution for the first part lesson (in blue is the teachers' speech, the other colours are students' ones).

Table 19: Lesson timing and duration frames: an example.

Lesson Timing	**# Frames**	**Discourse time duration**	**% Speech**	**% Teacher's Speech**	**% Students' Speech**
First part	70 (1-70)	900s	48%	81%	19%
Second part	54 (71 - 124)	961s	52%	93%	7%

The teacher's speech overrides all the other speeches. Students never build a dialogic discourse between peers but only give answers to the teacher's questions. This kind of discourse resembles the most common pattern of classroom discourse at all grade levels, the IRE model (Initiate - Response - Evaluate; Cazden, 2001; Lemke, 1990). But this pattern also reduces students' argumentation activation process (Kuhn and Udell, 2003; J. Osborne et al., 2013).

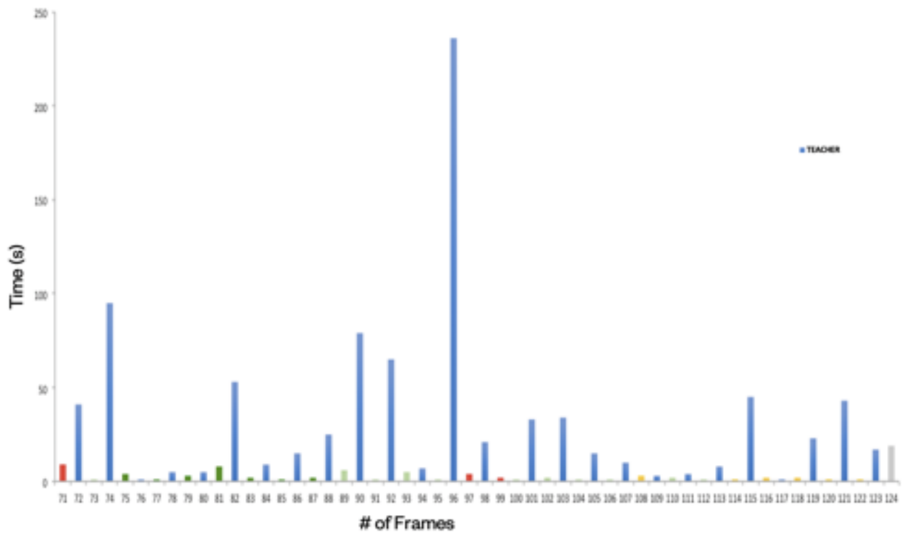


Figure 43: Time frames evolution for the second part lesson (in blue the teachers' speech, the other colours are students' ones).

More interestingly, if we look only at the students' speeches report timing frames, we notice that during the lessons, only a few students (more or less two or three among 24 students at all) take part in the classroom discourse (Fig. 44).

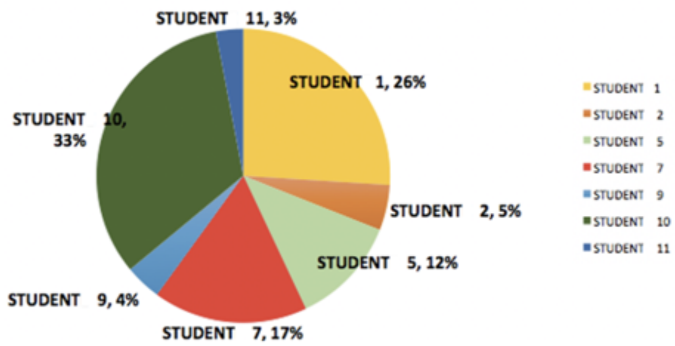


Figure 44: Percentage of students' speeches during the lesson (students are enumerated in order of intervention; the missing numbered students correspond to those without any answer if asked by the teacher).

Furthermore, if we deeply look at the teacher's questions, which activate students' speeches, we can notice that they are firmly evoking a direct-unique response, disabling students from exploring reasoning but encouraging them to guess the correct one.

In this way, the student will answer only if they think they have a correct response. They do not try or check any other possibilities in a context which persists in one direction of question-answer. Even the number of words used by students confirms their search for the right answer without any explanation (Table 20).

Table 20: Students' words distribution by frames.

Student	**# Frames**	**# Words**	**Mean frame duration (s)**	**Mean words value for frame**
Student 1	14	75	4	**5**
Student 2	1	13	11	**13**
Student 5	13	51	2	**4**
Student 7	6	89	7	**15**
Student 9	4	10	3	**3**
Student 10	22	78	4	**7**
Student 11	1	15	7	**15**

In fact, if the student-to-teacher dialogue is based on an 8-9 mean value of words, it means students' speech is very poor, and the sentences are very short (just defined only by one subject and verb, at least).

2.1.3.2 Brief discussion

The three analyses provided an overview of students' skills for reasoning. Starting from problem-solving towards classroom discourse insight, we could notice there are many difficulties. Many of them reside in how the students engage in classroom activities: the activation of a process of reasoning is commonly lacking in written and oral classroom practices. We cannot expect students could develop these skills on their own. We need to describe an approach which activates students' reasoning skills for two main purposes. Firstly, we hold to ensure the goal of science learning in the 21^{st} Century (J. Osborne et al., 2004). Secondly, reasoning skills are an essential component of the cognitive process (in terms of cognition, metacognition, and epistemic cognition; Kitchner, 1983) in which we need to engage our students to ensure meaningful Physics learning. In this defined framework, reasoning scaffolding has to become a recognisable teacher's task (Wang and Buck, 2016).

2.1.4 Research Question raised from the overview of students' conceptions

The overview of students' conceptions led us to formulate our first research question:

> *How to choose a teaching/learning approach to address students' attitudes and conceptual coherence and help teachers meet the challenges of the 21^{st} Century education?* (RQ1)

2.2 Overview of Teachers' Conceptions

There are many variables affecting Physics teachers' thinking and acting (Fischler, 1994) that set the backstage of teaching:

- conceptions of the nature of Physics science;
- conceptions of the goals and the purpose of Physics teaching;
- conceptions of learning and teaching Physics.

Each of them is interconnected to the teacher's subjective experience (pedagogical and scientific education), professional development, and age (Freire and de Fátima Chorão C. Sanches, 1992); they behave as the teacher's footprint. Science teaching conceptions could be labelled as traditional, experimental, constructivist, pragmatic, and social(Freire and de Fátima Chorão C. Sanches, 1992). A specific conception is shaped by teachers' knowledge and how it is heuristically built in the process of becoming and being a teacher.

2.2.1 Physics Teachers' PCK

The tripartite structure of teachers' knowledge has three anchoring points (Zeidler, 2002): Subject Matter Knowledge (SMK), Pedagogical Knowledge (PK), and Pedagogical Content Knowledge (PCK). These three knowledge domains are separated but strictly interconnected (L. S. Shulman, 1986; Zeidler, 2002). SMK, PK, and PCK stand at the forefront of what is essential to effective science teaching, and they could be represented in Fig. 45 (Etkina, 2005). This model portrays how Physics teachers extend special understand-

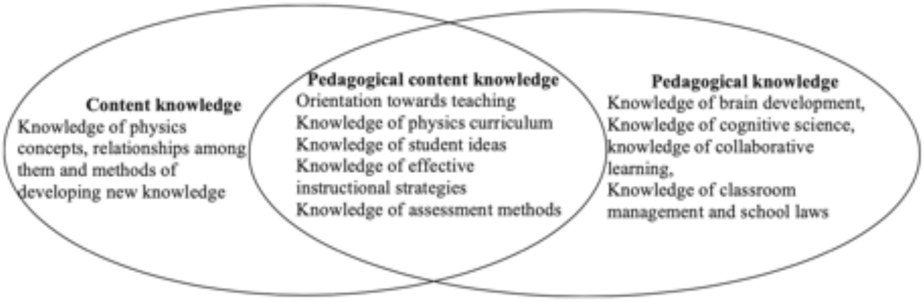


Figure 45: The structure of Physics Teacher's Knowledge (Etkina, 2005).

ings and abilities that integrate their Physics content knowledge and student Physics learning (Etkina, 2010).

More specifically, SMK refers to knowledge of Physics concepts, relationships among them, and to a teacher's quantity, quality, and organisation of information, conceptualisations and underlying constructs (Fazio, 2010).

PK concerns knowledge of cognitive processes, classroom management, communication strategy and specific methodology (such as the use of Information Communications Technology - ICT).

PCK represents a teacher's ability to convey the relevant constructs of the content knowledge in a manner that makes it understandable through the process of teaching(Etkina, 2010; Fazio, 2010; Zeidler, 2002). It is just the knowledge of the subject matter for teaching, citing properly Lee Shulman, who explained it very well in the framework of understanding teachers' knowledge (L. S. Shulman, 1986):

> *The special amalgam of content and pedagogy that is uniquely the providence of teachers, their special form of professional understanding (p.8)[...]*
>
> *The most regularly taught topics in one's subject area, the most*

> *useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations...including an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning (p.9).*

Specifically tailored to the content topic domain, the Science teachers' PCK has been conceptualised through the model used for teaching science (Magnusson et al., 1999). This model consists of five main components:

1. orientations toward Science teaching;
2. knowledge and beliefs about Science curriculum;
3. knowledge and beliefs about students' understanding of specific Science topics;
4. knowledge and beliefs about assessment in Science;
5. knowledge and beliefs about instructional strategies for teaching Sciences.

What is particularly mainstream is the connection between different components. The orientations towards science teaching work as shaping a conceptual map to create the mutual link between all the other components (Magnusson et al., 1999). The knowledge involved by each component is described in Table 21 (Fazio, 2010). The PCK is highly domain-specific, so it is necessary to individuate and address the domain of Physics specifically (Etkina, 2010). Teachers acquire their PCK through the process of teaching. Their backgrounds and experiences give an appreciable footprint to their class activities. For this reason, we could refer to PCK as a heuristic de-

Table 21: PCK components description (Fazio, 2010; Magnusson et al., 1999).

#	Aspect of PCK	Related Knowledge
1	Orientations toward Science teaching	Knowledge about the goals and general aims of teaching science in a particular grade
2	Knowledge of curricula	Knowledge of goals and objectives of teaching
		knowledge of specific curricular programs
3	Knowledge of students' prior understandings about any difficulties with key concepts and practices in science	Knowledge of requirements for learning specific concepts
		Knowledge of areas of student difficulty
4	Knowledge of what to assess and specific strategies to assess students' understandings of key concepts and practices	Knowledge of the dimension of science learning that is important to assess
		Knowledge of methods of assessment
5	Knowledge of instructional strategies to scaffold students' learning of key concepts and practices in science	Knowledge of subject-specific strategies
		Knowledge of topic-specific strategies

vice (Childs and McNicholl, 2014), where teachers' footprint is substantially depicted by their PCK and the process they build it on.

2.2.2 PCK for Phys/Math Interplay

We tried to look into a particular feature of Physics teachers' PCK that is the one used for defining Phys/Math interplay patterns. We thought this could target bettering the overview of teachers' conceptions (Bologna, Longo, Peressi, et al., 2022a). This choice is based on two main reasons:

- firstly, the crucial role of Phys/Math interplay in Physics Education (Pospiech et al., 2019);

- secondly, the prevalence of Italian Physics teachers with a mathematical background[9].

In Physics Education Research, the interplay between Maths and Physics is described by different patterns (Lehavi et al., 2015, 2017; Pospiech et al., 2019).

Teachers employ Phys/Math interplay as part of their practice. They foster a better understanding of Physics by analysing extreme cases and examining functional relations between physical quantities and the laws they describe (Pospiech et al., 2019). Teachers also commonly create grids of concepts, exploring and sometimes forcing similarities between phenomena referred to as different physical situations.

In other cases, the interplay is emphasised in the problem-solving process or in exercises of multiple representations of the physical situation. The main feature of the teachers' PCK of the Phys/Math interplay directly descends from the PCK model for Science (Magnusson et al., 1999), from the need to specify it to Physics teaching (Etkina, 2010) and from the development on focused patterns which follow different "steps" between physics and mathematics and within each domain (Lehavi et al., 2017).

Delineating a PCK for Phys/Math interplay means translating the main goals of Science PCK into the straight-forwards insight on the relation between two domains of knowledge: on one side, Mathematical, and on the other, Physics knowledge. With this lens, the five aspects of PCK address the following targets (Fig. 46).

[9] Italian system of instruction allows teaching Maths and Physics in secondary schools to those who have a master's degree in Maths, or Physics, or Engineering, with a prevalence of those with a Maths degree Magliarditi et al., 2020.

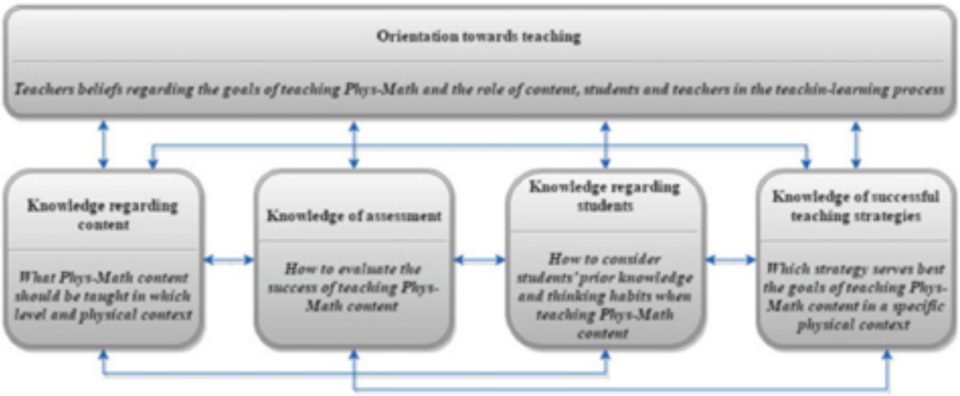


Figure 46: Aspetcs of PCK for Phys/Math interplay (by courtesy of Y. Lehavi -Lehavi et al., 2017).

Observing teachers' practices and classroom activities and covering different content areas of the physics curriculum, there have been identified four types of Phys/Math interplay patterns (Table 22).

Table 22: Phys/Math patterns' definition (by courtesy of Y. Lehavi - Lehavi et al., 2017).

Pattern	Teaching goal	Teaching practices
A. Exploration	To demonstrate how Phys/Math is used to explore the behaviour of physical systems	Exploring within Math ramifications for the physical system: limits (of validity, of approximation), extreme cases, etc.
B. Construction	To demonstrate how Phys/Math is used in constructing a model for physical systems	Constructing and developing (from experiments or first principles) mathematical tools to describe and analyze physical phenomena
C. Broadening	To demonstrate how Phys/Math can be used in broadening the scope of a physical context	Adopting a bird's-eye view, and employing general laws of physics, symmetries, similarities and analogies
D. Application	To demonstrate how Phys/Math provides aid in problem-solving	Employing already known laws and mathematical representations in problem-solving

To have a deep insight into Italian teachers' conceptions, we intentionally monitored their PCK, focusing on individuating the prevalent Phys/Math interplay patterns.

2.2.3 Monitoring Teachers' PCK

All the teachers we monitored were involved in classes where the students were in their first year of curricular physics studies: this is an important point in our investigation because it could be relevant to whether difficulties in learning and studying physics arise from a particular teacher's PCK at this specific educational step, immediately following previous studies characterized by a basic knowledge of mathematics. To compare the patterns between the first and the last year of the curriculum studies, we collected data from some classes involved in testing educational experience.

2.2.3.1 Monitoring Method

To perform a deep examination of teachers' PCK, the method of our investigation followed a well-defined sequence of implementation. We suggest that this sequence collects, in a more detailed way, the information we need to analyse the correlation between the different PCK aspects and the role of the Phys/Math interplay in each one. This sequence consists of three parts (Table 23).

First of all, we collected information **before** the observations of the lesson activity. The information was about the teacher's beliefs, methodologies, and Physics insights and then about class and students' skills, attitudes, and everything concerning learning strategies, emerging and recurrent difficulties, and assessments. Then, as a second step, we gathered information **during** the observations of lesson activities, from explanations to evaluation time. In the end, we got the information **after** the observations of lesson activities from the teachers' point of view to the students' self-reflection about their performance and learning. All these actions gave us a complete and exhaustive way to investigate teachers' PCK.

Table 23: Phys/Math patterns' definition (by courtesy of Y. Lehavi - Lehavi et al., 2017).

Time	Action
BEFORE	Teachers' monitoring in their lessons planning
	Teachers' interviewing to collect information about students and class educational trends
DURING	Observations during class activities in presence and online (in the first COVID lockdown period) for the extension of a learning module or a testing case study
	In some cases, preparing evaluation tests together with teachers at the end of the learning module, with particular attention to the integration of Maths and Physics languages
AFTER	Feedback discussions with teachers on monitoring activities.
	Test revisions and corrections trying to identify the most frequent mistakes and to classify them in terms of mastery and knowledge of Physics languages.
	Collecting students' interviews about their difficulties in that learning module and final evaluation test.

2.2.3.2 Monitored sample

We monitored teachers in their classes, and we referred to them as the monitored sample, including together teachers and students. All the classes were in the first year of Physics studies. Anyhow, there was an age difference among students. In fact, in Italian secondary instruction, some students start studying curricular Physics at 14 years of age, and others start later (at 16). Of course, this is relevant for PCK definition and features because of the cognitive development stage in abstraction functions and meta-cognitive processes. It could also be relevant in terms of content-building processes for obtaining successful learning.

The sample consists of thirteen classes: five from a scientific high secondary school (Liceo Scientifico), three from a technical institute (Istituto Tecnico Commerciale e Turistico) and three from a high school devoted to humanities (Liceo Classico e Linguistico) in Trieste (Italy)[10]

For a more extensive observation, we considered the sample of two classes of the last year of the curricular studies (students 18-19 years old) from a scientific high secondary school (Liceo Scientifico).

2.2.3.3 Data-collection

We observed teachers in classroom activities for about 153 hours (Table 24, and Fig. 47). We spotlighted in the table the hours of the first years of physics studies, referred to as monitoring activity, and those of the last year in the context of the testing of practical case studies. Instead, in Figure 47, we reported the distribution percentage of observations divided into the different high schools involved.

During the monitoring phase, we collected a lot of information about teachers' way of conducting lessons, how much time they spent on contents explanations and what time they spent on mathematical demonstration of physics laws. We focused our attention on their dialogic teaching (Alexander,

[10]The topics of secondary Physics curriculum is reported in Table 13.

Table 24: Hour of direct observation in classroom activities.

	Monitoring		**Testing**	
	In class	On line	Case Studies	
High school for Scientific Studies "Oberdan"	40	0	30	
High school for Scientific Studies "Galilei"	5	11	0	
High school for Ancient and Modern Languages Studies "Petrarca"	22	27	0	
High school for Technical Studies "Da Vinci"	18	0	0	**TOTAL HOURS**
	85	38	30	153

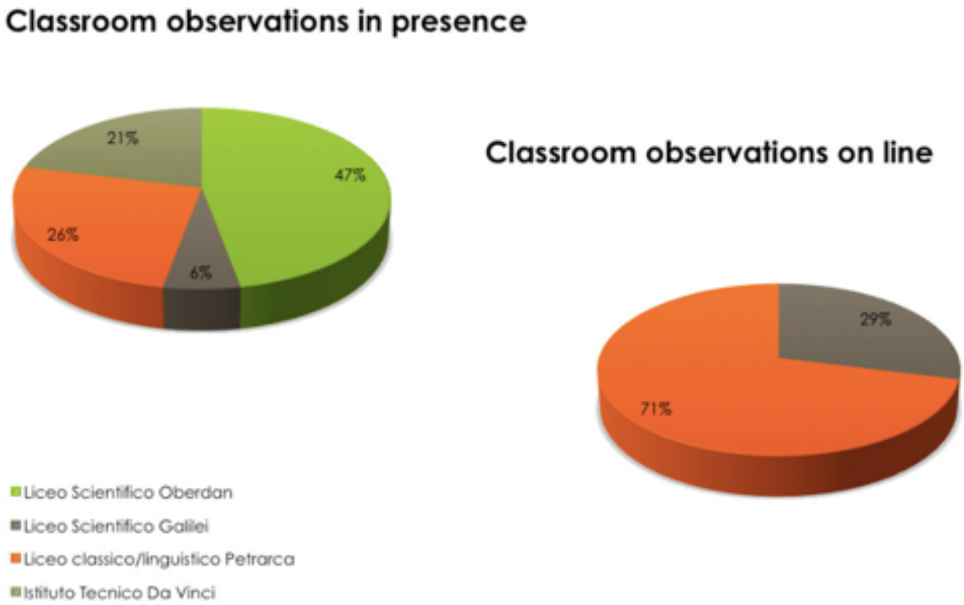


Figure 47: Percentage of involvements of schools in monitoring process.

2018; Lemke, 1990), scaffolding (Levrini et al., 2019) or other kinds of student supports in the learning process.

We then devoted particular attention to the problem-solving strategy adopted by the teachers and the corresponding students' responses in question times and resolving tasks (regarding requested formulas and applied procedures rather than explanations and conceptual inferences asked students).

We tried to notice which kind of interaction between Maths and Phys was drawn by teachers in their activities and if they could be referred to Lehavi's patterns (Lehavi et al., 2017), observing the use of graphs, equations, modelling structures and laws applications in problem-solving situations.

In the meanwhile, we paid particular attention to the time spent in reasoning (Wang and Buck, 2016) as a way of promoting a dialogic learning process (how many times the teachers ask students to discuss phenomenological causes, evidence and explanations, even while solving simple exercises).

2.2.3.4 Observation Analysis and Results

The PCK is the teacher's footprint (Bologna, Longo, Peressi, et al., 2022a). So, according to all the information we collected and the monitoring method we used, we could depict one PCK for each of the teachers that took part in our study.

Remarkably, we observed that even if each teacher has his/her PCK, which is strictly connected to an academic degree and pre-service and in-service training, we found some similarities among them that are not dependent on the specific school where they are teaching.

These similarities are referred to the way of conducting lessons, the weight of Maths demonstrations and the short time reserved for asking students for a deep argumentation of their results (in problem-solving) or an extension of their conceptual understanding.

This finding guided our analysis to catalogue certain numbers of these matching features and to identify them as part of the educational process involved in the first year of physics teaching. Of course, they are not directly dependent on the teacher's footprint.

On the contrary, we could think that physics teaching has some independent features that cause the teacher to create a subject matter-dependent footprint. This means that some of the following results from our analysis of the PCK correspond to a specific domain discipline feature and not to a specific teacher.

The application pattern often adopted by teachers discloses their orientation toward the discipline. More specifically, in our analysis, we distinguished two steps: the first examines similarities according to Magnusson's PCK model (Magnusson et al., 1999) e its declination to Physics (Etkina, 2005, 2010). In the second step, we tried to identify the prevalent pattern used by teachers at the beginning and the end of curricular studies according to Lehavi et al. (Lehavi et al., 2015).

In Table 25, we summarised the common features characterising monitored teachers. All of these have been collected during three different times described in the section above. They are mainly teachers' sentences during their interviews or recorded pre- and post-lesson discussions. A close reading of all the information, the discussions with the teachers and the attempt to group the observations according to teachers' features in the five points of their PCK gave us some suggestions about what could be revealed, which is the prevalent pattern used by teachers in the first year of the Physics studies.

We weren't surprised that teachers prefer the application pattern, with

Table 25: Monitoring results correspondent to a specific aspect of the PCK, by teachers' reported speeches.

Aspect of PCK	**Monitoring analysis**
Orientation to Science Teaching	It would be very important to carry out laboratory activities, but these require a large amount of school time.
	To understand physical law, students need to solve many problems.
	Students should arrive in the first year of learning physics with more consolidated mathematical skills.
Knowledge of curricula	To facilitate students' study, curricular activities almost always follow the sequence proposed in the textbook.
	Sometimes complex phenomena and processes (including extreme cases and borders of validity and approximation), difficult to be described mathematically, are omitted in the curricular treatment.
Knowledge of students' prior understandings and difficulties with key concepts and practices in science.	Students' mathematical difficulties clearly emerge when considering the use of procedures toward the solution, the manipulation of formulas (solving equations, using the properties of power laws, using the vector representation of quantities), and the simple use of the calculator.
	Students' intuitive knowledge is generally not used for the conceptual construction of new knowledge.
Knowledge of instructional strategies to scaffold students' learning of key concepts and practices in science.	In practical and laboratory activities, the teacher's support aspect (scaffolding) by the teacher is more structured and calibrated. The student is guided step by step through the activity; in the "theoretical" lesson in the classroom, this guiding role is attributed to the mathematical treatment.
	A lot of attention is given to the mathematical demonstration of physical law, using mathematics also for argumentative support.
Knowledge of what to assess and specific strategies to assess students' understandings of key concepts and practices.	Written/oral tests and class exercises based on problem-solving with peculiar characteristics (procedural/manipulative of formulas, with limited requests for argumentation, no request of representation in languages different by mathematical).
	Control questions during explanations are frequently aimed at clarifying mathematical rather than physical aspects.

some weak integration with the construction one. In both patterns, Maths controls the process even in an early Physics learning experience. Therefore, the Phys/Maths interplay is reduced to these two aspects, and only at the end of the studies are the other patterns (the exploration and the broadening one) sometimes used in teaching activities.

We found other interesting results by searching for the relationships between teachers' footprints and their prevalent application pattern. First, if the teachers are aware of students' difficulties in Maths or the absence of Phys/Math interplay, they try to support their learning process by focusing on mathematical languages.

This causes a large use of Maths in explaining Physics laws and many Maths exercises applied to Physics phenomena. The consequence is also recognisable in the evaluation assessments: they seem mathematically rather than physically oriented, without any or very few requests of reasoning (Bologna and Peressi, 2022b).

On the other hand, where the lack of students' Maths skills is relevant, the teacher adopts strategies converging to the strong use of qualitative description for conceptualisation. What happens is that some teachers try to resolve the students' difficulties in Maths using different language formats (formulas, graphs...), not really built in a conceptual physical context.

What comes from mathematics results and what corresponds to a physical phenomenological observation are, in certain ways, divided into two frames. This approach tends to amplify the distance between the two disciplines instead of favouring their interplay and integration in the form of interdisciplinarity to be thought and taught.

2.2.3.5 Brief Discussion

According to the evidence suggested by Pospiech (Pospiech et al., 2019), it might be useful to introduce students right from the beginning to the interplay of objects describing physical phenomena, such as physical and mathematical models. This is possible if teachers are encouraged to give a variety of different tasks which require flexible use of mathematics as well as physics concepts.

From our analysis, it emerges that currently, the monitored teachers adopt mathematics less flexibly than what could be desired to obtain a better integration between the two disciplines. In this sense, we could identify the need to provide further in-service training to achieve the main goals of the Phys/Maths interplay in the classroom's practices.

With a more deep insight (Bologna and Peressi, 2022a), we could also conclude that the prevalent adoption of the application pattern produces some relevant nested limits to the building knowledge process (Fig. 48):

- epistemological limit;
- linguistic/procedural limit;
- phenomenological limit;

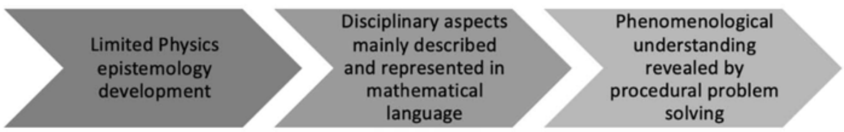


Figure 48: Limits encourage by a prevalent adoption of application pattern in Math/Phys interplay teacher's PCK.

The epistemological limits consist of building knowledge through the definitions of physical laws only through mathematical formulas. If it represents the core of the teaching process, it affects how students build their conceptual knowledge. The effect is precluding students from the possibility of investigating phenomenological aspects through disciplinary languages other than purely mathematical ones.

Students think that they understand a phenomenon only if they can solve related problems in the framework of the application of formulas.

If teachers were more aware of the limits due to the use of this pattern, they would surely change their PCK towards a wider and deeper Math/Phys interplay supported by a disciplinary languages' integration.

Furthermore, there is a close link between these epistemological limits, caused by the prevalent use of the application pattern, and students' development of reasoning skills (Elby, 2001; Wang and Buck, 2016).

If students are engaged in the process of applying formulas to explain physical phenomena, they will not explore the limits of validity, verify the model used, or try to test hypotheses and ideas also through experimentation. This happens because reasoning skills support epistemological building (Wang and Buck, 2016).

Improvements in epistemological development occur by integrating the development of reasoning skills into the learning processes. This integration is possible only if teachers revise their PCK of Math/Phys interplay, adopt all patterns, and include an epistemological building based on reasoning skills.

The advantage of this integration addresses two very important aspects of the learning process and the activation of learning skills:

- thinking like a scientist (in the framework of the epistemological building - Sin, 2014);

- critically thinking as the reasoning skills engage (Etkina and Planinšič, 2015).

Of course, changing PCK is a long-time process. To start the process, we needed to give evidence and show the effects of the Phys/Maths interplay pattern adopted. For this reason, we also investigated teachers' PCK for Argumentation.

2.2.4 PCK for Argumentation

Argumentation rarely happens in science classrooms (J. Osborne et al., 2013). Physics teachers play a key role in integrating argumentation into the learning process (McNeill and Knight, 2013), but they possess insufficient knowledge about argumentation (Wang and Buck, 2016).

Little work has been done regarding teachers' knowledge of the dialogic meaning of argumentation (as well described in McNeill and Knight, 2013). Other studies gave a broader insight into a science teacher's pedagogical content knowledge (PCK) (McNeill and Knight, 2013; Wang and Buck, 2016), trying to underline its features in terms of students' development of argumentation skills.

According to these works, we underpinned which is the knowledge regarding Physics teaching (Table 26).

It is the dialogic context that better activates a framework where the student can explore arguments and argumentation (Kuhn and Udell, 2003; J. Osborne et al., 2003). To foster teachers' awareness towards their specific knowledge of students' development of argumentation skills, we engaged some

Table 26: Five aspects of PCK related to Argumentation (Wang and Buck, 2016).

#	Aspect of PCK	Related Knowledge for Argumentation
1	Orientations toward Science teaching	Knowledge of the role of argumentation in science education
2	Knowledge of curricula	Knowledge of the implementation/adaption of argumentation in the existing curriculum
3	Knowledge of students' prior understandings about any difficulties with key concepts and practices in science	Knowledge of the student's background that would affect the argumentation practices in class
4	Knowledge of what to assess and specific strategies to assess students' understandings of key concepts and practices	Knowledge of the approach to assessing students' performances in argumentation and the efficacy of argumentation practice in facilitating students' learning
5	Knowledge of instructional strategies to scaffold students' learning of key concepts and practices in science	Knowledge of the appropriate instructional strategies to perform argumentation

teachers in the reflective debriefing of their classroom discourses.

We did not want to focus on the quality of individuals' arguments but on how the teachers start the interactive process of argumentation with their students. As we already noticed from studying students, they retain written and spoken difficulties in reasoning (Sec. 2.1 p. 50).

2.2.4.1 Monitoring Teachers' Discourses

To perform meaningful analysis, we audio-recorded sixteen lessons over two months during the Pandemic restriction for Covid-19 (February-March

2021). We involved three different teachers and their classes (Table 27).

Table 27: Sample features for monitoring teachers' discourses.

Grade	**Topic-Specific Content**	**Audio-recorded hours**
Grade 10	Dynamic of slope plane	2
Grade 10	Geometrical optics	8
Grade 11	Circular motion	6

Using the audio recordings, we analysed the classroom discourses by:

- the speech-duration frame;
- the words counting by frame;
- teacher-student question-answer dialogue.

Here we would like to focus on the last one for two main reasons: firstly because in all the audio-recorded lessons, we never identified student-to-student discussion or students' active response to their peers but only teacher-to-student. This absence of student-student interactions might be caused by the kinds of questions that the teachers pose. Secondly, even if each lesson was different from the others, there were similarities in the way teachers asked students to give responses. We would focus on those similarities.

We could distinguish between two main kinds of teachers' questions, as reported in Table 28 with some examples from the audio-recorded lessons. All of them enact a teacher-to-student discourse. This discourse frame is based on two moments: the teacher asking and the student responding. Most of the teachers' questions could be grouped into these two types, with a prevalence of the first than the second. The questions of the first kind have unique and correct answers. The students have two possibilities: giving the right or the wrong answer. There is no request for an explanation.

Table 28: Types of teachers' questions.

Type	Examples from teachers' speeches
Asking the result of a "product" or a "procedure"	*The result of this operation is...*
	What is the measure of the angle?
	On the right with a ray of...
	Which is the force acting on the mass?
	What is the closest point to Jupiter?
Ask the explanation of a process	*Why are periods longer when the earth moves away?*
	Why is the mass at rest along the inclined plane?
	How is the light passing through?

In the second case, we observed students' answers were full of hesitancy (poor words, brief sentences). It seemed they were searching for the right words, waiting for the teacher's endorsement. Even if this second type of question was why-how based (so, it could seem it involved the explanation of a process and then a form of argumentation), the dialogue enacted was affected, from a student's point of view, by the teachers' judgement of correctness.

Finally, we engaged teachers in a reflecting phase. This helped us to broaden the observations done to analyse classroom discourse. What happened was extremely interesting: they recognised the features of classroom discourses were not affected by the mode of teaching lessons in the time of distance learning.

These two kinds of questions represented their ways of conducting lessons' discourses even in presence. Listening to their questions, the teachers understood that the way they guided students to activate argumentation skills was based on their speech and not on the students'. And this kind of dialogue can not be properly considered what needs for the activation of reasoning skills.

2.2.4.2 Brief Discussion

Teachers recognised there is specific knowledge tailored to improve the reasoning discourses in the classroom environment. This knowledge is mainly reflected in the aspects of PCK related to the orientation towards Physics teaching and instructional strategies.

In fact, if argumentation is a core practice of building science knowledge (Bricker and Bell, 2008) and it has to be included in science education as a learning goal in the 21^{st} Century (Driver et al., 2000; Kuhn and Crowell, 2011; J. Osborne et al., 2004), then it has to become a core task of Physics teaching.

If argumentation is to become a core task, teachers need to develop knowledge to change their teaching approach, for example, towards an inquiry-oriented investigation environment creating classroom discourse opportunities that support argumentation (Kuhn and Crowell, 2011; McNeill and Knight, 2013).

2.2.5 Research Questions raised from the overview of teachers' conceptions

The overview of teachers' conceptions led us to formulate the following research questions:

> *How to develop a professional development program that helps physics teachers to adopt and implement a new approach?* (RQ2)

With this research question, we aim to find a theoretical approach to choosing an appropriate framework to guide teachers' professional development and to help teachers bring their instructional practices in alignment with the Recommendations of the European Union Council.

Then, the last two questions will help us determine the effects of the changes on teacher practices and students' attitudes:

> *To what extent do teachers' practices change after participation in such a program?* (RQ3)

> *To what extent do changed teaching practices improve students' attitudes toward physics?* (RQ4)

Answering These two research questions, we will sustain our aim in trying to give experimental evidence of:

- the effectiveness of professional growth of the teachers who participated in the professional development program governed by this framework
- the effects that the newly adopting teaching practices had on the attitudes towards physics of their students.

2.3 Overview Summary

These overviews are a starting point for our research. We needed to go into a depth insight into Italian Physics students' conceptions and teachers' conceptions.

A few very recent works investigate Italian Physics higher instruction; some of them concern the view of science (Testa et al., 2021), the attitude towards Physics from a semiotic-cultural perspective (Testa et al., 2022), or freshmen students' conceptual difficulties (Bozzi et al., 2021), or the effects of Pandemic restrictions on university Physics and Engineering students (Marzoli et al., 2021; Mazzola et al., 2022).

This investigation pursued another interesting goal: speaking to teachers about their teaching and their students. One thing is talking teachers to findings of educational research conducted far away, in foreign countries with different systems of instruction. Another thing is talking to teachers about themselves and their students. The effect is completely different.

Social proximity is a core in educational practice (Vygotsky, 1987): this is also true for in-service teachers' professional development if we apply the meaning of social proximity to the social context in which the teachers work.

The four Research Questions we identified are Physics Education Questions. They belong to teachers, and firstly to these teachers, we ought to answer.

From students' conceptions of knowledge, learning, and instruction, we are going to address the following question:

- Research Question n. 1 (RQ1)

  How to choose a teaching/learning approach to address students' attitudes and conceptual coherence and help teachers meet the challenges of the 21st Century education?

Indeed, from teachers' conceptions of the nature of Physics science, of the goals and purpose of Physics teaching, and learning and teaching Physics, we targeted the next three:

- Research Question n. 2 (RQ2)

  How to develop a professional development program that helps physics teachers to adopt and implement a new approach?

- Research Question n. 3 (RQ3)

  To what extent do teachers' practices change after participation in such a program?

- Research Question n. 4 (RQ4)

  To what extent do changed teaching practices improve students' attitudes toward physics?

First, we will try to address the research questions arising from students' conceptions, developing an approach targeting these goals.

Then we will explore the development of in-service training for teachers, fostering the adoption of the chosen approach.

* * *

Chapter 3

Towards an Early Physics Approach

The insight into students' conceptions about knowledge, learning, and instruction in Physics pushed and led us to describe an approach which helps them overcome their conceptual difficulties (Ekici, 2016), low confidence in Physics learning (P. Gardner, 1985; Sheldrake et al., 2019; Testa et al., 2022), and need to develop reasoning skills (Aguiar, 2016; Kuhn and Udell, 2003; J. Osborne et al., 2013; Tippett, 2009).

With European recommendations to foster the learning goals for the 21^{st} Century, we were encouraged to describe this approach as learner-centred and tailored to students' needs and cognitive demands. Actively engaging students in their learning process could be established as useful to facilitate knowledge integration, supporting deep conceptual understanding by a learning inquiry-based environment to involve scientific reasoning (Bao and Koenig, 2019).

From the perspective of disciplinary cross-cutting, enhanced by future-scaffolding skills development (Levrini et al., 2019), we pinpointed the features of an approach which supports, on one side, students' development of algebra thinking (D. W. Carraher and Schliemann, 2018; Malara and Navarra, 2018) and, on the other, critical and scientific thinking (Hammer, 1996; Mercer et al., 2004), trying to bridge the gap in the learning process of the two disciplines (Meltzer, 2002).

This chapter is broken into five sections and aims to describe an *Early Physics* approach to target the research questions that arose from Italian students' conceptions overview presented in the previous chapter.

In the first section, as a conceptual and theoretical framework, we account for *Early Algebra* approach in teaching/learning algebraic thinking and reasoning (D. Carraher and Schliemann, 2007; Kaput et al., 2008; Navarra, 2022). This approach gave us the frame to build the design idea of an *Early Physics*, depicted in detail in the same section.

Second, we describe the theoretical framework of using Multiple Representations as reasoning tools (R. J. Dufresne et al., 1997; Hubber and Tytler, 2017; P. B. Kohl and Finkelstein, 2017; Munfaridah et al., 2021; Van Heuvelen, 1991; Zou, 2000). In the third section, we deeply overviewed learning by Inquiry (Dobber et al., 2017; Kuhn et al., 2000; Pedaste et al., 2015). We focused on Multiple Representations and learning by inquiry from cognitive and epistemological perspectives, particularly on defining teachers' role in these frameworks.

The fourth section is dedicated to the ISLE approach (Etkina, Brookes, et al., 2019). From theoretical perspectives, we made a deep insight into this learning environment which we pinpointed to describe an *Early Physics* approach.

The last section summarises the outcomes of our literature review; we highlighted how the choice of the ISLE approach addressed the research questions concerning students' conceptions of knowledge, learning and instruction. In the same section, we described the conceptual model we developed for Italian Physics teachers to help them adopt this approach in their classrooms, based on the development of habits (Etkina et al., 2017) through cognitive apprenticeship (A. M. Collins et al., 1991) and community of practice (A. M. Collins et al., 1991; Etkina et al., 2017).

3.1 From *Early Algebra* to *Early Physics*

3.1.1 The *Early Algebra* Approach

In the last two decades, there has been a great deal of research interest towards a new domain of Maths Education Research, the so-called *Early Algebra* (D. W. Carraher and Schliemann, 2018; Kaput et al., 2008; Kieran, 2004).

To overcome the persistence of Maths difficulties in secondary and higher education, researchers profoundly revised the teaching approach to arithmetic and algebra, thinking of a trans-inter-domain of integration between them based on functional relations (D. W. Carraher and Schliemann, 2018; Kaput et al., 2008).

Moving from a historical to a modern pedagogical framework, *Early Alge-*

bra refers to the algebraic knowledge, the algebraic thinking, and the (initially rather unconventional) representations and techniques of young students in solving problems that we would generally expect more advanced students to solve using modern algebraic notation. The focus on representing relationships among quantities affords its origins in the Russian-based approach developed by Davydov and his colleagues at the end of the past century (Davydov et al., 1999). They emphasised the teaching of Algebra based not on its numerical foundations but on relationships among quantities. In this way, young students do not solve equations by thinking about "doing and undoing" numerical operations but by direct comparisons between quantities (Kieran et al., 2016).

There is no clear-cut break between *Early Algebra* and Algebra. *Early Algebra*, not to be referred to as "pre-algebra", is not to be viewed as a bridge students cross after they have studied arithmetic and before they study algebra (Fig. 49).

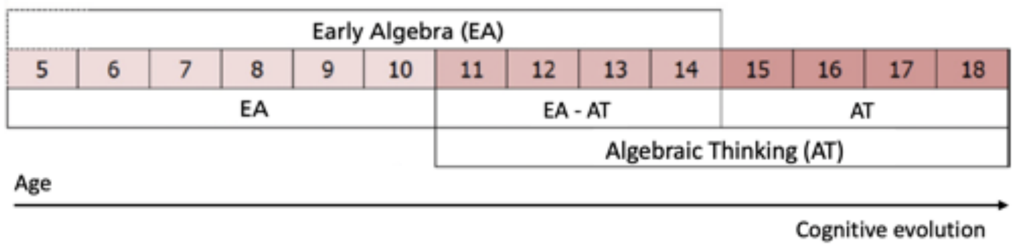


Figure 49: Temporal progression and intertwining of *Early Algebra* and the development of algebraic thinking (Navarra, 2019).

In principle, it can be developed and nurtured wherever there is arithmetic. This is because arithmetic is inherently algebraic (D. W. Carraher and Schliemann, 2018; D. Carraher and Schliemann, 2007).

Algebraic reasoning is thus identified through formulating and operating upon relations, particularly towards functional relations.

The notion of functions and their representations provide powerful means also for modelling physical attributes and measures, for justification or proof, and for the necessity to adapt mathematical models when dealing with every day or science applications (D. W. Carraher and Schliemann, 2018).

Discovering the role of functional relations, the algebraic nature of arithmetic is brought out for many reasons:

1. arithmetic operations are functions;
2. introductions of variables as placeholders for arbitrary members of sets and the extension of the classes of numbers supported by the concept of domains and range (or co-domain);
3. multiple representations of functions are profitably employed in unison;
4. comparison of two functions is inherently interpreted as equations and inequalities.

With this framework, functions and relations become an unexploited resource for teaching and learning: this is a unique role in early algebraic thinking.

The conceptual development focus on evoking students' view about a problem involving relations among sets of quantities and gradually introducing new mathematical representations, conventions and tools. Students discuss, represent and solve open-ended problems, focusing on relations between sets of quantities instead of performing computations on specific pairs of numbers. Firstly, they express their ideas and representation of the problem and the relationships among the quantities described in the problem or situation. Then they discuss and provide justifications for their ideas, contrasting their views to those proposed by others and the teacher.

The teacher acts following-up questions and suggestions built upon students' ideas and representations, introducing new ideas and representations. In this way, students are engaged in classroom discourses which could be called "algebraic babbling" (Malara, 1994; Malara and Navarra, 2018; Navarra, 2019, 2022). Analogous to how children learn natural language, students learn to communicate in algebraic language by starting from its meaning and, through collective discussion, verbalisation, and argumentation, gradually become proficient in syntax (Kieran, 2004; Kieran et al., 2016).

In order to establish a setting in which students engage in this manner, a teacher needs to:

- set the expectation that students support their ideas with explanations, probing and challenging each other's ideas to make sure they follow classmates' reasoning;
- clarify questions to help students make the details of algebraic thinking explicitly;
- acknowledge and validate students' proposals to encourage classroom discussion;
- helps students address contrasts in their thinking.

All these teachers' tasks involve students in meta-cognitive acts, reflecting on their observations and then moving to a level of generalisation and argument (Kieran et al., 2016). Students improve their understanding by substituting the act of calculating with looking at oneself while calculating (Malara, 1994; Malara and Navarra, 2018; Navarra, 2022). Teachers support this perspective's shift-changing questions. In an *Early Algebra* framework, the question "How did you solve the problem" becomes "How did you know that?", "Will that work for all numbers?" or even, "What is it that will work for all numbers?". But the teacher only asks these questions if the algebraic goal is clear. And this implies a change in teachers' dispositions, knowledge and skills (Etkina et al., 2017) in teaching Maths in an *Early Algebra* context.

To clarify what happens in the construction of knowledge of algebraic equations, we could consider the example where the equality-equivalence aspect is stressed. Treating the equal sign as a procedural symbol that announces the answer after a series of operations has been conducted is so common that it hides its strong meaning of showing two different representations of the exact quantities. Underlining, highlighting, expressing and emphasising this mutual role (equality-equivalence) enact the power of different representations instead of the direction of something to resolve to obtain a number (that, of course, it's the unique right solution). So, again the teachers' change is in the scaffolding questions: not more "How much is it" or "How much does it make?" (that is a literal translation of a typical Italian Math teacher's question), but "Which is the process you did to represent this relation between quantities?".

The focus is on the process, not the product (intending the result of a sequence of operations), on multiple representations and not on a single resolution (the result of computing or problem-solving). In this way, the emphasis is on natural language and its role of paramount importance (Malara and Navarra, 2018; Navarra, 2022) as a semantic facilitator. Treating Algebra with a language (Malara and Navarra, 2018; Navarra, 2019) changes the teaching approach as explained in Fig.50.

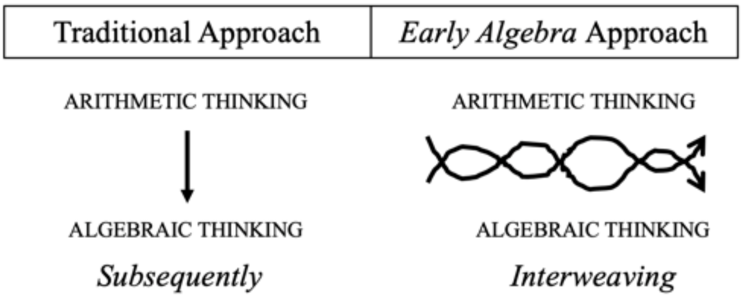


Figure 50: Algebra as a Language: approaches' differences (Navarra, 2019).

3.1.2 Drafting a conceptual framework for *Early Physics*

When students start to study Physics during the high level of secondary schooling, teachers immediately find their lack of algebraic thinking. This also happens at the beginning of introductory college courses (Bing and Redish, 2007; Brahmia et al., 2016; E. Redish and Kuo, 2014; E. F. Redish, 1994). Many students struggle with using Maths to describe the physical world (E. Redish and Kuo, 2014; E. F. Redish, 1994).

A simple analogy could help to describe the features of students' difficulties (Ekici, 2016; E. F. Redish, 1994). The analogy comes from the learning disorder definition of dyslexia (Lyon et al., 2003). We refer to dyslexia for the external effects (what appears in terms of difficulties a dyslexic student conveys). Of course, from a cognitive point of view, the origin of difficulties is different. They have in common the effect over the semantic structure of languages: for a dyslexic student, the spoken/written language; for a student with difficulty in Physics, the algebraic language used in a Physics context.

If we "translate" the most common difficulties in dyslexia disorder for

Physics learners, we find how the analogy works (Table 29; Bologna, Longo, Peressi, et al., 2022b).

Table 29: Principal Dyslexia Learning Disorder features (Lyon et al., 2003) and the corresponding Physics learning ones (E. F. Redish, 1994).

Dyslexia difficulties	**Physics learning difficulties**
Confuse letters	Confuse maths writings
See letters moving around reading	Forget the correct order and position of variables and constants when writing formulas
Find it very hard to remember lots of instructions	Forget the order of instructions and procedures for problem-solving
Have trouble telling and recognising left from the right	Have trouble predicting a phenomenological behaviour or describing it
Be slow in requesting more thinking time, remembering the right word	Forget the right words to tell something about the physics description
Memorise sequences	Memorise sequences to derive a physical law
Organise themselves	Organise their studies

The analogy does not mean that Physics learning difficulties have to be treated as they would belong to Learning Disorders. The analogy amplifies natural and mathematical language's role in the Physics learning process. As there are strategies to support dyslexic students, we could support Physics learners in the same manner. So, transposing the analogy to strategies' instructions from dyslexia compensating tools to Physics teaching instruction, strategies should include:

- to find different ways to present and solve problems;
- to emphasise how things work;
- to narrate and tell in more details descriptions of observations;

- to sketch and draw pictures, doing experiments.

And these instructions should be present in an *Early Physics* design to support learning from its beginning, avoiding increasing difficulties in Physics studies.

Furthermore, analysing in a more profound insight the Physics learning difficulties in Table 29, we could identify two groups of difficulties: those that arise from Maths integration in Physics and those from epistemology.

We will explore how these two aspects could be related to describing an *Early Physics* approach.

If we first consider those referred to as Maths ones, they regard different purposes–representing meaning about physical systems rather than expressing abstract relationships (E. Redish and Kuo, 2014). So, these difficulties stress the two distinct semiotics (the way meaning is put into symbols) and the different "languages" they refer to.

The formal mathematical syntax may be the same across the disciplines, but the uses and meanings of that formal syntax may differ dramatically between them. The apparent similarity in the formal syntax may mask these differences in semantic meaning (Brahmia et al., 2016; E. Redish and Kuo, 2014).

The key difference is that loading physical meaning onto symbols works for physicists and leads to differences in how physicists and mathematicians interpret equations. We not only use Maths in doing Physics[1], but we also use Physics in doing Maths (E. Redish and Kuo, 2014). For this reason,

[1]For a more detailed review about the use of Maths in Physics, we suggest reading the recent articles of E. F. Redish, *The Physics Teacher*, **59**, p. 314; p. 397; p. 525; p. 599; p. 683 (2021).

the languages of "Maths in Maths" and "Maths in Physics" may need to be considered separate (E. Redish and Kuo, 2014).

This is a step forward point for teachers when they start to teach Physics in secondary school. They need to sustain students in their "Algebraic babbling" and at the same time in their "Physical babbling", simultaneously distinguishing and interweaving them in a cognitive blending development (Bing and Redish, 2007; Brahmia et al., 2016). The blend of scientific and algebraic thinking and reasoning needs to be heterogeneous, representing a continuous inter-dependence between the physical world and a conceptual understanding of algebraic operations and representations (Brahmia et al., 2016), and, at the same time, it has to emphasise the meaning-related differences. In the framework of this cognitive blending, we could distinguish two states (Fig. 51):

- the disentangled state;
- the entangled state.

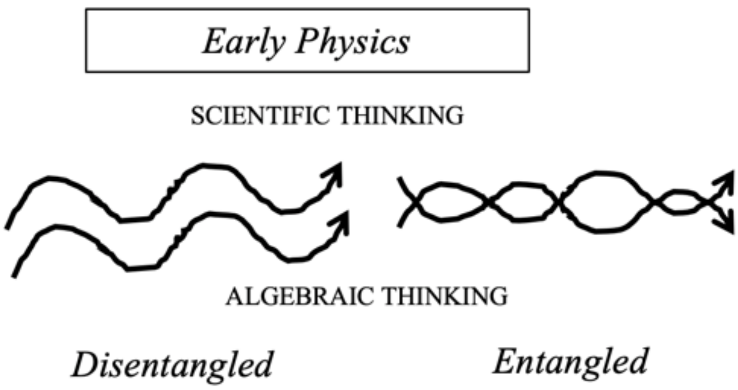


Figure 51: Cognitive blending framework design for an *Early Physics* approach.

These states may configure cognitive processes in building Physics knowledge supported by increasingly algebraic thinking.

These two states, overlapping or separate, enable:

- to underline the differences between languages, semantic structures, and uses;
- to support interplay through integration and modelisation (Bing and Redish, 2007; Etkina, Warren, et al., 2006; Hestenes et al., 1995);
- to enhance disciplinary epistemology.

Referring to the framework of an *Early Algebra* learning environment, we could think of designing an *Early Physics* approach by encouraging the use of Algebra as a language to be learnt very soon (Fig. 52) and scaffolding the building of different semantic structures even at pre-primary and primary levels of instruction (Bembich and Bologna, 2022; Carey, 2000), when the scientific thinking begins to take shape engaging children in constructing explanations and explanatory understanding (Carey, 2000; Sorzio, 2022).

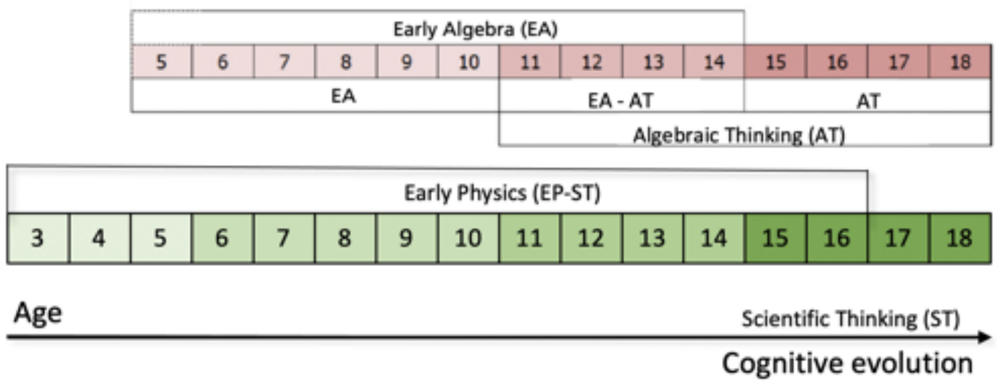


Figure 52: Temporal progression of *Early Algebra* development of algebraic thinking, *Early Physics*, and development of scientific thinking.

With respect to age, students are guided from simpler to more articulated structures, from qualitative to quantitative conceptualisation, eliciting the process of building knowledge respecting cognitive evolution and promoting the natural language as the semantic facilitator in describing both Maths and Physics and their representations.

Emphasising the different semantic meanings, teachers help students to handle representations more consciously.

If we look, for example, at the differences between the meaning of equals sign in Algebra and in Physics (Alaee et al., 2022), in an *Early Physics* context, we would need to underline and clarify all the meanings/categories the equals sign could be adopted (Table 30).

Table 30: Summary of categories identified in textbooks, including operational articulation used to identify type, example, and direction in which equations containing this type of sign are most easily read (courtesy of use by Alaee et al., 2022).

Category	Articulation	Example	Direction
Definitional	“Is defined as...”	$m = F/a$	Left-to-right
Causality	”Leads to...”	$a = F/m$	Right-to-left
Assignment	“Let this = that”	$Y = c/2m$	Left-to-right
Balancing	“This is balanced by...”	$kx = -mg$	Bidirectional
Calculate	“The rest is just math...”	$4 + 5 = 9$	Left-to-right

The *Early Algebra* framework guides students to overcome their misinterpretation of the equal sign as an operational rather than a symbol of mathematical equivalence.

The *Early Physics* framework embodies the Algebra meaning, extending it in the physical context, which does not always follow the equivalence balancing but rather the causal-effect relation.

In the meantime, stressing the differences and enhancing the meaning of representations supports teachers in building knowledge with a clear distinction between disciplines, which is crucial to reinforce the disciplinary epistemology construction.

What is relevant to underpin is the fundamental role of the exchange between representations using different disciplinary languages. Teachers must continuously stress switching and translating disciplinary languages from one to another in instructional activities. Passing from one disciplinary language to the other, the teacher infers students' learning skills of argumentation (Kuhn and Crowell, 2011) and representation (Ainsworth, 2008).

We could be considered a process between disciplinary languages (Fig. 53), where each component sustains and interacts with the others.

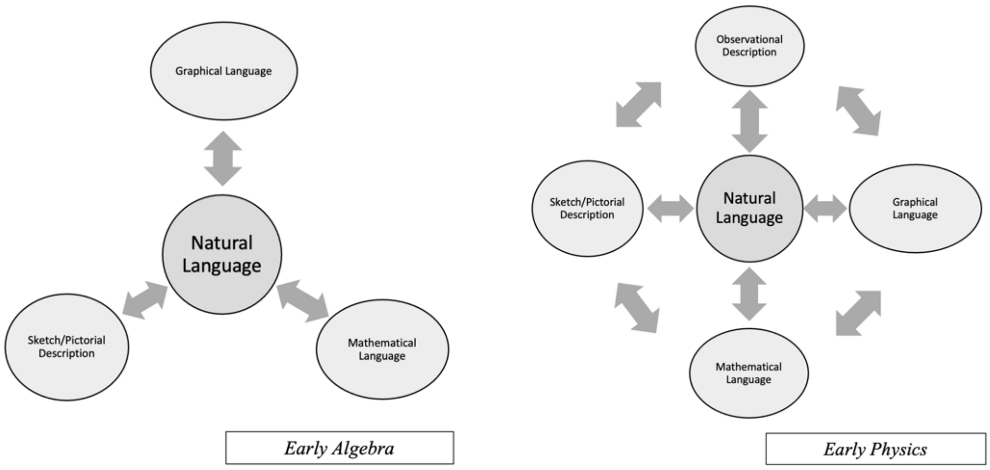


Figure 53: Comparison between *Early Algebra* and *Early Physics* disciplinary languages/descriptions interaction process, where Natural Language is the semantic facilitator.

In an *Early Physics* framework, we need to add the Observational Description in the interaction process between disciplinary languages/descriptions; this need grants the development of the disciplinary-specific epistemological perspective.

Observational Description specifically refers to the practice of scientists to inquiry phenomena, observing reality. If this practice is avoided (or negligibly included) in teaching activities, teachers explain Physics as it would be an application of Algebra. So, there is no reason to distinguish the two processes in Figure 53.

We could expect that adopting these two frameworks would mutually support each other in developing students' algebraic and scientific thinking, even if they remain distinguishable by the epistemological purpose (E. Redish and Kuo, 2014) of building Algebra (Malara and Navarra, 2018) and Physics (Brookes et al., 2020) content knowledge.

Taking into account the conceptual and theoretical framework of the *Early Algebra* approach, we tried to describe an *Early Physics* one in detail.

First, we studied Physics Education Research with a particular focus on the last thirty years of scientific literature. This insight gave us a broad overview of Physics teaching/learning innovation.

Then, we identified two main strands which could delineate *Early Physics*: on one side, the use of Multiple Representations in Physics learning (Van Heuvelen, 1991) as a reasoning tool, on the other side, the use of inquiry-based teaching/learning practices (Dobber et al., 2017).

In an *Early Physics* approach, they work together to sustain cognitive development and support conceptual and epistemological building (Hammer and Elby, 2003).

In the next sections, we'll describe the main features of these two strands, highlighting their role in learning from cognitive and epistemological points of view, whereas in teaching, emphasising teachers' tasks.

3.2 Tools for Reasoning and Conceptualising

The use of Multiple Representations (MR) to scaffold students' Physics learning afforded its origin during the Nineties (Ainsworth, 1999; R. J. Dufresne et al., 1997; Van Heuvelen, 1991, 2001; Van Heuvelen and Maloney, 1999), based on previous works of the use of representations in Physics problem-solving (Chi et al., 1981; R. J. Dufresne et al., 1997; Larkin, 1983).

The role of MR in Physics learning and teaching is noteworthy and well documented by scientific literature (Ainsworth, 2008; Opfermann et al., 2017; Rosengrant et al., 2007). Its use has been explored in many Physics topics, such as energy processes (Van Heuvelen, 1991; Van Heuvelen and Zou, 2001; Zou, 2000), mechanics (Etkina et al., 2008), electric currents (C. L. Wong and Chu, 2017), supporting students in regular problem-solving (R. Dufresne and Gerace, 2004; Finkelstein et al., 2005; P. Kohl et al., 2007) or Jeopardy problems (Van Heuvelen and Maloney, 1999).

The use of MR is extensively recommended in teaching practices (P. B. Kohl and Finkelstein, 2017; Opfermann et al., 2017; Van Heuvelen, 1991), even if there is limited research regarding how teachers use representations affecting their teaching and students' learning and how MR is implemented in textbooks (Munfaridah et al., 2021)[2].

[2] We analysed Italian Physics textbooks for secondary and college levels and did not find MR implementation. We also looked at textbooks adopted in College University in the US, and we found only in the textbook *College Physics - Explore and Apply* (Etkina, Planinsic, et al., 2019), MR play a very significant role in every chapter. A brief report of our analysis is reported in Bologna and Longo, 2022.

Based on a brief literature review, we will try to conceptualise MR, delineating cognitive and epistemological perspectives. Then, we will analyse the main tasks teachers need to scaffold using MR.

3.2.1 Conceptual Description

Multiple Representations can generally be divided into two main categories: internal and external (Ainsworth, 1999). The internal ones regard the mental models as structural analogies of situations or processes. External representations are those that others can see, such as pictures, text narrations, graphs, symbols, etc. (Ainsworth, 1999; Munfaridah et al., 2021).

Referring to external representations, they serve four main functions in learning situations:

- to complement (representations present complementary information and support complementary cognitive processes in the complementary function - Ainsworth, 1999);
- to constrain (the constraint function reduces (mis)interpretations in mutual use, and controls use, assisting students with unfamiliar representations of a physical concept - C. L. Wong and Chu, 2017);
- to construct (this function supports students' deeper understanding by multiple representing of situations. It constructs an abstract concept and establishes relations among representations - Ainsworth, 1999; C. L. Wong and Chu, 2017).
- to connect different representations, making explicit what is implicit by bridging abstract words with abstract mathematical relations (Van

Heuvelen, 1991; Zou, 2000). This function enhances the evaluative purpose of MR, in the process of checking for the consistency between representations (Rosengrant et al., 2007; Rosengrant et al., 2009.

The main functions' components and their specificity are detailed in Table 31.

Table 31: External Multiple Representations Functions (Ainsworth, 1999; Ainsworth, 2008; Van Heuvelen, 1991).

Functions of MR	**Components**	**Specificity**
Complementary Roles	Complementary processes	Task
		Strategies
		Individual differences
	Complementary Information	Different information
		Shared Information
Constrain Interpretation	Constrain by Familiarity	
	Constrain by Inherent Properties	
Construct Deeper Understanding	Abstraction	Subtraction
		Re-ontologisation
		Reification
	Extension	
	Relations	
Evaluative	Evaluation by Consistency	Semiotic aspects
	Evaluation by Meaning	Semantic aspects

Based on these functions, in the framework of a conceptual description of multiple representations, their use could assist fostering the following processes of thinking and learning: elementarization and reconstruction (Duit et al., 2012). Elementarization lies in the analysis of conceptual elements of MR, reinforcing to constrain the interpretation.

Whereas reconstruction of physical concepts is based on deeply understanding the reasoning among its representations in a constructivist conceptual change (Duit et al., 2012).

3.2.2 Cognitive Science Perspectives

There are two main aspects to highlight regarding cognitive enhancement through the use of MR, mainly concerned with the process of externalisation (A. M. Collins et al., 1991). The first aspect regards the students' negotiation of representations' meaning (Prain and Tytler, 2013; Tytler et al., 2013); the second refers to the reasoning activation process.

Each individual knows and learns not only by manipulating stored symbols in memory but also by the interplay between mind, body, feelings and environment. That's because thinking, reasoning and abstracting are based on perception, such as situated action, embodiment and environmental inputs. The negotiation between teacher and student is strictly concerned with how the teacher presents representations, and students activate the symbolisation and abstraction process through those representations (Tytler et al., 2013).

In the negotiation process, another factor is relevant to underline: there are cognitive differences between reasoning with self-constructed external representations and reasoning with presented representations (Cox, 1999). Effective reasoning with external MR concerns a threefold interaction involving:

- the semantic and cognitive properties of representations;
- the matching between the task requirements and the information read-off provided by the representation;

- subject-dependent factors such as prior knowledge or cognitive learning style.

The more direct instructions on the use of MR are given, the more efficacy their effects are addressed (Cox, 1999; Stenning and Oberlander, 1995). MR could be used as a tool for many different forms of reasoning: initial and speculative thinking, showing sequences or time processes, sorting information, recording observation, and predicting outcomes. These reasoning abilities are achieved because external MR possess exploitable perceptual effects.

Implementing their uses, students learn how to select the most appropriate one and develop critical judgement in its use for expressed purposes. A crucial learning component is constructing and interacting through external representations (Ainsworth, 1999; Cox, 1999). This activity is more than a simple translation for the presence of signs such as language, graphical or mathematical objects (Stenning and Oberlander, 1995; Vygotsky, 1987). Moreover, translating information from a linguistic representation such as natural language or logic to a graphical representation might be more effective than translating from one representation to another within the same modality (Stenning and Oberlander, 1995; Van Heuvelen, 1991).

Searching and working memory loading are reduced in this reasoning activation process because the information is stored by location (Stenning and Oberlander, 1995).

Therefore, external representations are a kind of distributed cognition where "cognitive tasks are neither wholly internally represented nor wholly externally represented but distributed across both" (Cox, 1999, p.348).

In the meantime, students may use MR in two different ways: concurrently (Ainsworth, 1999) or switching between them (Brookes et al., 2020; Cox, 1999).

The first use enacts complementary roles, whereas the second focuses on constraining interpretation by familiarity or inherent properties (Ainsworth, 2008).

Lastly, we would stress the role of external MR in assisting problem-solving-related cognitive skills, which is a very important cognitive task in Physics learning (Chi et al., 1981; Cox, 1999; R. J. Dufresne et al., 1997; P. Kohl et al., 2007; Larkin, 1983; Rosengrant et al., 2007).

In problem-solving, MR support the cognitive process by reordering the information in ways useful for solutions and by laying out the range of possible models of the information, making explicit missing information and representing implicit information explicitly and as a form of evaluation (Table 32, Rosengrant et al., 2009).

3.2.3 Epistemological Perspectives

Multiple representations could have an epistemological meaning both in students' building of scientific explanations and the teacher's use of them in concept explanations. On one side, students use representations to access and deploy their explanatory intuition. Whereas teachers use them to build knowledge and physical meaning.

So, the use of a system of multiple representations in the Physics teaching/learning process is related to the different functions of scientific explanation (Yeo and Gilbert, 2017). These functions refer to three dimensions

Table 32: External Multiple Representations Functions in problem-solving (Cox, 1999; Larkin, 1983; Rosengrant et al., 2009).

Organising problem information
Representing information properly
Switching between representations
Translating information
Reordering information
Evaluating consistency
Activating cognitive processes
Exploiting phonological component of working memory
Using visuospatial sketchpad component of working memory
Providing perceptual assistance
Directing attention to unsolved parts of the problem
Keeping track of progress through the problem
Transferring information between cognitive subsystems
Refining and disambiguating mental images
Changing what is recalled
Enhancing reasoning
Promoting the self-explanation effect
Shifting the subject's mode of reasoning
Sustaining evaluation process

of explanation: function, form and level. Each of them clarifies a particular meaning in scientific explanation building.

We need to describe these dimensions to highlight the epistemological role of multiple representations in this framework (Table 33 - Yeo and Gilbert, 2014).

A system of multiple representations used to construct scientific explanations embodies the epistemological meaning, affording the defined three dimensions. So, developing students' representational capabilities for producing scientific explanations go beyond conceptual understanding. It po-

Table 33: Dimensions of scientific explanation (Yeo and Gilbert, 2014).

Dimension	**Description**
Function	Answering specific types of questions
Form	Structural organisation (how different elements are put together into a whole)
Kind of Level	Precision
	Abstractness
	Complexity

tentially produces epistemological meaning intrinsic to explanation building (Yeo and Gilbert, 2017).

3.2.4 Teacher Perspectives

Trying to define the Physics teacher's role in using MR, we referred to the representation construction approach, which is a guided inquiry approach to teaching and learning (Tytler et al., 2013). This approach links student learning and engagement with the epistemic (knowledge production) practices of science (Hubber and Tytler, 2017). In this learning environment, the functions of multiple representations are enhanced in a structured, well-design context for learning (C. L. Wong and Chu, 2017); also, the teachers' roles are well-depicted.

We generalised the role established in this framework to try to define the main tasks for Physics teachers using MR. We summarised them in Table 34.

Table 34: Teachers' role in building representations (Hubber and Tytler, 2017).

	Teaching Tasks	**Description**
Teaching sequences	Clarifying the representational resources underpinning key concepts	Identifying big ideas, key concepts and their representations, during all the process of conceptual building
	Establishing a representational need	Involving students' explorations to identify the problematic nature of phenomena and the need for explanatory representation
	Coordinating/aligning student-generated and canonical representations	Supporting the interplay between teacher-introduced and student-built representations where students are challenged and supported to refine and extend and coordinate their understandings
		Supporting to refine and extend and coordinate students' understandings
Teaching discourses	Scaffolding discussions to critique and support student representation building in a shared classroom process	Helping students to understand that a number of representations are needed for working with multiple aspects of a concept (*Selective Purpose*)
		Guiding students in a critical evaluation of their representations (*Generative Group Agreement*)
		Focusing on representational form and function (*Clarification Discussion*)
		Mutually assessing representations introduced both by teacher and students (*Ongoing Assessment*)
Learning environment	Providing meaningful learning through strong perceptual/experiential contexts and encouraging environment	Creating a perceptual context where students get involved with a strong perceptual context (i.e. hands-on, experiential) and allow constant two-way mapping between objects and representations
		Engaging students in learning that is personally meaningful and challenging
	Assessing through representations	Providing formative and summative assessments in the framework of generating and interpreting representations
		Involving students in continuous, embedded process of assessing their use of representations also in explanatory context

3.3 Learning by Inquiry

The definition of inquiry-based teaching/learning approach covers a variety of ideas in education (Dobber et al., 2017; Pedaste et al., 2015). Following the main prominent approaches, we could distinguish three kinds, which overlap many others by meaning and using:

1. Problem-based learning;
2. Project-based learning;
3. Inquiry-based Science learning.

Among these kinds, we identified that Inquiry-based Science learning could satisfy the requirements for an *Early Physics* design. Before detailing this kind of inquiry, we briefly describe Problem-based and Project-based learning as completing the theoretical framework.

3.3.1 Problem-based learning

Problem-based learning is a specific approach to inquiry-based learning developed in higher education contexts (firstly, in medical education). Based on the ideas of Dewey at the beginning of the last century (Dewey, 1922; Sorzio, 2009), problem-based learning spread out its use in many disciplines (Barrows, 1996; Kuhn et al., 2000; Yew and Goh, 2016), not only scientific. Despite the wide-ranging of its definitions that could be found in the literature (Yew and Goh, 2016), there are six features which characterise this pedagogical approach (Barrows, 1996):

- learning is student-centred;

- learning is based on working-group;
- in each group, there is a facilitator or a guide;
- authentic problems are presented at the beginning of a learning sequence before any preparation or study has occurred;
- the problems encountered are used as tools to achieve the required knowledge and the problem-solving skills necessary to solve the problems eventually;
- new information is acquired through self-directed learning.

Problem-based learning is effective teaching and learning approach, particularly when it is evaluated for long-term knowledge retention and applications (Yew and Goh, 2016).

3.3.2 Project-based learning

Project-based learning is a model in which learning is organised around projects, which are complex tasks based on challenging questions or problems. These tasks involve students in design, problem-solving, decision-making, or investigative activities, allow students to work relatively autonomously over extended periods, and culminate in realistic products or presentations (Thomas, 2000). In the process of project-based learning, students are active learners through recurrent cycles of analysis and synthesis, action and reflection, similar to what happens in the other inquiry-based learning types.

Unlike problem-based learning, this approach focuses on projects, which may be organised in various configurations (single or multiple activities, lasting several weeks or an entire schooling year). Projects are bridges between phenomena in the classroom and real-life experiences; the questions and answers that arise in their daily enterprise are given value and are shown to be open to systematic inquiry (Blumenfeld et al., 1991).

3.3.3 Inquiry-based Science learning

Even if within the domain of inquiry-based learning, there is no consensus about the meaning of the term "Inquiry" (Dobber et al., 2017), one of the acknowledged definitions is that scientific inquiry learning is a tool for developing scientific thinking strategies and deep understanding of science content (Ben-David and Zohar, 2009). So, “Inquiry” refers to scientists’ work when they study the natural world, proposing explanations that include evidence gathered from the world around them. The term also includes the activities of students—such as posing questions, planning investigations, and reviewing what is already known in light of experimental evidence—that mirror what scientists do (Martin-Hansen, 2002).

In general, inquiry-based classroom practices consist of a simplified set of steps, which engage students in the 'inquiry cycle' based on thinking strategies for developing thoughtful inquiry processes. To be productive in inquiry-based learning, students need to explicitly understand how and why scientists think in that specific way, not only what scientists investigate (Dobber et al., 2017). Many phases in the inquiry cycle could be defined, depending on the model inquiry used. In many frameworks, the most acknowledged phases are five; in Table 35, we compare two five-phases cycles (Bybee et al., 2006, Pedaste et al., 2015). The inquiry cycle emphasises developing the abil-

Table 35: The inquiry cycle: different models and definitions.

5E Instructional Model (Bybee et al., 2006)		**Inquiry-Cycle Phases Reviewed** (Pedaste et al., 2015)	
Phases	**Description**	**Phases**	**Description**
Engagement	To engage students in the learning task. The students mentally focus on an object, problem, situation, or event.	Orientation	The process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement.
Exploration	Exploration activities are designed so that the students in the class have common, concrete experiences upon which they continue formulating concepts, processes, and skills. This phase is concrete and hands-on.	Conceptualisation	The process of stating theory-based questions and/or hypotheses.
Explanation	The process of explanation provides the students and the teacher with a common use of terms relative to the learning task.	Investigation	The process of planning exploration or experimentation, collecting and analysing data based on the experimental design or exploration.
Elaboration	Once the students have an explanation and terms for their learning tasks, it is important to involve them in further experiences that extend or elaborate the concepts, processes, or skills. This phase facilitates the transfer of concepts to closely related but new situations.	Conclusion	The process of concluding the data. Comparing inferences made based on data with hypotheses or research questions.
Evaluation	This is an important opportunity for students to use the skills they have acquired and evaluate their understanding.	Discussion	The process of presenting findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the whole learning process or its phases by engaging in reflective activities.

ity and disposition to investigate, construct knowledge and understanding through active learning, to attain specific science process skills, and communicating scientific explanations (Martin-Hansen, 2002). Then, there are different levels of performing inquiry. This depends on many factors, such as the degree of teacher-centred or student-centred learning that takes place in the classroom. Essential features of the classroom, levels of inquiry and their variations are described in Table 36.

Table 36: Levels of inquiry (Martin-Hansen, 2002; National Research Council, 2000).

Inquiry Phase	Level of Inquiry			
	Confirmation/ Demonstrative Inquiry	**Structured Inquiry**	**Guided Inquiry**	**Open Inquiry**
Engage	Learner engages in questions provided by the teacher, materials, or other sources	Learner sharpens or clarifies question provided by the teacher, materials, or other sources	Learner selects among questions, poses new questions	Learner poses a question
Explore	Learner given data and told how to analyse	Learner given data and asked to analyse	Learner directed to collect certain data	Learner determines what constitutes evidence and collects it
Explain	Learner provided with evidence	Learner given possible ways to use evidence to formulate explanation	Learner guided in process of formulating explanations from evidence	Learner formulates explanation after summarising evidence
Elaborate		Learner given possible connections	Learner directed toward areas and sources of scientific knowledge	Learner independently examines other resources and forms the links to explanations
Evaluate	Learner given steps and procedures for communication	Learner provided broad guidelines to use sharpened communication	Learner coached in development of communication	Learner forms reasonable and logical argument to communicate explanations

Different types of lessons, and therefore different types of inquiry, are used for specific needs in the science classroom (Martin-Hansen, 2002).

In this wide range of inquiry-based learning designs, a teacher could be disoriented and effort many resources to implement the inquiry cycle in the classroom. The teacher's role is paramount in developing students' skills for inquiring.

We'll try to underline the relevance of the teacher's role before exploring the cognitive and epistemological perspectives behind an inquiry-based approach to science learning.

3.3.3.1 Teacher Perspectives

Two aspects often distinctively defined in inquiry-based education describe the teacher's role. The first aspect concerns the amount of teacher direction, whereas the second regards the type of teacher regulation (Dobber et al., 2017; Furtak et al., 2012; Kuhn et al., 2000). In literature, teacher direction seems to be of great importance (Furtak et al., 2012), so much so that if the teacher strongly guides the inquiry process, it is called teacher-directed, if less, student-directed, passing through a possible mixed direction (Table 37). The teacher's direction is key in defining the type of teacher

Table 37: Definition of teacher direction role in inquiry process (Dobber et al., 2017).

Type of direction	**Teacher's role**
Teacher-directed inquiry	The teacher decides on the questions to be investigated, how these are to be investigated, and what needs to be presented.
Mixed direction	The teacher determines some aspects of the research, but there is also space for students to make some choices.
Student-directed inquiry	The teacher sets the stage and guides or facilitates the process if necessary.

regulation. Three main components are inter-twinned in featuring teacher regulation: meta-cognitive regulation (Kuhn et al., 2000), social and conceptual regulation (Furtak et al., 2012). In Table 38, the three components of regulation are presented, and the role of the teacher is depicted, emphasising the teacher's tasks in the inquiry process.

Table 38: Definition of teacher regulation in inquiry process (Dobber et al., 2017; Furtak et al., 2012; Kuhn et al., 2000).

Regulation component	Description	Teachers' tasks	Description
Meta-cognitive regulation	Focus is on learning to act and think as a scientist	Focusing on thinking skills	The teacher stimulates his or her students to engage in the process of self-explanation by asking them questions about their inquiries and by asking their peers to respond to the answers.
		Promoting a culture of inquiry	The teacher explicitly communicates new expectations about student roles (more active) in the classroom.
		Guiding inquiry discourse	The teacher teaches the pupils to use the 'Ask to Think-Tell Why' approach to stimulate children to ask thought-provoking questions such as 'How is ... related to ...? explain your answer'.
		Making students familiar with the nature of science	The teacher works with pupils in an actual laboratory and focuses on thinking about hypotheses, predicting results and analysing data.
Conceptual regulation	Focus is on subject-specific knowledge and rules	Providing information on the research topic	The teacher starts an inquiry activity by asking the students to search for and write down everything they know about the object under study.
		Focusing on conceptual understanding	The teacher focuses on linking new information from the inquiry project to students' prior knowledge.
Social regulation	Focus is on guiding the social processes of learning	Bridging the gap between high and low achievers	The teacher supports a low achieving student to become a more meaningful partner in group discussions.
		Organising student learning in groups	The teacher uses different strategies to form student groups.
		Focusing on collaboration processes	The teacher determines and discusses with students the ground rules of collaboration before the activities start.

The role of the teacher in inquiry-based education is complex, multi-faceted and demanding (Dobber et al., 2017). Teachers need to be prepared to focus on the different types of regulation and reflect on the effects of the direction of inquiry.

3.3.3.2 Cognitive Science Perspectives

In defining learning by inquiry, it is noteworthy to underline the cognitive processes involved in these practices. We would highlight two cognitive facets: experiential learning is an effective learning method for developing critical thinking and other meta-cognitive skills (Kuhn et al., 2000; Zimmerman, 2000; Zull, 2004). Secondly, it could be useful to compare the cognitive processes involved in authentic inquiry (the inquiry performed by scientists in their scientific practices) and the inquiry performed in science classrooms (Chinn and Malhotra, 2002). These facets contribute to the effectiveness of learning by inquiry in terms of achieving learning outcomes.

Experiential learning

Experiential learning has been shown to be an effective learning method for scientific disciplines to learn critical thinking skills. It refers to how students learn and apply knowledge from an experiential learning experience (Experiential Learning Theory, Kolb, 1984). The learning process follows a four-stage cycle involving four adaptive and interwoven learning modes. Effective learning is seen when a person progresses through a cycle of these stages (Table 39):

1. having a concrete experience;
2. observation of and reflection on that experience;

3. the formation of abstract concepts (analysis) and generalizations (conclusions);
4. used to test a hypothesis in future situations, resulting in new experiences.

Table 39: Components of Experiential Learning Cycle (Kolb, 1984).

Cycle components (clockwise reading)

CONCRETE EXPERIENCE The learner encounters a concrete experience. This might be a new experience or situation or a reinterpretation of existing experience in the light of new concepts.	REFLECTIVE OBSERVATION The learner reflects on the new experience in the light of their existing knowledge. Of particular importance are any inconsistencies between experience and understanding.
ACTIVE EXPERIMENTATION The newly created or modified concepts give rise to experimentation. The learner applies their idea(s) to the world around them to see what happens.	ABSTRACT CONCEPTUALISATION Reflection gives rise to a new idea or a modification of an existing abstract concept (the person has learned from their experience).

The learning process starts by transforming the experience into knowledge (Kolb, 1984 p. 38). Under this setting, linking the four-stage to what is occurring in the brain during each one states a deep explanation of the cognitive process (Zull, 2002).

Combining the four brain regions with the experiential learning cycle, students engage in deeper learning which involves using more parts of their cerebral cortex (Zull, 2004). The matching between brain regions and learning cycle components is described in Table 40.

The concrete experience involves the sensory cortex, reflective observation involves the integrative cortex at the back, creating new abstract concepts occurs in the frontal integrative cortex, and active testing involves the motor brain (Kolb, 1984; Zull, 2004). For learning to occur, students need to be gained from concrete experience to flow from the back of the brain to the

Table 40: Four Major Regions of the Cerebral Cortex and Experiential Learning Cycle Matching (Kolb, 1984; Zull, 2004, 2002).

Cerebral cortex region	**Function**	**Learning component**
Sensory cortex	Getting information	Concrete Experience
	Storage of knowledge obtained from sensory input	
Back integrative cortex	Making meaning of information	Reflective Observation
	Storage of knowledge gained from the sensory input in the form of images and meaning	
	Knowledge stored permanently in the individual's long-term memory	
Frontal integrative cortex	Creating new ideas from these meanings	Abstract Conceptualisation
	Responsible for short-term memory	
Motor cortex	Acting based on acquired ideas	Active Experimentation

front, where the experience is conceptualised and stored in the brain. If the process happens safely, students become aware of their mental progression and increase their willingness to learn (Zull, 2002).

To be effective, learning by inquiry should reproduce the learning cycle depicted. Indeed, inquiry includes engaging with the content/material in questioning, investigating, and collaborating to make meaning. In each phase described in Table 35, there are recognisable aspects which recall the experiential learning cycle. What could be less evident is whether all the inquiry levels satisfy the learning cycle requirements. For this reason, we explored better how the process of building scientific reasoning is encountered by inquiry-based learning.

Cognitive processes in inquiry practices

Helping students to scientifically reason is one of the primary goals of inquiry-based approaches (Kuhn et al., 2000). There are many differences in cognitive processes activated to succeed at many school tasks compared to the scientific research required of scientists (Chinn and Malhotra, 2002). Table 41 lists some cognitive processes, comparing their activation in authentic inquiry and simple inquiry (referring to the inquiry adopted in teaching practices). For this list, we refer to the taxonomy of Chinn and Malhotra, 2002; according to their framework, there are different reasoning tasks corresponding to scientists engaged in authentic inquiry and those to students engaged in simple inquiry. In the taxonomy, we chose the cognitive processes related to tasks in school inquiry practices.

Table 41: Comparison between cognitive processes activated in authentic inquiry practices and school practices (Chinn and Malhotra, 2002).

Cognitive Process Description	**Reasoning tasks**	
	Authentic Inquiry (scientist standpoint)	**Simple Inquiry** (student standpoint)
Questions posing	Generating research questions	Listening to questions posed by teacher
Implementing procedures	Inventing complex procedures to address questions	Guided in using procedures selected by teacher
Making observations	Employing elaborate techniques to control observation bias	Conducting observation without controlling observation bias
Explaining results	Repeating more time measures and procedures before claiming results	Conducting single measure or single procedure to claim results
Types of reasoning	Employing multiple forms of reasoning	Employing simple forms of reasoning, such as deductive, inductive or contrasting
Generalisations	Comparing procedures and measures searching for generalisation	Replicating exactly the same situation without exploring generalisation

The effect of the gap between cognitive processes of authentic inquiry and school inquiry contributes to increasing the difference between the epistemology of school inquiry tasks and that of scientific practices (Chinn and Malhotra, 2002).

Designing an *Early Physics* approach and choosing which kind of inquiry model could be adopted, we have to consider these two cognitive demands: enacting a complete learning cycle and developing scientific reasoning skills based on cognitive processes of authentic inquiry[3].

3.3.3.3 Epistemological Perspectives

One of the goals of adopting learning by inquiry is to change the epistemological perspective in which traditional teaching affects the scientific building of knowledge (Bybee et al., 2006; Dobber et al., 2017; Pedaste et al., 2015; Sin, 2014). Nonetheless, even when students are engaged in active scientific inquiry, there is often a push toward one right answer, which promotes a singular vision of science (Sin, 2014).

The same vision is given by textbooks[4], presenting scientific processes through a systematic analysis of data leading only to secure conclusions (S. L. Wong and Hodson, 2009). It seems as if the majority of Physics textbooks

[3]In promoting inquiry-based science learning, we trained professional in-service development for science teachers in the so-called IBSE method (Inquiry Based Science Education) (Bologna and Zappa, 2021). IBSE is a model for inquiry as defined by Bybee et al., 2006. In Italy, this method is better known by teachers for learning by inquiry. From 2011 to the present, the National Association of Natural Science Teachers (Associazione Nazionale Insegnanti di Scienze Naturali, ANISN, 2011) founded many centres for training science teachers in primary and secondary schools to use IBSE methods. They gained teachers in courses, performing activities inquiry-based, preparing materials and experimenting practices in classrooms. Most of the proposed activities were based on a level of inquiry demonstrative/confirmation, with teacher-directed guiding. Teachers were rarely invited to engage students in open inquiry practices.

[4]We mainly refer to Italian textbooks for high school instruction which are still not implemented in the inquiry-based learning framework (Bologna and Longo, 2022).

do not yet develop the inquiry habits [5].

Then, classrooms are hierarchically structured, with the teacher and the text controlling which knowledge counts, even in practices of working groups and cooperative learning: these are typically used by teachers as a methodology for practices which do not correspond to a change in an effective negotiation of knowledge building (Driver et al., 2000; J. Osborne et al., 2013; Sin, 2014).

The overlapping of all these factors influences how students build their view of science in terms of epistemological beliefs (Hammer and Elby, 2003). Students undergo practices promoting "a vision of science as factual, decontextualized, linear, objective, and rational" (Sin, 2014, p. 15), where the emphasis is given on 'ready-made science' (with implicit messages about certain knowledge obtained through 'the scientific method'), as opposed to 'science-in-the-making' which emphasises social construction (Sin, 2014; S. L. Wong and Hodson, 2009).

The epistemological discrepancy affects Physics learning more than teachers are aware of it. This also happens as a consequence of adopting simple rather than authentic inquiry (Chinn and Malhotra, 2002). One of the effects is that "simple inquiry tasks assume an epistemology that is opposed to the epistemology of authentic science. Students who learn about scientific reasoning through simple inquiry tasks may actually learn a nonscientific epistemology" (Chinn and Malhotra, 2002, p. 187). Looking at the dimensions of epistemology enacted in inquiry practices, there could be defined at

[5] A well-designed textbook with the clear intentionality of development students' inquiry habits is the already mention *College Physics - Explore and Apply*, Etkina, Planinsic, et al., 2019.

least five different frames in which scientists and students face off (Chinn and Malhotra, 2002, p. 188):

1. purpose of research;
2. data coordination theory;
3. treatment of anomalous data (including method-confidence);
4. nature of reasoning;
5. social construction of knowledge.

An authentic inquiry differs from the simple one mainly because of activated scientific reasoning. On one side, scientific reasoning is articulate, uncertain, heuristic, and non-algorithmic; on the other, it is viewed as simple, certain, algorithmic, and focused at a surface level of observation (Chinn and Malhotra, 2002).

3.3.4 Describing an *Early Physics* Approach

Our overview of Multiple Representations and Learning by Inquiry led us to consider how they better could be blended in an *Early Physics* framework. We focused on Inquiry-based Science Learning (such as IBSE) because it is better known in the Italian context.

But, even if this learning method has great potential (as we tried to depict) and has been demanded and recommended by National and European Governments (Bianchi, 2021; European Council, 2018)[6], we disclosed some constraints regarding cognitive and epistemological perspectives in our literature review.

[6]The recommendations do not inform which kind of inquiry adopts but only the indication of encouraging the adoption contrasting traditional methods of teaching.

What we considered most important was the need for a warranty in terms of using an authentic inquiry in the teaching process. We did not want that *Early* could be confused with *Simply* in implementing simple inquiry.

Then we needed to merge the learning environment of Multiple Representations with the one developed by an inquiry with respect to cognitive and epistemological framework. In the meantime, teachers' tasks concurrently had to answer our demands to sustain the development of students' cognitive skills and epistemological beliefs.

One of the possibilities we found in the literature is the Representation Construction (Hubber and Tytler, 2017; Prain and Tytler, 2013; Tytler et al., 2013). This is a guided inquiry approach developed within an Australian Research Council (ARC) project that links student learning and engagement with the knowledge-production practices of science.

This approach involves students generating and negotiating the representations (text, graphs, models, diagrams) that constitute the discursive practices of science rather than focusing on the text-based, definitional versions of concepts. The Representation Construction approach is based on sequences of representational challenges involving students constructing representations to explore and make claims about phenomena actively (Tytler et al., 2013). It has also been developed for astronomy (Hubber and Tytler, 2017) and more recently for scientific inquiry in primary schooling (Tytler et al., 2022). We did not find any research confirming that this approach could be considered a practice of authentic inquiry. For this reason, we did not recognise in this approach what we were looking for in designing an *Early Physics* one.

In any case, we would underline the efficacy enacted by this approach which adopts Multiple Representations in terms of supporting student transduction, that is, the way students connect and remake meanings across representations in different modes (Tytler et al., 2022).

From a content point of view, we could identify the same peculiarity in inquiry-based practices, such as in Representation Construction. Like many other inquiry examples, this approach prepares challenging activities based on specific content topics. Teachers experience the approach, pedagogy and content management in isolated, spotting cases.

They occasionally replicate in their classrooms what they learnt in training courses. But, after then, they encounter significant difficulty applying the approach to other content topics and, of course, to a curriculum perspective and coherent design.

Consequently, students' experience in inquiry-based learning is also mainly fragmented. It does not produce the desired effects regarding cognitive skills development of scientific reasoning and epistemology beliefs.

The experience in an *Early Physics* framework (from both teaching and learning side) needs to be immersive and not spotty. This requirement is substantial to improve students' scientific reasoning and thinking.

We overcame all the constraints we had encountered in the approaches investigated when we faced the ISLE approach (Etkina, Brookes, et al., 2019).

The following section presents this learning environment and its features from a cognitive and epistemological perspective, also describing teachers' roles through teaching tasks.

What we did not find in other approaches, we pinpointed in ISLE. For this reason, we recommend that an *Early Physics* framework should be developed ISLE-based. The following section explains better why.

3.4 The ISLE Approach

ISLE stands for Investigative Science Learning Environment. It is an intentional-holistic learning environment (Etkina, Brookes, et al., 2019): intentional to curriculum design, which means how and what students learn has the same importance (Brookes et al., 2020), whereas holistic regarding learning Physics as a whole, coherent frame (Etkina, 2015a). The two main goals of the ISLE approach are:

- "engaging students in the process of doing physics with a simplified model of the actual logical progression of the activities of physicists" (Brookes et al., 2020);
- improving students' well-being while they are learning Physics, motivating them to be engaged in the process of doing Physics (Brookes et al., 2020).

These goals correspond to the two intentionalities of the approach itself (Etkina, Brookes, et al., 2021):

1. how students learn Physics;
2. how they feel themselves while learning it.

These intentionalities are the core of the ISLE approach, even determining the choices for its underpinned theoretical perspectives (Brookes et al., 2020). Three key features engage students in doing Physics (Table 42).

All the learning features are student-centered: students are actively engaged and learn content knowledge through constructing knowledge (Etkina, Brookes, et al., 2019).

For this reason, the ISLE approach is an example of authentic inquiry

Table 42: Key Features of ISLE approach (Brookes et al., 2020; Etkina, Brookes, et al., 2021; Etkina, Brookes, et al., 2019; Etkina, Heuvelen, et al., 2006).

Key feature	**Description**
Learning process and learning tools	Developing Physics concepts as their idea through a series of "knowledge-generating activities", which mirror scientific practice
	Representing physical processes using Multiple Representations as tools for conceptual building, reasoning, and evaluation
Assessment and community of learners	Assessing student's ability to reason like a physicist and simultaneously help them develop these abilities
	Making social interactions and sharing ideas as a natural part of student progress
Need to know and time for telling	Proving intrinsic motivation through jump-start of extrinsic one
	Generating in-classroom moments where the students can share, reflect on, and compare ideas to what physicists think.

(Brookes et al., 2020; Chinn and Malhotra, 2002).

Every ISLE activity follows a well-defined process diagram: the ISLE process (Fig. 54). The process is not intended as a linear progression (Etkina, 2015a; Etkina, Brookes, et al., 2019) but repetitive (Brookes et al., 2020), supporting students in their reasoning.

In this setting, at any step, students could go back and revisit their assumptions and change their explanations through three categories of experimental activities: observational experiment, testing experiment and application experiment (Etkina, Brookes, et al., 2019).

These three categories are quite different from the most common definitions of experimental activities performed in the classroom, in which the performance is for demonstrative or "cookbook" experiments, such as "demo",

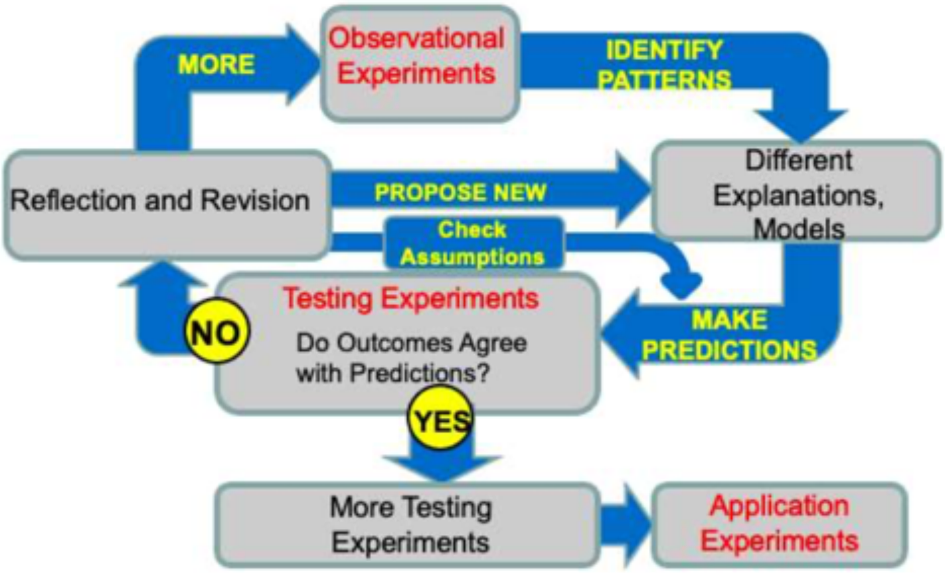


Figure 54: Process for doing Physics in ISLE environment (by courtesy of E. Etkina).

"labs", or "hands-on" experiments (Brookes et al., 2020). The ISLE experiments emphasise the interplay between experimentation and theory development (Brookes et al., 2020), where students are not passive viewers but are actively engaged in the process of doing Physics (Etkina, Brookes, et al., 2019). This development occurs in three forms:

- students develop new physics ideas from the need to explain something unexplained in an observational experiment;
- students generate multiple explanations and use these explanations to make predictions for possible outcomes in a testing experiment;
- students apply the hypotheses tested to a new real physical situation to investigate using an application experiment.

Table 43 reports a more detailed description of these kinds of experiments.

The observational and testing experiments lead students to model and

Table 43: ISLE experiments description (Etkina, Brookes, et al., 2019).

Type of experiment	**Description**	**Students' tasks**
Observational experiments	Experiments designed to investigate a phenomenon by collecting qualitative or quantitative data without specific expectations of the outcome. They are properly designed hypothesis-generating and explanation-generating experiments, enacting the search for a recurring pattern/model that describes the observed phenomenology	Analysing a new phenomenon
		Identifying a pattern
		Developing an explanation or multiple explanations
Testing experiments	Experiments designed to predict the outcomes based on the hypothesis/explanation under testing	Having multiple hypotheses to test
		Arguing which hypothesis applies to the situation
Application experiments	Experiments designed for problem-solving in a real context, for determining the value of some physical quantities using relations/models that have not been refuted by multiple testing experiments	Applying existing knowledge to solve practical, real-world problems

explain (using models in instructions, Hestenes et al., 1995; Treagust et al., 2003). There are four types of simplification in modelling physical situations (Etkina, Warren, et al., 2006):

- model of objects;
- model of interactions between multiple objects;
- model of systems;
- qualitative and quantitative models of processes;

In the ISLE activities, students are engaged in the process of using models to describe and explain phenomena and to predict new ones (Etkina, Warren, et al., 2006). They are also guided to reflect on the limitation of the models, change their assumptions, and revise the model adopted (Brookes et al., 2020). These practices help students do Physics as scientists do (Etkina, Warren, et al., 2006).

Thus, looking better into the ISLE process in Fig. 54, every new concept starts with a simple observational experiment. Students analyse the physical situation or the data collected by the observation and try to identify and define a pattern (Etkina, Brookes, et al., 2019).

Students use different representations to employ a pattern that helps find relations between quantities they are observing. In this way, representations are used for sense-making and not only as answer-making, as they are commonly adopted in traditional use (Etkina, 2015a). Three main types of representations are used in finding a pattern (Table 44). Students use representations to reason, building a bridge between phenomena and algebra (Etkina, 2015a; Van Heuvelen, 1991; Van Heuvelen and Zou, 2001), helping them in the process of conceptualisation.

Table 44: Representations used in ISLE observational experiments (Etkina, 2015a).

Type of representations	Examples
Traditional Representations	Sketches, Graphs, Ray diagrams, Tables, Circuit Diagrams, Ray Diagrams
Modified Traditional Representations	Motion diagrams, Force diagrams
Novel Representations	Energy Bar Charts, Momentum Bar Charts (conserved quantity bar charts)

Observational experiments activate the first step in constructing a concept. This step involves inductive reasoning (Etkina, 2015a). Then, students construct explanations, which switch to analogical reasoning because explanations are mainly based on p-prior knowledge (diSessa, 1993). Students test their explanations (even many times) by proposing experiments and making predictions of their outcomes based on the explanations under test and comparing the outcomes to the predictions(Etkina and Planinšič, 2015). They could confirm or reject the hypothesis under the results of the testing experiment. In carrying off this process, they activate hypothetico/deductive reasoning (Etkina, 2015a). And this happens in testing experiments.

Lastly, in the application experiments, students practice reasoning in an authentic context:

- exploring and extending the use of Multiple Representations in solving paper-and-pencil and experimental problems (Brookes et al., 2020);

- gained in instructional laboratories where they design experiments (Etkina, Brookes, et al., 2019).

In all these activities, students develop abilities which are the same scientists use in their work, such as, for example, model building, use of multiple representations, and experiment design (Etkina, Brookes, et al., 2019). Therefore, the assessment needs to be implemented in the ISLE-based classroom to address those scientific reasoning abilities.

The matching of learning goals with formative assessment is a detailed feature of the ISLE approach (Brookes et al., 2020).

Scientific abilities are purposefully defined instead of the most common terms used in educational practices, "science-process skills" with a precise aim: "to underscore that these are not automatic skills, but are instead processes that students need to use reflectively and critically" (Etkina, Heuvelen, et al., 2006, p.1).

The seven scientific abilities refer to habits like processes, procedures, and methods, which are typical physicists' habits. They are (Etkina, Heuvelen, et al., 2006):

1. representing information in multiple ways;
2. designing and conducting an experiment to investigate a phenomenon;
3. designing and conducting a testing experiment (testing an idea/hypothesis/explanation or mathematical relation);
4. designing and conducting an application experiment;
5. communicating scientific ideas;
6. collecting and analysing experimental data;
7. evaluating models, equations, solutions, and claims.

The expectation for *scientific abilities* is laid out by rubrics. The ISLE rubrics (Etkina, Heuvelen, et al., 2006)[7] help instructors in the practical implementation of formative assessment for grading and help students in self-assessment, as a self-regulatory process (Buggé and Etkina, 2020). To achieve the goal of students' well-being in doing Physics in the ISLE framework, teachers encourage and permit students to revise and improve their work by adopting a re-submission policy (Etkina, Brookes, et al., 2019) for all kinds of learning products (homework assignments, lab reports...).

The rubrics are one of the resources developed to guide instructors in adopting the ISLE approach. The other resources are the textbook, *College Physics: Explore and Apply* (Etkina, Planinsic, et al., 2019), the Instructor Guide, *Active Learning Guide* (Etkina, Brookes, Planinsic, and Van Heuleven, 2019), the site of the ISLE approach (Etkina, Brookes, and Planin-

[7]sites.google.com/site/scientificabilities (last visited 31/12/22)

sic, 2021)[8] with all info and online resources freely available. There are also specific materials expanded for middle school and high school classrooms in the Physics Union Mathematics (PUM) curriculum modules (Etkina, Brahmia, et al., 2010)[9].

ISLE develops and constructs the process of learning Physics based on cognitive, epistemological, socio-cultural and human theoretical perspectives (Brookes et al., 2020). These underpinnings proceed from the two ISLE intentionalities (Buggé and Etkina, 2020). Teachers who want to adopt this learning system must revise their role in the classroom, enhancing these perspectives in their teaching framework.

3.4.1 Cognitive Science Perspectives

Learning Physics as a representational activity allows students to overcome cognitive learning difficulties (Brookes et al., 2020). This occurs for two main reasons: the role of representations in human cognition (A. M. Collins et al., 1991) and the role of communication as a fundamental level negotiation of meaning shaped by different representations (Brookes and Etkina, 2009; Cox, 1999; Prain and Tytler, 2013).

Representations and communication are the core of the epistemic process of "doing Physics" (Brookes et al., 2020; Kitchner, 1983). The use of Multiple Representations aids knowledge building and makes it visible to share with others. Different representations mean different modal systems activated in the brain (Chi et al., 1981; Cox, 1999; R. J. Dufresne et al., 1997; P. Kohl

[8]https://www.islephysics.net/ (last visited 31/12/22)
[9]https://pum.islephysics.net (last visited 31/12/22)

et al., 2007; Larkin, 1983).

In the framework of the ISLE approach, students are engaged in an authentic learning experience, that is, a complete learning cycle (Kolb, 1984; Zull, 2004, 2002), where different brain areas are involved and activated in the process of sharing ideas (Brookes et al., 2020, see Table 40).

Students enact the cognitive transition they need for conceptual building by making their thinking visible. So, sharing ideas through the use of multiple representations (graphs, sketches, words, diagrams, equations, kinesthetic actions, and even physical stuff) as tools for reasoning means shaping cognition (Brookes et al., 2020; Sapir, 1929). Natural language is the facilitator between speeches and thoughts, knowledge and understanding.

3.4.2 Epistemological Perspectives

The epistemological commitment of ISLE sounds clear in all the steps of the learning process. Every activity has an identifiable epistemological purpose (Etkina, Brookes, et al., 2019).

ISLE is an example of epistemologically authentic inquiry (Brookes et al., 2020; Chinn and Malhotra, 2002). The authenticity deals with the approach's intentionality: "students should learn physics by engaging in activities that mimic the authentic knowledge-generating activities of practising physicists" (Brookes et al., 2020).

By developing simpler tasks in experimental practices, it is possible to engage students in an authentic process of scientific reasoning (Chinn and Malhotra, 2002). This arises from the different kinds of experiments developed for learning Physics in the ISLE process.

The observational, testing and application experiments are designed in order to create a framework of epistemic practices for the students. These experiments assume an epistemological role in learning Physics (Etkina, Brookes, et al., 2019). They activate a cognitive process based on scientific reasoning, guiding students in inductive and hypothetico/deductive reasoning.

Therefore, students' engagement in a cognitively well-designed inquiry activity ensures the fulfilment of the requirements of developing authentic cognitive processes grounding the epistemological frame (Brookes et al., 2020; Chinn and Malhotra, 2002).

3.4.3 Teacher Perspectives

Focusing on how students develop habits of mind not finding the right answers (Brookes et al., 2020), the teacher perspectives drastically change. In the ISLE approach, the focus switches from correctness to reasoning (Etkina, Brookes, et al., 2019).

Therefore, in classroom discourse, the role of teachers becomes utterly different from a traditional approach to Physics teaching and needs to shift towards a new standpoint (Cazden, 2001; Driver et al., 2000; Etkina, 2015a; Lemke, 1990).

The difference stands in the kind of answers and the kind of questions teachers give and pose. The flow of classroom discourse differs basically for the negotiation process activated by using multiple representations (Etkina, Brookes, et al., 2019).

Teaching students physics through ISLE means a paradigmatic change in tasks of teaching. Table 45 reports ISLE teaching tasks (Etkina et al., 2018)[10].

An ISLE teacher[11] becomes "a *master* of Physics reasoning who is slowly apprenticing her/his students into this craft" (Etkina, 2015a). This happens by creating a learning environment where students can make mistakes without being afraid to do (Etkina, 2015a; Zull, 2002).

[10] The table is reported by courtesy of E. Etkina, adapted from the one present in Appendix A of the article Etkina et al., 2018.

[11] Teacher who is teaching Physics through the ISLE approach will be referred to as "ISLE teacher."

Table 45: Tasks of teaching in the ISLE approach (Etkina et al., 2018).

Task of teaching	**Specific tasks**
Anticipating student thinking around science ideas	Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes
	Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes
	Recognising student interest and motivation around particular science content and practices
	Understanding how students' background knowledge both in physics and mathematics can interact with new science content
Designing, selecting, and sequencing learning experiences and activities	Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes
	Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas
	Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation
	Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories
	Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones
	Providing students with evidence to support their understanding of short- and long-term learning goals
	Integrating, synthesising, and using multiple strategies and involve students in making decisions
	Prompting students to collectively generate and validate knowledge with others
	Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic
	Eliciting student understanding and help them express their thinking via multiple modes of representation
	Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect

(Table 45 continued)

(Table 45 continued)

Task of teaching	Specific tasks
Monitoring, interpreting, and acting on student thinking	Employing multiple strategies and tools to make student thinking visible
	Interpreting productive and problematic aspects of student thinking and mathematical reasoning
	Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction
	Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction
	Providing students with descriptive feedback
	Engaging students in meta-cognition and epistemic cognition
	Devising assessment activities that match their goals of instruction
Scaffolding meaningful engagement in a science learning community	Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know
	Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse
	Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners
	Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom
	Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class
	Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities
	Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms
	Helping students make connections between their collective thinking and that of scientists and science communities
	Scaffolding learner flexibility and the development of independence
	Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts

(Table 45 continued)

3.5 Describing an *Early Physics* Approach - Summary

Starting from *Early Algebra* theoretical frameworks, we tried to draft which could be the features of an *Early Physics* approach.

(Table 45 continued)

Task of teaching	Specific tasks
Explaining and using examples, models, representations, and arguments to support students' scientific understanding	Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary
	Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn
	Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know
	Encouraging students to invent and develop examples, models, and representations that support relevant learning goals
	Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations
	Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models
	Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms
	Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields
Using experiments to construct, test, and apply concepts	Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts
	Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.
	Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts
	Providing opportunities for students to pose their own questions and investigate them experimentally
	Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment
	Helping students draw connections between classroom experiments, their own ideas, and key science ideas
	Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out

We stressed the constraint of differentiating the two learning environments mostly from cognitive and epistemological perspectives, maintaining the role of switching and exchanging between disciplinary languages in learning sequence development (Fig. 55).

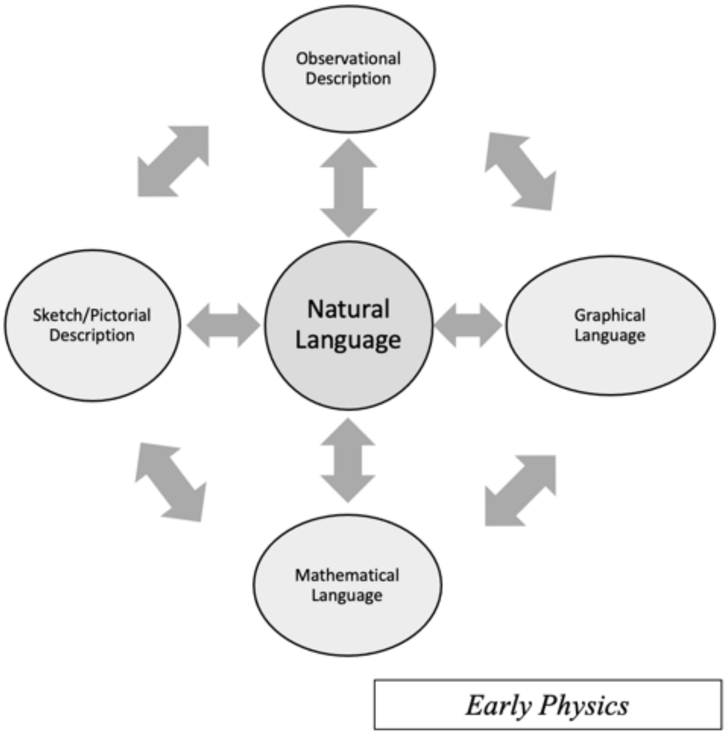


Figure 55: *Early Physics* interaction process between different disciplinary languages.

This conceptual design considers the natural language as the semantic facilitator in describing Physics phenomena and their representations.

In this context, the teacher activates students' learning skills of argumentation and representation (Driver et al., 2000; Kuhn and Crowell, 2011), letting them pass from one disciplinary language to the other in the learning activities (P. Kohl et al., 2007; Rosengrant et al., 2007; Van Heuvelen, 1991).

For this reason, in depicting the conceptual framework, we highlighted the role of the use of Multiple Representations as a reasoning tool (Ainsworth, 2008; R. J. Dufresne et al., 1997; Etkina et al., 2008; Finkelstein et al., 2005; Hubber and Tytler, 2017; P. Kohl et al., 2007; P. B. Kohl and Finkelstein, 2017; Munfaridah et al., 2021; Opfermann et al., 2017; Tytler et al., 2013; Van Heuvelen, 1991; Van Heuvelen and Zou, 2001; Zou, 2000).

We focused on cognitive enhancement concerning the process of externalisation (Ainsworth, 1999; A. M. Collins et al., 1991; Cox, 1999), regarding students' negotiation of representations' meaning (Prain and Tytler, 2013) and reasoning activation process (Cox, 1999; Stenning and Oberlander, 1995), also in problem-solving (Cox, 1999; Larkin, 1983).

From an epistemological point of view, Multiple Representations are related to the different functions of scientific explanation (Yeo and Gilbert, 2017), supporting conceptual understanding (Ainsworth, 2008; Munfaridah et al., 2021; Opfermann et al., 2017).

To integrate the Observational Description in the *Early Physics* interaction process between disciplinary representations, we investigated which inquiry approach could better satisfy the conceptual requirement.

Our overview of inquiry-based learning instructions (Barrows, 1996; Ben-David and Zohar, 2009; Blumenfeld et al., 1991; Bybee et al., 2006; Dobber et al., 2017; Furtak et al., 2012; Kuhn et al., 2000; Martin-Hansen, 2002; Pedaste et al., 2015; Yew and Goh, 2016; Zimmerman, 2000) provided a deep insight into these approaches. We tried to focus on cognitive processes involved in inquiry practices, exploring how they could activate and regulate a complete learning cycle (Kolb, 1984; Zull, 2004, 2002).

More interestingly, we faced the conditions by which the cognitive processes are comparable with those of an authentic inquiry (Chinn and Malhotra, 2002). If these conditions are not satisfied, the epistemological perspective is also limited by the inquiry adopted, resulting in no-authentic.

We needed to pinpoint an inquiry-based learning epistemologically authentic (Chinn and Malhotra, 2002).

In the ISLE approach (Etkina, Brookes, et al., 2019), we acknowledged all the conceptual requirements underpinned by describing an *Early Physics* approach from cognitive and epistemological perspectives. They are woven into the core of the approach, defined by its two intentionalities:

1. "students should learn physics by thinking like physicists; by engaging in knowledge-generating activities that mimic the actual practices of physics and using the reasoning tools that physicists use when constructing and applying knowledge" (Brookes et al., 2020).
2. "the way students learn physics should enhance their well-being" (Brookes et al., 2020)

The ISLE approach is an epistemologically authentic inquiry-based learning environment (Brookes et al., 2020), where doing Physics is substantiated by the reasoning tools, such as the use of Multiple Representations.

Students' learning skills of reasoning (Kuhn, 1991) are sustained by representational practices, intrinsically integrated into the learning process of acquiring content knowledge (Brookes et al., 2020). In this process, the degree of abstraction of representation increases in the form of eliciting progress and learning sequences of activities, including kinesthetic ones.

In the framework of the ISLE approach, the learning community is a key feature, where students interact with each other, develop and use representations collaboratively, share their own ideas, debate, and feel free to wrong (Etkina, Brookes, et al., 2019). All are synthesised and summarised by teachers in "time for telling".

We identified in this learning environment the role of natural language as a semantic facilitator.

The ISLE process should be adopted in an *Early Physics* framework for all these features. ISLE is a learning system which could be applied to any Physics course (Etkina, 2015a): in primary schools (Etkina and Van Heuleven, 2007; Etkina and Heuvelen, 2001), in middle schools (Etkina, Brahmia, et al., 2010), in high schools (Buggé, 2020; Buggé and Etkina, 2020), and introductory college courses (Etkina, Karelina, et al., 2010).

We recommended and chose to suggest adopting the ISLE approach in Italian high schools. This implied facing and overcoming two main stumbling blocks:

- translating the ISLE materials into the Italian language;
- merging ISLE curriculum design to the Italian one.

Part of this research work tried to face these hurdles. This is still a work in progress, developed in the community of researchers, undergraduate students in Physics, and Physics teachers we engaged in our research project. We created a shared drive where Italian Physics teachers could find the following resources[12]:

[12] All the resources are available online: they are enriched by the works and dedications of those we are involved in this research project, with many thanks in particular to the passionate Physics teachers Francesca Antoci, Simon Peter Leban, Orsola Pignatti, Maria Elisabetta Pezzoli, Cristina La Mura, Andrea Bussani, Valentina Valenta, Georgia Turri, Anna Zanmarchi, Raffaella Dussich. All the materials have been reviewed and produced consistently with the ISLE approach.

1. Instructor Guide resources (by content-topics: Introduction to Physics, Kinematics, Newtonian Mechanics, Applying Newton's Laws, Circular Motion, Impulse and Linear Momentum, Work-Energy, Rotational Motion, Gases, Fluids in motion, First Law of Thermodynamics)[13].
2. Lab experiments materials (by specific content-topics: Forces and Vectors; one dimension Kinematics; Energy Conservation Processes; Heating processes; Magnetic properties of matter)[14].
3. Exercises and problems ISLE-based[15].
4. specific learning sequences paths regarding One Dimension Kinematics through kinesthetic activities and Work-Energy processes using toys[16].

3.5.1 Targeting Research Question #1

In Chapter 2, we detailly overviewed Italian students' and teachers' conceptions. This led us to highlight the need to describe an approach which could answer the following research question that arose from our deep insight:

(RQ1): *How to choose a teaching/learning approach to address*

[13]shorturl.at/inrNP; most of the translation work is performing by the Physics high school teacher Francesca Antoci, who used them in her classrooms' activities.

[14]shorturl.at/uWXZ7; this work is part of a Master's Degree Thesis in Physics of Alberto Frontino. All these materials have been tested within the high school for Scientific studies Liceo Scientifico G. Oberdan Trieste, under the supervision of the Physics teacher Georgia Turri.

[15]shorturl.at/gktE2; this material is part of the apprenticeship work of an undergraduate student in Physics, Giovanna Modugno, and part of the Bachelor's Degree Thesis in Physics of Francesco Piccoli, tested in classroom activities with the Physics teachers Cristina La Mura, Georgia Turri and Sara Noviello.

[16]shorturl.at/bgr13; and shorturl.at/vQTW2; these activities were implemented explicitly for secondary school for professional training, under the collaboration with the Physics teachers Andrea Bussani and Valentina Valenta.

students' attitudes and conceptual coherence and help teachers meet the challenges of the 21^{st} Century education?

In describing an *Early Physics* framework, we pinpointed in the ISLE approach all the features we were looking for concerning cognitive and epistemological perspectives.

We can also establish that the ISLE approach targets our research questions. The ISLE intentionalities and goals respond to the need to implement a learning environment which involves students in scientific practices through observational, testing and application experiments (Etkina, Brookes, et al., 2019).

ISLE students demonstrate "consistency and coherence in model-based and evidence-based reasoning in making predictions and interpreting results" (Etkina et al., 2018).

Consistency and coherence have been claimed by many studies conducted for evaluating ISLE students' development of scientific reasoning (Etkina et al., 2008; Etkina, Karelina, et al., 2010; Rosengrant et al., 2009), and also using traditional PER assessments (Etkina, 2015a), such as FCI (Hestenes et al., 1992). In the ISLE framework, the progression in conceptualisation building goes step-by-step, supported by the increase in the use of reasoning tools (Etkina, Brookes, et al., 2019). The conceptual coherence in the ISLE framework allows students to learn without conceptual discrepancy but activating the conceptual change (diSessa, 2014) students need for deep learning and deep Physics understanding.

In ISLE classrooms, students are actively engaged in doing Physics as physicists do (Etkina, 2015a). How students are cognitively and epistemologically involved in the ISLE process supports them in developing scientific abilities (Buggé, 2020; Buggé and Etkina, 2020; Etkina, Heuvelen, et al., 2006). Among them, the use of Multiple Representations fulfils the requirement of activating students' reasoning skills as a learning goal in the 21^{st} Century.

All these requirements were in RQ1.

3.5.2 The role of teachers

In this chapter, we tried to highlight the teachers' role in all the frameworks we depicted, analysing and listing the tasks of teaching (Ball et al., 2008; Etkina et al., 2017). We precisely underlined this role with the specific purpose of delineating how substantial is a teaching change for implementing a new learning approach.

The change regards teachers' conception of knowledge, learning and teaching. The change utterly regards the purpose of Physics teaching.

In the ISLE approach, the purpose of Physics teaching is "to empower students with the thinking skills of physicists so that they are able to learn about the physical world both in the Physics course and in their future careers" (Brookes et al., 2020).

This would be the purpose of many Physics teachers. But in teaching practices, they face many difficulties, limitations, and constraints, as described in Chapter 2. It seems that teachers develop "unproductive habits directed towards "survival" instead of student learning" (Etkina et al., 2017, p.1). This is a heavy burden on teachers' professional development, affecting the challenge of change.

A possible way of enacting a change is by supporting teachers in developing habits in a community of teacher-learners (Etkina et al., 2017). Supporting each teacher and growing together could successfully overcome stumbling blocks. This choice is a possible design of teachers' professional training programs, recently shaped by E. Etkina, B. Gregorcic and S. Vokos (Etkina et al., 2017) based on giving more emphasis to the "often under-considered component of teacher preparation, that is the formation of habits" (Etkina et al., 2017).

In fact, the main effort in research-validated practices to portray teachers' preparation programs focuses on conceptualising teacher knowledge and then defining the features of teacher preparation (Etkina et al., 2017).

There are several approaches to conceptualise teacher knowledge, regarding how to train pre-service or in-service teachers (Fazio, 2010), concerning the way of defining teachers' PCK (Magnusson et al., 1999; Zeidler, 2002), also specifically to Physics teachers (Etkina, 2010), the way teachers embody Math and Phys knowledge (Lehavi et al., 2015, 2017), and how teachers' PCK affects students' motivation (Keller et al., 2017), students' future-scaffolding skills development (Levrini et al., 2019), or argumentation skills (McNeill and Knight, 2013; Wang and Buck, 2016). Whereas teacher preparation programs are delineated according to the way the learning is conceived, such as the acquisition of knowledge - the cognitive, constructivist perspective - and the use of knowledge - the situated, socio-cultural perspective - (Etkina et al., 2017; Irving and Sayre, 2014). Integrating teacher knowledge into training programs fulfils some requirements but, at the same time, does even not always take into account teachers' attitudes and beliefs.

Developing habits means establishing a way for conceptualising teacher preparations, based on Dewey's perspective that habits shape human thought and behaviour (Dewey, 1922; Sorzio, 2009). This perspective is an all-encompassing frame for training teachers.

We based our teachers' professional training on this theoretical framework, applying the idea that to change habits, we need to modify conditions

(Dewey, 1922), helping teachers to replace unproductive habits with productive ones. "*New* habits need *new* conditions, different from those that invoke and cement the *old* habits" (Etkina et al., 2017, p. 6).

We extended the model of developing habits from the context of pre-service Physics teacher professional training (Etkina et al., 2017) to an in-service program.

We targeted the goal of encouraging and sustaining Physics teachers with already-formed habits to develop other habits through reflecting, reviewing and adopting *new* tasks of teaching[17], emphasising the developmental need to overcome "survival" habits (Etkina et al., 2017).

Therefore, we employed teachers' adoption of *new* habits as a qualitative measure of the change in their teaching practices when testing a new approach in their classes.

To better pinpoint the feature of this measure, we adopted a conceptual reference frame (Etkina et al., 2017) for describing the habits of Physics teachers.

3.5.3 Defining Habits for Physics Teaching

Dispositions, *knowledge*, and *skills* are the three established concepts for defining habits in teacher education (Etkina et al., 2017). In Table 46, we summarise their definitions and some features concurring in shaping teachers' habits.

Furthermore, there are two main features detailing habits: one is teacher-

[17] We intend *new* referring to the fact that the adoption of a new teaching/learning approach implies *new* tasks of teaching.

Table 46: Habits' concepts definition (Etkina et al., 2017).

Concept	Description	Concept's Details
Dispositions	Intellectual and affective context in which habits develop, shaping teacher's behaviour and thought, relating to teachers' attitudes and beliefs	Towards Learning Physics
		Towards Students Learning Physics
		Towards Learning Physics through ISLE
Knowledge	Intellectual context for the shaping of habits, affecting actions, decisions, and teacher's noticing	Content Knowledge
		Pedagogical Content Knowledge
		Content Knowledge to Physics teaching
Skills	Precompiled procedure that one deploys automatically without consciously thinking about it	Mental Skills
		Emotional Skills
		Technical Skills

intrinsic, and the other is teacher-extrinsic. The teacher-intrinsic feature is flexibility: teachers continually change their dispositions, knowledge and skills in career progression. Many in-service training programs expressly intend to promote innovation in teaching practices, supporting teachers' skills improvements[18] or offering content-topic specific knowledge[19]. Less frequently, these programs focus on dispositions[20]. In any case, the Italian system of instruction does not have mandatory claims to in-service teachers' training; this means that the professional development, and therefore the development of *new* habits, is left to personal interests, attitudes and beliefs

[18]We refer to Italian teaching programs; most of them are methodological training courses, such as those for implementing the use of new technologies in education practices or to empower teachers' scaffolding abilities in classroom management.

[19]For example, after the reform Gelmini of secondary instruction by the schooling year 2010/2011, secondary scientific schools have to provide in their curricula elements of Quantum Mechanics. Many Physics teachers, especially those with a degree in Maths or Engineering, had to enhance their content knowledge about these topics and attended courses targeting this aim.

[20]In Italy, we take as an example of in-service teacher's training targeting the dispositions towards Learning Maths through *Early Algebra*, the *ArAl* Project.

concerning dispositions.

Whereas the teacher-extrinsic feature is the context-dependency: teachers would change their dispositions, knowledge and skills but not rarely are there external constraints which limit the occurrence of habits' changing. These constraints regard the curriculum goals and organisation[21], tools for making laboratory practices, textbooks with traditional settings (based on content transmission teaching, lacking in promoting experimental approach), or *old* habits held by Physics teachers in the same school preventing the others from changing.

To change habits, a training teachers' program must set up, sustain, and perpetuate conditions for forming productive habits (Etkina et al., 2017).

We interrogated the description of productive habits for Physics teachers' preparation program of E. Etkina, B. Gregorcic and S. Vokos (Etkina et al., 2017). Our examination would aim the goal of evaluating if these habits, designed to help teachers create a classroom consistent with the Next Generation Science Standards[22], could be employed in order to address the Italian National Guide Lines (MIUR, 2012) and the Recommendation of the European Council (European Council, 2018). The aim of engaging students in active Science learning practices and building knowledge by cross-cutting concepts is also afforded in our country's instruction policy.

So, we blended the productive habits outlined for the American system

[21]The curricular organisation is related to the timing of specific contents, scheduling of shared assessments for different classes, and preparing final examination tests. This creates a sort of homogeneity in the school environment, making it difficult and sometimes preventing the adoption of different teaching practices.

[22]NGSS Lead States, *Next Generation Science Standards: For States, By States* (The National Academies Press, Washington, DC (2013).

(Etkina et al., 2017) with those needed to sustain the development of habits for Italian in-service Physics teachers. We embraced the outlined habits in terms of habits of mind, habits of practice and habits of improvement and maintenance (Etkina et al., 2017).

In Table 47, we list some examples of each kind of these habits regarding Physics teachers: they could be referred to as an aiming point for teachers' training.

Every habit is conceptually shaped by its specific *dispositions*, *knowledge*, and *skills* (Etkina et al., 2017). There is a nested interrelation between what a Physics teacher believes is right to do in teaching practices, how to lead students to Physics learning, which knowledge needs to accomplish the learning, how to conduct lessons, and experimental activities, for instance.

In the meantime, shaping dispositions, knowledge, and skills is provided by the tasks of teaching.

So, suppose we want teachers to develop *new* habits. In that case, we need to promote in teaching practices *new* tasks of teaching (such as those reported in Table 45), which, day-by-day, through teachers' reflection and revision, become *new* dispositions, *new* knowledge, and *new* skills, substituting *old* unproductive habits with *new* productive ones (Etkina et al., 2017).

3.5.4 Developing Habits for Physics Teaching

We distinguish between developing habits of mind and practice and developing habits of maintenance and improvement.

Table 47: Habits' components (Etkina et al., 2017).

	Component	Description	Examples
Physicist	**Habits of mind**	Looking reality with inquiry's eyes	Noticing application of physics laws in the surrounding world
			Approaching problem solving as a physicist
			Treating physics as a process, not a set of rules or a collection of information
			Using mathematics in a physics-specific way
Physics Teacher	**Habits of minds and practice**	Spontaneous thinking and attending to student physics-related reasoning, questioning, and development. Managing classroom activities, leading to student learning	Helping students connect new ideas to their previous
			Attending to students' thinking regarding the physical world
			Listening to student conversations, comments, and questions related to physics
			Treating all students as capable of learning physics
			Reflecting on the role that language plays in student learning
			Being aware of the "surroundings" as a source for learning Physics
	Habits of improvements and maintenance	Providing effective actions to avoid "survival" teaching mode	Engaging in ongoing professional development
			Taking part in professional learning community
			Being engaged in Physics education research
			Disseminating good practicing

3.5.4.1 Physics teaching cognitive apprenticeship

As the theoretical framework for developing productive in-service teachers' habits of mind and practice, we considered cognitive apprenticeship (A. Collins and Kapur, 2014). This is a" model of instruction that works to make thinking visible" (A. M. Collins et al., 1991, p.13). It consists of learning-through-guided-experience on cognitive and meta-cognitive skills and processes (A. M. Collins et al., 1991).

Involving in-service teachers in this practice needs to mix different programming teachers' training models. There are many constraints to overcome; the most important is "finding time" in a work which engages completely teacher under different viewpoints. Looking at teaching work, the teacher spends:

- time-employment in classrooms;
- time-preparation (of lectures, tests, activities...);
- time-assessment (correction, revision, re-submission...)
- time-school practices (plenary or classroom meetings, school management, meetings with parents...);
- time-for-training courses (if time left).

A possible way to overcome the time constraint is to take part in teaching work. Not asking teachers to find time but accompanying them in the teaching process they are still employing daily. In this context of cognitive apprenticeship, the learner is the teacher, and the researcher embodies the role of the facilitator.

Therefore, teachers are engaged in a cognitive apprenticeship based on clinical practice in their school context, in their classes, and with their students. So, we could refer to this kind of cognitive apprenticeship as context-environmental. This supports:

- teacher self-regulation, as the process through which teachers transform their mental abilities into task-related skills (Zimmerman, 2000);
- teacher self-efficacy, as the degree to which teachers evaluate their abil-

ities to bring about positive student change in facing unforeseen difficulties (Tschannen-Moran et al., 1998);

- teacher motivation, as the factor determining teachers' instructional behaviour and hence students' outcomes (Keller et al., 2017).

All of them sustain the development of *new* habits.

Referring to cognitive apprenticeship (A. Collins and Kapur, 2014), we defined the related actions and main role activated (Table 48).

Table 48: Cognitive apprenticeship phases (A. Collins et al., 1987).

Description Phase	**Phase**	**Main Role**
Contexts that model proficiency	Monitoring Phase	Researcher
	Reflection Phase	Teacher
		Researcher
Providing coaching and scaffolding	Coaching Phase	Researcher
	Reflection Phase	Teacher
		Researcher
Slowly removing scaffolding	Tutoring Phase	Researcher
	Reflection Phase	Teacher
		Researcher
Independent practice	Reflection Phase	Teacher
		Researcher

For each phase, we briefly describe the setting, timing and aims related to the development of habits. Each phase is a specific method tailored to implement cognitive apprenticeship based on clinical practice in classrooms.

- In the *Monitoring* phase, the researcher took part in all teacher's classroom activities, observing, recording observations, and noticing all could be relevant in terms of teachers' dispositions, knowledge and skills (Etkina et al., 2017). This phase is relevant to activate the revision process of teaching practice and eventually profile unproductive habits. It is not properly part of the cognitive apprenticeship process, but it is a stressed starting point to contextualise the change's activation. It feeds the reflection phase. From a teacher's point of view, it could be better to call it *Diagnostic phase.*

- *Coaching* consists of observing teachers while they carry out a task and offering hints, scaffolding, feedback, modelling, reminders, and new tasks (A. Collins et al., 1987). *Coaching* focuses on the enactment and integration of skills in the service of a well-understood goal through highly interactive and highly situated feedback and suggestions.
- The *Tutoring* phase consists of the *Scaffolding* phase and the *Fading* phase. *Scaffolding* the supports the researcher provides to help the teacher carry out a *new* task (A. Collins and Kapur, 2014; Reiser and Tabak, 2014). This could happen at different timing of teachers' practices (lessons' preparation, lessons' implementations, lessons' revision). Whereas *Fading* consists of the gradual removal of supports until teachers are on their own (A. M. Collins et al., 1991), adopting the *new* tasks, and *new* habits.
- The *Reflection* phase pervades all the others (A. Collins et al., 1987; A. M. Collins et al., 1991). It gives consistency to professional development training. With reflection during development, planning, designing, implementing, and analysing, teachers revise their tasks of teaching, comparing the *old* ones with the *new* ones, and become more confident to move towards the adoption of the *new*, even without any facilitator's support. This is crucial to make effective the process of

development of productive habits.

3.5.4.2 Physics teaching community of practice

In order to develop habits of maintenance and improvements, we needed to create a teachers' community of practice. The learning community serves multiple roles in teaching programs (Etkina et al., 2017; Etkina, 2015b).

A community of practice serves as (Etkina et al., 2017, p.11-12):

1. "a complex of positive feedback loops";
2. "it reinforces habits and common values";
3. "a social network";
4. "a safe environment in which in-service teachers can share dilemmas of practice".

For the purpose of our project research, the most important goal is to sustain teachers in their challenge of changing habits.

Sustaining teachers means:

- creating a "physical" place where teachers with researchers could share ideas, difficulties, outcomes and perspectives;
- promoting and planning together activities carrying out professional training towards teaching innovation practices;
- reducing the overwhelming effect of the Physics teacher's isolation.
- preparing materials, resources and whatever is necessary for *new* teaching practices dissemination.
- documenting teachers' good practices with reports, papers and applying to conferences of Physics teachers.

By forming a community of practice, we intentionally want to give a sense of identity to all of those teachers who recognise the need to change and are engaged in a productive apprenticeship (A. M. Collins et al., 1991) in the adoption of a *new* Physics teaching/learning approach.

This means a long-term in-service teacher training program because changing habits is noteworthy and difficult to achieve. It needs time and a supportive community where each participant is enhanced by the others and becomes self-confident about realising the change.

3.5.5 Targeting Research Question #2

In Chapter 2, we established the aim to find a theoretical approach to choosing an appropriate framework to guide teachers' professional development and to help teachers bring their instructional practices in alignment with the Recommendations of the European Union Council.

This aim led us to formulate the following research question:

> (RQ2): *How to develop a professional development program that helps physics teachers to adopt and implement a new approach?*

We pinpointed the answer to this question, motivating our choice towards the program for developing teachers' habits in a cognitive apprenticeship with the support of a community of practice(Etkina et al., 2017).

* * *

Chapter 4

Developing Teachers' Habits: Case Studies

This Chapter consists of two main sections. The first section details the research methodology chosen to monitor and analyse the teachers' process of developing *new* habits (Etkina et al., 2017), providing information about the setting, the sampling, the implementation, how the data has been collected and analysed.

Whereas the second section furnishes a deep insight into sampled teachers' cases as the follow-up of our analysis. The analytical description of each teacher tried to emphasise the features of the process embraced, how they reflected upon and inside their teaching practices and how they answered their need to change. At the end of this section, we briefly included a whole perspective behind all the schools involved in this research project.

4.1 Methodology

In this research, we used a multi-phase mixed-method design (Creswell and Clark, 2017; Johnson et al., 2007; Sawyer, 2014) to analyse how teachers changed their dispositions, knowledge and skills (Etkina et al., 2017) by adopting a new teaching approach and how they redefined their habits of mind and practice. This method allows great flexibility by combining qualitative and quantitative data in sequential or concurrent timing (Creswell and Clark, 2003, p.70). Furthermore, it provides a deep insight into evolving situations and programs, featuring changing progress and process (Creswell and Clark, 2003; Johnson et al., 2007).

We could acknowledge teachers' development by combining the simultaneous collection, analysis, mixing, and merging of qualitative and quantitative data. The concurrent data collection method is then recollected into the whole design to emphasise better the intervention's role (K. M. Collins et al., 2006).

As a category of the rationale for this study, we mainly referred to triangulation which enables crosschecking and corroborating results using different types of data (Creswell and Clark, 2017; Greene et al., 1989).

This method research section includes a brief overview of the research setting, implementation phases, sample features, data collection and analysis methods.

4.1.1 Setting

Trieste is a town of middle dimensions situated in the North-East region of Italy. It lies at the borders of Slovenian country in a strip of land with mixed cultures and languages (in the surroundings, there are two spoken languages, Italian and Slovenian). The main feature of Trieste is multiculturalism, covering many fields of interest, from literature to science. For a long time, it was the sea town of the Austro-Hungarian empire (1700-1900), which influenced its industrial evolution and development. Today Trieste is internationally recognised as the "City of Science" for the number of international science institutes here. For this reason, Trieste is the European city with the highest density of researchers (37,1 research workers per 1.000 workers), with almost 30 research centres, more than ten thousand researchers, and one-half of foreigners (Comune di Trieste, 2022).

In this fruitful context of scientific dissemination, knowledge building and development of scientific ideas, there are 20 high schools, five of them with Slovenian spoken language (Table 49).

Local secondary students and teachers often engage in events and activities organised by researchers. Therefore this research project was well-accepted by almost all the secondary schools involved.

In our secondary schools, the Physics teachers have similar characteristics, including master's degrees (Fig.56)[1], teaching years as in the Italian ones (Magliarditi et al., 2020, p. 151), and subject matters of teaching (Fig.

[1] *Others* include Astronomy, Statistics, and Chemistry for teaching Integrated Science, which also includes Physics.

Table 49: High schools in Trieste (Italy); Slovenian schools are labelled (SLO).

Description	**Italian Denomination**
High school for scientific studies	Liceo Scientifico G. Galilei
	Liceo Scientifico G. Oberdan
	Liceo Scientifico F. Preseren (SLO)
High schools for linguistic studies (ancient and modern)	Liceo Classico-Linguistico F. Petrarca
	Liceo Classico-Linguistico D. Alighieri
	Liceo Linguistico Bachelet
High schools for Humanities Sciences	Liceo delle Scienze Umane e Musicale G. Carducci
	Liceo delle Scienze Umane A. M. Slomsek (SLO)
High schools for Arts	Liceo artistico E. e U. Nordio
Technological Istitutes	Istituto Tecnico Industriale A. Volta
	Istituto Tecnico Industriale J. Stefan (SLO)
	Istituto Tecnico Commerciale Da Vinci - Carli
	Istituto Tecnico Commerciale e per geometri Ziga Zois (SLO)
	Istituto Tecnico per Geometri M. Fabiani
	Istituto Tecnico Biologico-Sanitario G. Deledda
	Istituto Tecnico Nautico Tomaso di Savoia
Professional Istitutes	Istituto Professionale L. Galvani
	Istituto Professionale Commerciale S. De Sandrinelli)
	Istituto Professionale Industriale e Artigianale J. Stefan (SLO)

57)[2]. It is important to know that the teachers in the category "Maths

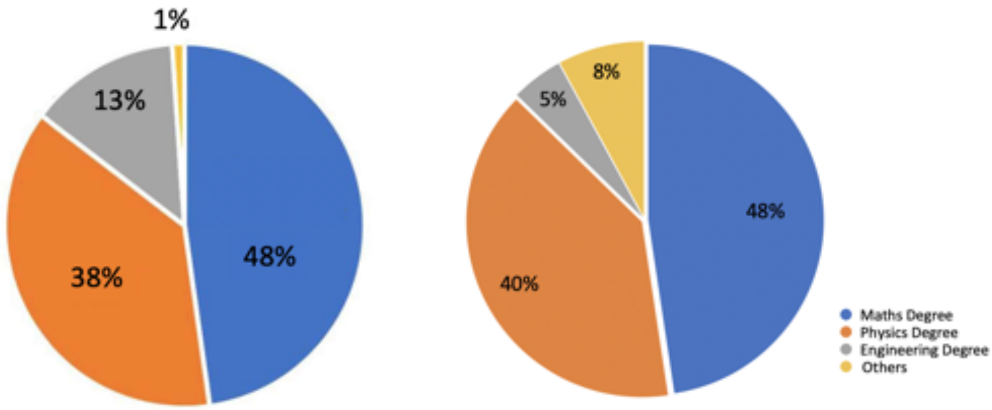


Figure 56: Distribution of Italian Physics teachers (on the left, Magliarditi et al., 2020) and local Physics teachers (on the right) in secondary schools according to their Master's Degree.

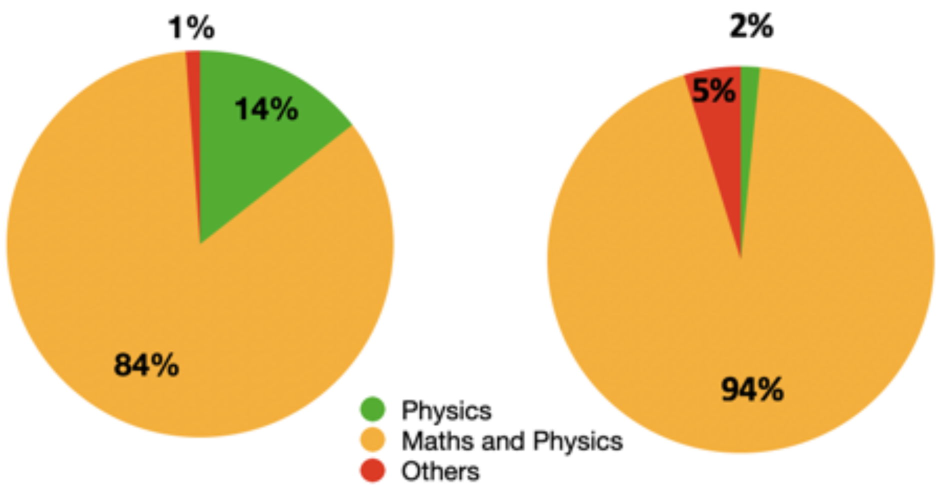


Figure 57: Distribution by teaching subject matters of Italian Physics teachers (on the left, Magliarditi et al., 2020) and local teachers (on the right) according to their teaching subject matters.

and Physics" typically have a background in Maths, Physics or Engineering (with a prevalence of Maths); those who teach only Physics have a Physics Degree or specific Engineering. The effect of this instructional organisation

[2] *Others* include Optics, Electronics and Informatics.

and subdivision is that, at scientific high schools, many teachers with a Maths Degree also teach Physics for all five curricular years of Physics instruction. Teachers with a Physics Degree work in technological/professional secondary schools where Physics is a subject matter only the first two years (for more details on the Physics curriculum at secondary schooling, see Table 13 in Chapter 2).

There is another aspect relevant to our study. There are two kinds of teachers in Italian schools: one with a permanent position (full-time or part-time) and the other with a temporary position. The "permanent" teachers remain in the same school until they ask to change. In this way, they could guarantee teaching continuity (the same class over the years if the school management agrees). The "temporary" teachers could occasionally (and mandatory by temporary position management) change schools also during the academic year (the vacancies are established and filled by regional-national lists of who can teach) without any teaching continuity for the school administration and the class activities.

From a teaching/learning perspective, this turnover of temporary teachers is not worthwhile and could affect the quality and efficacy of the teaching/learning process. There have been many tentative reforms to resolve the problem in Italian instruction of "temporary teachers" because it affects both young people and those who have been teaching in this unstable situation for more than twenty years. But until now, the problem is still unresolved.

The "temporary" feature does not limit the teachers' possibility to participate in in-service training programs. Teachers could improve their work professionally even in a "temporary" condition. They could not measure the changes over the years and the same students. But they could start to reflect and develop habits as permanent teachers do. In the schools involved in this study, the 25% of teachers are temporary, while the 75% is permanent.

As relevant for the description of the setting, we'd like to focus on teachers' professional isolation (Dussault et al., 1999; Pedditzi, 2005; Porru et al., 2022) as a consequence of the intrinsic organisation of teachers' work in secondary schooling. They prepare lessons, materials, and worksheets for assessments alone. Timing for exchanges, discussions and professional growth is not included in working hours; in-service training is not mandatory and is left to personal interest and needs. There are disciplinary departments that group teachers by area of teaching.

But the roles of these departments are mainly:

- to build the school curriculum in the framework of National Guidelines (MIUR, 2012);
- to ensure students' formative success in organising recovery courses (by year and not by teacher) for those who need them at the end of the first or the second schooling period[3];
- to approve participation in educational projects (internal or external).

Also, in our study, we recorded professional isolation through teachers' interviews.

Finally, teachers' work is organised weekly for 18 hours/week (full-time position, 13 hours/week or less part-time); they have three or more classes where they teach Maths, Physics, or both. The number of hours of Physics

[3]Every academic year has two terms, one with the intermediate summative grading and one with the final.

courses depends on the kind of secondary school. In Table 50, there is the detailed distribution of hours for Physics courses in Italian secondary schools.

Table 50: Weekly hours per Physics course in Italian secondary schools.

High School Description	**1st year** (grade 9)	**2nd year** (grade 10)	**3rd year** (grade 11)	**4th year** (grade 12)	**5th year**
Scientific	2	2	3	3	3
Tech. Industrial	2	2	*3*[a]	*3*[a]	*3*[a]
Ancient Languages	–	–	2	2	2
Modern Languages	–	–	2	2	2
Humanities Sciences	–	–	2	2	2
Arts and Music	–	–	2	2	2
Technical	2	–	–	–	–
Professional	2[b]	2[b]	–	–	–

[a] Physics-based technical course.
[b] The course is named "Integrated Sciences", and includes Physics hours. All teachers with a Master's Degree in Sciences could teach the course.

4.1.2 Implementation

The teachers involved in our research took part in the process of developing their habits through the implementation of activities for their classes. The researcher guided and supported the implementation, with the role of a facilitator in adopting the new approach to teaching activities. In the following description, we stressed the researcher and the teacher's role during the implementation time. This implementation regards each class chosen by the teacher (about one class per academic year per teacher). The implementation's sequence consists of the phases:

- Context-Class Phase

- Content-Design Phase
- Clinical-Practice Phase
- Reflection-Review Phase

These phases are part of the in-service cognitive apprenticeship (A. Collins and Kapur, 2014) teachers got involved in. We can distinguish the researcher's actions that sustain teachers in each phase (see Table 51).

Table 51: Implementation phase and correspondent actions (by the researcher (R), by the teacher (T)).

Implementation phase	**Action**
Context-Class Phase	Monitoring (R)
	Reflecting (R - T)
Content-Design Phase	Coaching (R)
	Tutoring (R - T)
	Reflecting (R - T)
Clinical-Practice Phase	Monitoring (T)
	Tutoring (R - T)
	Coaching (R - T)
	Reflecting (R - T)
Reflection-Review Phase	Reflecting (R - T)

It is worth emphasizing that the process can be described as the same even if each teacher had an individual training and a different classroom implementation.

4.1.2.1 Context-Class Phase

The Context-Class Phase consists of a long and detailed description of the classroom. The researcher guides the teacher through analysing the course from different points of view. The information collected concerns both the learning and teaching aspects. From the learning point of view, this phase allows the teacher to take a snapshot of the course, describing students' learning difficulties or the learning environment, such as engagement in lessons. Table 52 reported each aspect of the description pursued by the teacher.

Table 52: Learning features to contextualise the class.

Aspect of learning	**Description**
Learning difficulties	Analysing past written and oral tests
	Examining difficulties in a specific content-topic
	Concerning specific students' scientific abilities
Learning environment	Classroom setting
	Classroom feedback
	Classroom engagement
Learning Context	School/Department expectations/tasks
	Parents' expectations
	Students' expectations

Regarding teaching, the context-class phase outlines the teacher's instruction strategy and methodology used. This phase helps to gain insight into PCK, referring to this specific classroom context. The teacher reports about curricular goals, the way used to achieve them, and the timing for planning activities (to satisfy the department's requirements concerning National Guidelines).

In this phase, the role of the researcher is to develop a detailed description of the teaching/learning environment to build the Content-Class phase. In the acquisition process of information, the teacher and the classroom could be monitored by the researcher [4].

The Context-Class phase could be considered the first step in the teacher's reflection process. For each teacher, the time spent to make this phase was not the same and depended on the teacher's disposition to go in depth in the classroom analysis.

4.1.2.2 Content-Design Phase

The Content-Design Phase is fundamental in developing teachers' habits of mind and practice (Etkina et al., 2017). In this phase, the role of the researcher is to guide the teacher to recommend the tasks of teaching needed in a specific topic content-building knowledge process and to set them up in the context of the classroom and in the framework of an *Early Physics*.

This phase began with analysing the textbook and how the teacher used it to explain the topic. We could refer to this step as revising the teacher's Content Knowledge for Teaching (Ball et al., 2008; Etkina et al., 2017; Etkina et al., 2018). Most teachers involved in the research project have many years of teaching experience. In this step, they reviewed teaching experiences in past academic years, how they taught specific content, and how they built the explanatory process. The review also concerned the choice of problem-solving exercises and knowledge-reinforcing activities. Then, we approached teachers with the adoption of the main framework we described by the characterisation of an *Early Physics* (as detailed in Chapter 3).

We gradually trained and coached each teacher in transitioning from the

[4] In the research design, we also planned the monitoring activities in this phase. Due to Covid-19 restrictions, we could not monitor all the classes, and sometimes the monitoring was done during online lesson activities in the lock-down periods.

traditional approach (based on a mathematical model of physical law) to adopting the ISLE one. In the beginning, we started focusing on the Content-Design implementation by using Multiple Representations (Ainsworth, 1999; Munfaridah et al., 2021; Opfermann et al., 2017) and Observational Experiments (Brookes et al., 2020). This intermediate throughout was necessary to give teachers time (and not the same time for every teacher) to explore and be confident with the ISLE (from a content management point of view). In the meantime, we investigated with them the ISLE textbook (Etkina, Planinsic, et al., 2019), noticing the differences between the Italian ones. This investigation led us to convey teachers' knowledge towards a different way of Concept-Design.

Step by step, we prepared together the class organisation and set-up, enhancing some features of the learning activities, such as the use of the *need to know* question at the beginning of the exploration of a new concept (Brookes et al., 2020, pg. 020148-10), and the inclusion of all types of ISLE-based experiments (Brookes et al., 2020), which are profoundly different from the "Demonstrative" (Demo) ones[5].

During this phase, we studied with the teachers the ISLE-based curriculum materials, which are all in the English language[6]. We simultaneously worked exploring the two distinguished categories: the materials for the algebra-based College Physics courses (Etkina, Brookes, Planinsic, and Van Heuleven, 2019) and the ones for secondary schools (Etkina, Brahmia,

[5]Demonstrative Experiments are the most common in Italian Laboratory practices (LS-OSA, 2022) in high schools.

[6]For some teachers, the different language relevantly hinders the use of the materials without the researcher's support.

et al., 2010). Comparing the ISLE-based curriculum with the Italian one, we chose those activities which better satisfied the requirements of our system of instruction, mainly from the algebra-based College Physics ones; in this process of selecting, choosing, adapting and translating into Italian, we devoted many efforts to structure activities with increased scaffolding and emphasised mathematical reasoning (Buggé, 2020), with the mainstream of requiring students to coordinate multiple representations (Brookes et al., 2020; Etkina and Planinšič, 2015).

The more deeply teachers discovered and studied the materials, the more skilled they became in integrating the Content-Design with all the features of the ISLE learning Cycle (see Fig. 54).

This Content-Design phase included planning all the activities, preparing the materials, homework and assessment. The teachers immediately highlighted the lack of an Italian version of the ISLE textbook. The ISLE textbook discusses the same experiments and contains homework problems, most of which are nontraditional in structure and relate to everyday phenomena (Brookes et al., 2020, p. 020148-10). On the contrary, there were no problems or exercises for homework assignments in Italian textbooks that could support the content-knowledge-building consolidation activated in the classroom in the ISLE environment. In Italian textbooks, at the end of each chapter, there are regular problems based on a mathematical representation of Physics laws, requiring the manipulation of formulas to give the result (Bologna and Longo, 2022; Leban et al., 2020). So, a great amount of time was spent by teachers during this phase to create or translate exercises for homeworking and then for assessment.

As time went by, the role of the researcher in supporting and helping teachers decreased gradually. Initially, coaching and tutoring actions were necessary. Then, the teachers became self-confident and self-efficient and started preparing lessons and materials without the researcher's support.

4.1.2.3 Clinical-Practice Phase

The Clinical-Practice Phase consisted of performing the activities planned in the Content-Design phase in the classroom. This phase concerned the development of teachers' habits of practice.

For each Content-Design phase, a Clinical-Practice phase follows. In this phase, the role of the researcher depended on the teacher's self-confidence and the school's restriction rules for COVID-19. Most of the teachers, if allowed, preferred the coaching, scaffolding and tutoring in the co-presence of the researcher also in this phase. So, the activities were employed together, with the role of the researcher as a facilitator to improve the teaching practices towards the ISLE approach.

The Clinical-Practice has to be considered the most difficult from the teacher's point of view. A well-done and detailed Content-Design provided planned lessons and activities. Instead, the Clinical-Practice encouraged teachers to develop the habit of student-centred teaching in the ISLE environment (Etkina, 2015b). The change from teacher-centred to student-centred teaching is slow and needs a lot of practice, even if the Content-Design sustains it.

4.1.2.4 Reflection-Review Phase

The Reflection-Review Phase involves the development of teachers' habits of maintenance and improvements. The reflection phase is also fundamental in cognitive apprenticeship (A. Collins et al., 1987; A. Collins and Kapur, 2014). The main outcome of this phase is activating the teacher's awareness towards professional growth. The Reflection-Review phase could be distinguished into two moments and involves the teacher's reflection from both teaching and learning standpoints:

- the self-reflecting time;
- the community-reflecting time.

The first was activated by the change process in which the teacher was engaged. In the self-reflecting time, a teacher could share ideas, feedback, and doubts with the researcher regarding Content-Design or Clinical-Practices.

Each teacher decides how much time to spend on this phase. Some teachers asked for a review moment after each lesson or activity in the classroom, while others only at the end of the Clinical-Phase. With increasing self-confidence and self-efficacy, the need to reflect on time decreases. In this phase, we also considered the time spent reflecting on students' learning improvements, assessments, or difficulties.

The reflecting time was gradually increased in the research project, promoting teachers' meetings, training activities, focus groups and time for exchanges of experiences. The time for community reflection was necessary to create the sense of belonging teachers need to overcome professional isolation in their schools (Pedditzi, 2005; Porru et al., 2022).

4.1.3 Sampling

The research project was proposed to many high schools in Trieste and its surroundings. In our proposal, at each school Department of Maths/-Physics teachers, we presented the main goals, the outcomes desired and the timing for realising the project, encouraging teachers' participation and the professional improvement they could enact by being engaged. There was no funding for teachers' participation (as sometimes happens in other school projects, recognising extra work). Physics teachers were volunteers to get involved and chose to participate in the research for almost two to three academic years (2019/20; 2020/21; 2021/22). So, the sampling consists of those teachers recruited for the research project. According to the method of recruitment used, we could refer to our sample as purposeful random (Palinkas et al., 2015), knowing the population and the purpose of the study (Merrian and Tisdell, 2016).

Table 53 summarises the features of a prior sampling, referring to teachers' schools, the number of teachers and classes sampled. In this Table, we do not consider the academic year 2019/20 because it was basically employed for studying teachers' and students' conceptions (see Chapter 2). With respect to this prior sampling, we definitively considered sampling eight teachers. With them, we could implement research activities in classrooms throughout the years. This ensures we can describe the process of each teacher's developing habits through all the implementation phases.

Table 54 reports information about these teachers' backgrounds (Master's Degrees), years of teaching experience, kind of position and teaching subject matters.

Table 53: Prior sample feature: schools, Physics teachers, classes.

School	Number Physics Teachers	2020/2021		2021/2022	
		Number Teachers Sampled	Number Classes Sampled	Number Teachers Sampled	Number Classes Sampled
Galilei (LS)[(a)]	15	1	1	1	1
Oberdan (LS)[(a)]	15	2	3	3	7
Petrarca (LL[(b)]/LC[(c)])	11	2	2	2	2
Carducci/Dante (LSU[(D)]/LL[(b)]/LC[(c)])	15	2	/	1	1
ISIS Gregorcic[(e)] (LS[(a)]/LL[(b)]/LC[(c)])	5	1	4	1	4
Carli/DaVinci Sandrinelli (IT[(f)]/IP[(g)])	2 (Sciences)	2	/	2	3

(a) LS: Liceo Scientifico - High School for Scientific Studies.
(b) LL: Liceo Linguistico - High School for Linguistic Studies.
(c) LC: Liceo Classico - High School for Classical Studies.
(d) LSU: Liceo Scienze Umane - High School for Humanities Sciences.
(e) SLO: Slovenian spoken language.
(f) IT: Istituto Tecnico - Technological Institute.
(g) IP: Istituto Professionale - Professional Institute

Looking at Table 54, we can recognise some interesting features of our sample. First, among the teachers, only one has a temporary position; two are a novice teachers in Maths/Phys, but one with a background in teaching at middle schools; all the others are expert teachers with professional experience between eight to almost twenty years (both in temporary and permanent positions). Secondly, most of them also teach (or have taught) Maths (only one teaches Physics purely). Lastly, the 50% has a Master's Degree in Maths, the 25% in Physics and another 25% other (Astronomy and Chemistry); the teachers' background distribution is similar to the local and Italian ones (Fig. 57), mainly referring to those having a Maths Degree. The

Table 54: Sample feature: teachers, background, professional features (in order to protect the anonymity of the teachers in the study, pseudonyms are used, and we'll refer to the teachers with the label of this Table).

Sampled teachers	**Background**	**Number of Years of teaching experience**$^{(1)}$	**Kind of position**$^{(2)}$	**Teaching Subject Matters**$^{(2)}$
Teacher #1	Maths	8	Temporary	Maths Tutoring for Engineering
		9	Temporary	Maths/Phys
		6	Permanent	Maths/Phys
Teacher #2	Maths	8	Temporary	Maths/Phys
		8	Permanent	Maths/Phys
Teacher #3	Physics	2	Temporary	Maths/Phys
		Sept. 2022	Permanent	Physics, Optics
Teacher #4	Maths	9	Temporary	Maths/Phys
		10	Permanent	Maths/Phys
Teacher #5	Maths	8	Temporary	Maths
		3	Permanent	Maths, Sciences
		3	Permanent	Maths/Phys
Teacher #6	Astronomy	4	Temporary	Maths/Phys
		16	Permanent	Maths/Phys
Teacher #7	Physics	3	Temporary	Maths/Phys, Informatics
		14	Permanent	Physics, Integrated Sciences
Teacher #8	Chemistry	3	Temporary	Chemistry, Maths and Sciences
		5	Permanent	Chemistry, Integrated Sciences

$^{(1)}$ The number of years refers to September 2022.
$^{(2)}$ The highlighted cells correspond to the professional features during the research project.

similarity between distribution advises our sample could be considered representative (Aiken et al., 2021) of the context population (Physics teachers of High schools in Trieste).

Many other teachers participated in the research project at different stages and manners. They mostly participated in clinical practices or community-reflecting activities in the in-service training opportunities we offered them. We could occasionally collect data from their feedback, experiences, and reflections.

The overall group of teachers engaged in the research is described by years in Table 55. In the Table, we add a column to show how many Physics teachers are still involved in developing habits during the academic year 2022/2023.

Table 55: Total number of Physics teachers engaged in the research project (the teachers sampled are included).

Phase	**20/21**	**21/22**	**22/23**
Context-Class	10	10	14
Content-Design	10	10	14
Clinical Practice	10	11	24
Reflection-Review	10	17	24

4.1.4 Data Collection

The data we collected in our research refers to the teachers' process of developing productive habits (Etkina et al., 2017) in the cognitive apprenticeship program developed (A. Collins and Kapur, 2014). The insight into this process addresses the two research questions (RQ3 and RQ4).

The data gathered from the process of developing habits mainly concerns how teachers responded to the tasks of teaching we proposed to them. We could collect data in each implementation phase. These data are both qualitative and quantitative. We briefly described them in the following subsections. As preliminary to the data collected list, we describe how teachers were recruited for the research project.

4.1.4.1 Recruiting Teachers

The teachers recruited for this research followed the invitation we offered to secondary schools in Trieste at the beginning of the academic year 2019/20. We planned two meetings in every secondary school: one with the school administrator/director-in-chief and the other with the members of the disciplinary department (usually the Maths/Phys or Science department).

In the two meetings, we detailed our research goals, the main actions, the timeline planning, and what kind of requests the teachers had to accomplish.

Then, the research project was approved for the next three years by the school board of teachers and inserted into the design of the school's main formative project (the so-called PTOF, Piano Triennale dell'Offerta Formativa). In this way, we could participate in lessons, school activities and what we could need to realise the project. Therefore, the researchers of the Physics Department of the University of Trieste signed an agreement with each school board staff.

Even if the research project had been accepted, inserted into PTOF, and reciprocally signed (by the school director and Physics Department researchers) in eight secondary schools, only six schools got involved in the research project with their teachers. This was a limitation for our data collection in terms of sampling, mainly due to the spread out of the COVID-19 pandemic.

4.1.4.2 Classroom observations

Data was collected from the classroom observations of physics teaching through field notes documented in a research log. Written accounts from meetings or field notes served as data as needed to substantiate and document happenings or emergent meaning. Field notes came in many forms and included descriptions, direct quotations, and observer comments.

All classroom observations were scheduled at the teachers' discretion and in advance to ensure that observations did not conflict with other teaching activities at the school, such as a test of other disciplines or a larger school activity.

The observations were planned and conducted during the first research project year (2019/20). All the sampled teachers were observed during their teaching practices, unless Teacher #3 and Teacher #6. Teacher #3 joined the research project during the academic year 2020/21, whereas we planned the observations with Teacher #6, but we could never enter classrooms for the restrictions due to the pandemic.

For the same reason, some observations occurred in online classroom activities in distance learning mode activated during lockdown periods. The schools adopted different protocols and policies for managing the emergency: in some schools, it was possible to observe teaching practices during online lessons, but in others, it was not. This motivates the fact that we did not observe teachers working the same hours.

During each classroom observation, only notes were taken to record the events of each lesson in order to document its features and the teachers' practices, including student-teacher interactions, part of classroom discourses, and tasks carried out by teachers.

As it was possible, we observed teachers for at least an entire Learning Unit: this is a technical Italian didactic term to delineate the part of the curriculum regarding specific content topics to develop in classroom activities. Each Learning Unit generally concerns one key concept, from its explanations to related problem-solving, exercises, and final assessment.

Observation data is reported in Table 56.

Table 56: Observation data for each sampled teacher.

Teacher	**Observation hours in presence**	**Observation hours online**	**Total hours**
Teacher #1	5	11	16
Teacher #2	8	-	8
Teacher #3	n.d.	n.d.	n.d.
Teacher #4	12	11	23
Teacher #5	10	16	26
Teacher #6	n.d.	n.d.	n.d.
Teacher #7	12	-	12
Teacher #8	6	-	6

4.1.4.3 Teaching Artifacts

Teaching artifacts are ”things” that document the work done “off stage” in preparation for and reflection upon the work with students. We collected teachers’ artifacts as a sample that exemplify their lesson planning and preparation practice. Collecting, creating, analysing and discussing artifacts is also central to the development of teacher-as reflective-practitioner.

The kinds of artifacts to collect are those listed in Table 57, with corresponding indicators of which their analysis could retrieve information.

Table 57: Teaching artifacts and their indicators.

Teaching Artifact	**Indicator**
Lessons and unit plans	Organising Content Knowledge Building
	Designing Student Assessments
	Designing Coherent Instruction
Annotated lesson plans	Reflecting of teaching
Teacher log	
Assessment with scoring rubric	Designing Student Assessments
Instructional map	Designing Coherent Instruction
Resources and Materials	

A brief description of teaching artifacts is the following:

(1) *Lessons and unit plan*: description of one curriculum topic. A Unit plan encompasses key content components to be covered and student learning outcomes. A lesson plan is a step-by-step road map for teaching one lesson. There could be different lessons plan for each day of teaching. Unit plans are the macro, and lesson plans are the micro.

(2) *Annotated lesson plans*: statements in the lesson plan to clarify what the lesson will cover and focus on how to help students with the upcoming content.

(3) *Teacher log*: the teacher's notebook with all the notes for the lessons. Some teachers use teacher logs as lesson plan sheets.

(4) *Assessment with scoring rubric*: Tests elaborated to formative assessment at the end of each Learning Unit and their rubrics with assessment

criteria.

(5) *Resources and materials*: all the materials developed for conducting lessons, such as worksheets for lab activities, multimedia presentations, exercises and problems, and learning paths using online tools and software (some of them could be considered as resources).

Table 58 presents the teaching artifacts collected during the research project. The number of artifacts varies for each teacher sampled.

Table 58: Teaching artifacts collected.

Teacher	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**TOT.**
Teacher #1	4	2	1	8	8	**25**
Teacher #2	3	-	-	3	2	**8**
Teacher #3	5	-	-	4	6	**15**
Teacher #4	2	-	-	5	4	**11**
Teacher #5	2	-	-	4	3	**9**
Teacher #6	2	-	1	2	2	**7**
Teacher #7	1	1	1	2	2	**7**
Teacher #8	1	1	-	1	2	**5**

The great differences between teachers reside in the custom of practices. Some prefer to prepare unit plans, lesson plans, and logs, writing step-by-step instructions thoroughly.

Italian teachers are not compelled to report their teaching work through these artifacts. The mandatory artifacts are the Year-long plan (scope and sequence) and students' summative and formative assessments (documenting student's learning progress).

We collected all those that are the indicators of the teacher's dispositions, knowledge and skills (Etkina et al., 2017). All artifacts are written in Italian language. We used these data as they were, without translating them into English.

These artifacts document the activities teachers conducted in their classes. In Table 59 and 60, there are listed the hours teachers spent in their classes implementing innovation in their practising.

Table 59: Teaching activities report by year 2020/21. In **bold**, the activities performed with or without the researcher's presence.

Teacher	Hours implemented	Investigation	# Teaching Artifacts
Teacher #1	**20**	Geometrical Optics	5
Teacher #2	**25**	Incline plane	3
		Wave Phenomena	1
Teacher #3	24	Circular motion	3
		Work and energy	3
Teacher #4	**15**	Work and Energy	4
Teacher #5	**10**	Work and Energy	3
Teacher #6	-	-	-
Teacher #7	-	-	-
Teacher #8	-	-	-

4.1.4.4 Formal/Informal Discussions

Formal and *Informal Discussion* are the core of our cognitive apprenticeship program. We assisted teachers in their process of developing habits through a meaningful, intensive, collaborative dialogue. This time of talking could be distinguished between *Formal* and *Informal* concerning the dis-

Table 60: Teaching activities report by year 2021/22. In **bold**, the activities performed with the researcher's presence or without.

Teacher	**Hours implemented**	**Investigation**	**# Teaching Artifacts**
Teacher #1	80	Circular motion	5
		Impulse and momentum	5
		Work and energy	5
Teacher #2	**16**	One dimension Kinematics	2
		Electric Field	1
		Magnetic Induction	1
Teacher #3	122	Introduction to Physics	2
		One dimension Kinematics	1
		Force and motion	1
Teacher #4	**16**	One dimension kinematics	2
		Circular motion	2
		Newton's Laws	2
Teacher #5	**10**	One dimension kinematics	2
		Newton's Laws	1
Teacher #6	12	Electrostatic phenomena	7
Teacher #7	**8**	Energy	3
Teacher #8	**10**	One dimension Kinematics	3

cussion topic, its function and communication media preferred. Table 61 summarises these features.

We took into account the hours dedicated to *Formal* and *Informal* discussion by each teacher. This data is representative of the process of developing habits. Each teacher had different needs: the cognitive apprenticeship pro-

Table 61: Formal/Informal Discussion Features.

Type	Topic	Function	Media
Formal	Content Knowledge	To support the teacher in preparing the unit plan, lesson plan, materials and resources, homework worksheets and tests. To revise lessons and students' artifacts.	Meetings (face-to-face and online), phone callings, e-mails and short conversations by social networks.
	Exercises and problems		
	Lab activities		
	Assessments		
Informal	Teacher's difficulties	To reinforce and sustain teacher in making changes, facing difficulties and overcoming constraints.	
	Students' difficulties		
	Teacher's changes		
	Students' changes		

gram was specifically tailored for each one. The report of the discussions is presented in Table 62. During the discussions, we collected notes, part of teachers' dialogues, and statements that could lead to information about their teaching practices, dispositions, skills and knowledge.

Table 62: Formal/Informal discussions' report by year.

Teacher	Academic Year		On going	TOT.
	20/21	21/22		
Teacher #1	50	70	Weekly	**120**
Teacher #2	20	14	Monthly	**34**
Teacher #3	33	48	As needed	**81**
Teacher #4	20	22	-	**42**
Teacher #5	16	19	-	**35**
Teacher #6	20	23	As needed	**43**
Teacher #7	4	15	As needed	**19**
Teacher #8	4	15	-	**19**

4.1.4.5 Audio and/or Video Recorded Lessons

To convey the learning environment from teacher-centred to student-centred, we needed to be teachers aware of how they construct classrooms' discourses.

We would address this aim by analysing teachers' audio/video recordings of lessons before and after adopting the ISLE approach.

We encountered three problems in collecting this data. First, we did not obtain permission for the data treatment of students' privacy to record lessons and use the recordings for research purposes. For this reason, collecting this kind of data for all the teachers sampled was not possible, or, in some cases, it was possible only in remote teaching.

Second, after the lockdown, when teachers and students returned to classrooms, they had some restricted rules to observe: the use of masks, at least a one-meter distance from each other, and banned working groups. These were constraints for recording clean audio and well-distinguishable students' voices and words.

Third, the classroom setting changed during the research project. Periods of lockdown and remote learning alternated periods in classrooms with restrictions. Teachers adjusted their lessons to online activities and then re-adapted to a classroom setting with many limitations. Conducting lessons and discourses in remote mode implies rethinking teaching practice to account for learning outcomes (Bjurholt and Bøe, 2022). Nonetheless, teachers sampled who recorded their lessons during lockdown took many advantages by listening to their classroom discourses. For none of the teachers sampled, we could collect audio/video recordings in the two schooling periods.

In Table 63, we report the data collected in this scenario with these constraints. The videos recorded during the academic year 20/21 were in remote learning, the ones in 21/22 in presence.

Table 63: Number of Audio/Video recorded lessons by year.

Teacher	**Academic Year**		**TOT.**
	20/21	**21/22**	
Teacher #1	8	-	**8**
Teacher #2	2	-	**2**
Teacher #3	6	-	**6**
Teacher #4	-	1	**1**
Teacher #5	-	-	**-**
Teacher #6	-	-	**-**
Teacher #7	-	1	**1**
Teacher #8	-	2	**2**

4.1.4.6 Teacher's Survey about Tasks of Teaching

We developed a simple descriptive instrument to evaluate the frequency of the use of tasks of teaching (Ball et al., 2008; Etkina et al., 2018) based on the ISLE approach (see Table 45), asking teachers the frequency of adoption in teaching practices.

The survey was based on a five-point frequency Likert-scale (Likert, 1932) to be treated as quantitative data, as shown in Table 64.

The survey is divided into six sections and designed to take no more than thirty minutes to complete (an extract of the survey is reported in Table 65). The six sections are:

(1) anticipating student thinking around science ideas;

Table 64: Five points Likert scale (Likert, 1932) for frequency measure (with referring colour scale).

Frequency Rank	**Score**
Always	5
Very Often	4
Sometimes	3
Rarely	2
Never	1

(2) designing, selecting, and sequencing learning experiences and activities;

(3) monitoring, interpreting, and acting on student thinking;

(4) scaffolding meaningful engagement in a science learning community;

(5) explaining and using examples, models, representations, and arguments to support students' scientific understanding;

(6) using experiments to construct, test, and apply concepts.

Teachers completed the survey through a Google Form, and their responses were stored in an Excel spreadsheet at the end of the research project. So, we acquired this data as a post-test survey.

As a pre-test, we completed the same survey for each teacher based on the monitoring activities and the classroom observations. We validated our responses with the teacher's agreement. We could not complete the pre-test for the teacher #3 for his later incoming research project (by the second year).

The collected responses are given on evidence-based of our monitoring, motivating and validating our choice. At the beginning of our research project, we were still describing the feature of an *Early Physics* approach;

Table 65: Extract of the tasks of teaching survey questions given to teachers at the end of the research project.

Task of teaching	**Specific tasks**	**Frequency scale**				
		1	**2**	**3**	**4**	**5**
Anticipating student thinking around science ideas	Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes					
	Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes					
	Recognising student interest and motivation around particular science content and practices					
	Understanding how students' background knowledge both in physics and mathematics can interact with new science content					

(The tasks of teaching of the survey are defined in Etkina et al., 2018.)

for this reason, we could not straight-administer this survey to teachers.

4.1.5 Data Analysis Methods

A concurrent triangulation mixed method design (Fig. 58) was used to analyse the data collected for responding to the research questions arising from teachers' conceptions (RQ3 and RQ4).

In the concurrent triangulation mixed methods approach, both qualitative and quantitative data are concurrently collected and then compared, in our case, for a cross-validation purpose (Creswell and Clark, 2017).

In this concurrent approach, each implementation phase supports data

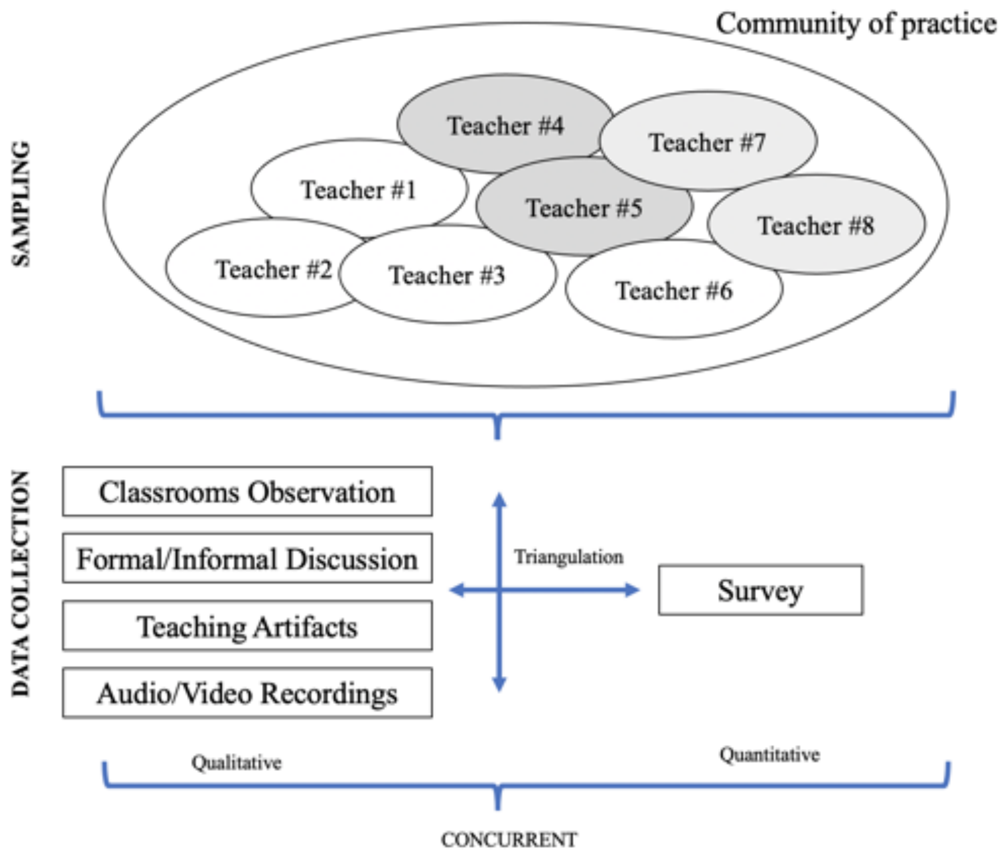


Figure 58: The mixed-method study design (Sampled teachers with the same background colour belong to the same secondary school).

collection. A detailed description of the data acquired in this multi-phase design is given in Figure 59.

We concurrently conducted also the data analysis (Combs and Onwuegbuzie, 2010; Creswell and Clark, 2017). We tried to define criteria for data analysis to overcome possible discrepancies merging information by a different type of data collected using mixed method design (Creswell and Clark, 2017).

We referred to the following criteria (Combs and Onwuegbuzie, 2010; Tashakkori and Teddlie, 2009) to substantiate our process of analysis:

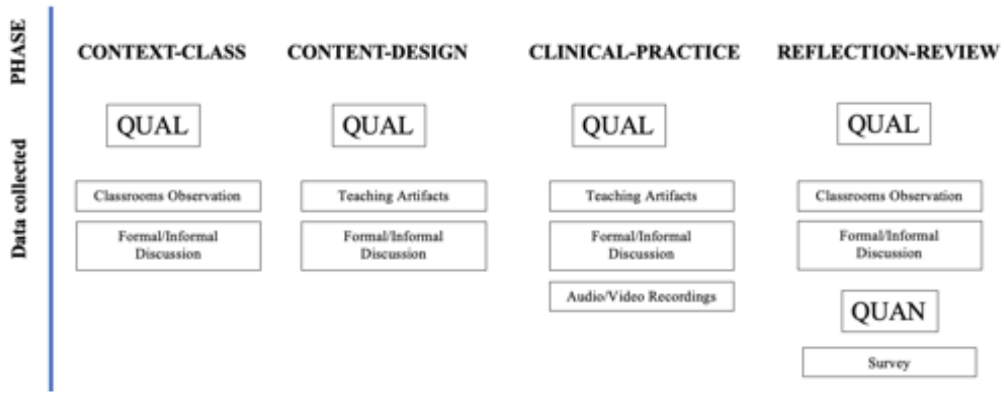


Figure 59: Multi-phase design supporting data collection.

- as analysis orientation, we combined case-oriented analysis with process-experience-oriented analysis (Combs and Onwuegbuzie, 2010);
- as a priority of analytical components, we considered qualitative and quantitative strands with equal priority for addressing the research questions (Combs and Onwuegbuzie, 2010);
- as the level of interaction between data analysis, each set of analysis provides an understanding of the phenomenon under investigation combined with the others (Tashakkori and Teddlie, 2009).

Data analysis for this study was divided into two parts. Part one consisted of analysing the survey responses regarding the quantitative data. Part two consisted of analysing the qualitative data collected, teaching artifacts, reports of formal and informal discussions, and transcription of audio/video recordings (if possible).

The two analyses would encounter the goal of investigating if teachers began a process of teaching revision, developing *new* habits of mind and practice (Etkina et al., 2017). This investigation substantiated answering our research questions (RQ3 and RQ4).

We analysed our data by choosing a well-defined key. The adoption of *new* habits means the change in tasks of teaching (Ball et al., 2008; Etkina et al., 2017). For each research question to address, we used the teacher's addressing tasks of teaching as a coding scheme (Combs and Onwuegbuzie, 2010; Creswell and Clark, 2017; Tashakkori and Teddlie, 2009) for the analysis (Table 66).

The coding scheme is detailed by the specific tasks defined in every macro area-tasks (see Table 45). Each task could be considered a category to investigate the process of developing habits. In the framework of this coding scheme, we analysed data collected, with distinctive procedures for those qualitative and quantitative (Creswell and Clark, 2017).

Therefore, we combined information-category from both the quantitative and qualitative data analysis (Creswell and Clark, 2017). The analysis of quantitative data collection focuses on process-progress frequency. The analysis of qualitative data collection informs on the implementation-innovation of teaching practices.

Comparing the two, we could extrapolate how the process of changing habits is ongoing developing and how much it is meaningful (in terms of persistence) in teaching practices.

Thus, qualitative and quantitative data were used to substantiate and cross-validate findings in the triangulation process.

4.1.5.1 Part one: analysis of quantitative data

We analysed quantitative data collected by the survey about tasks of teaching (see Table 58) by descriptive statistical technique (Tashakkori and

Table 66: Coding scheme for data analysis based on tasks of teaching and their description (as defined by Etkina et al., 2017).

Research Question	**Task of teaching** / **Coding scheme**	**Description**
How could we engage in-service Physics teachers in a deep revision of their PCK to overcome the limits that an application pattern of Phys/Maths interplay affected?	Designing, selecting, and sequencing learning experiences and activities	*Classroom learning experiences and activities are designed around learning goals and involve key science ideas, key experiments, and mathematical models relevant to the development of ideas and practices.*
		Learning experiences reflect an awareness of student learning trajectories and support both individual and collective knowledge generation on the part of students.
	Monitoring, interpreting, and acting on student thinking	*Teachers understand and recognize challenges and difficulties students experience in developing an understanding of key science concepts; understanding and applying mathematical models and manipulating equations; designing and conducting experiments, etc. This is evident in classroom work, talk, actions, and interactions throughout the course of instruction so that specific learning needs or patterns are revealed.*
		Teachers recognize productive developing ideas and problem solutions and know how to leverage these to advance learning.
		Teachers engage in an ongoing and multifaceted assessment process using various tools and methods.
		Teachers draw on their understanding of learners and learning trajectories to accurately interpret and productively respond to their students' developing understanding.
	Using experiments to construct, test, and apply concepts	*Teachers provide timely and meaningful opportunities throughout instruction for students to design and analyse experiments to help students develop, test, and apply particular concepts.*
		Experiments are an integral part of student construction of physics concepts and are used as part of scientific inquiry in contrast with simple verification.

(Table 66 continued)

Teddlie, 2009). We monitored the teaching gain in adopting *new* teaching practices by the frequency of addressing tasks of teaching. To estimate the trend in teaching gain, we compared the following data:

Research Question	Task of teaching / Coding scheme	Description
How could we (the teachers) improve our pedagogical content knowledge for argumentation to foster classroom discourse from teacher-centred to student-centred?	Anticipating student thinking around science ideas	*While planning and implementing instruction, teachers can anticipate particular patterns in student thinking. They understand and recognise challenges students are likely to confront in developing an understanding of key science concepts and mathematical models.*
		Teachers are familiar with student interests and background knowledge and enact instruction accordingly.
	Scaffolding meaningful engagement in a science learning community	*Productive classroom learning environments are community-centered. Teachers engage all students as full and active classroom participants. Knowledge is constructed both individually and collectively, with an emphasis on coming to know through the practices of science.*
		The values of the classroom community include evidence-based reasoning, the pursuit of multiple or alternative approaches or solutions, and the respectful challenging of ideas.
	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	*Teachers explain and use representations, examples, and models to help students develop their own scientific understanding.*
		Teachers also support and scaffold students' ability to use models, examples, and representations to develop explanations and arguments.
		Mathematical models are included as a key aspect of physics understanding and are assumed whenever the term model is used.

- pre-post responses of the survey for each item (sub-categories of tasks of teaching) - detailed trends;
- average of pre-post responses of the survey for each section (categories of tasks of teaching) - broad trends;
- mode frequency value for the whole survey.

Then, we used an average normalised gain (Hake, 1998), $\boldsymbol{g}$, as a standard approach widely used in Physics Education Research to measure change.

$$\boldsymbol{g} = \frac{\overline{x}_{post} - \overline{x}_{pre}}{100\% - \overline{x}_{pre}}$$

We used Hake's definition normalised to the higher score value of frequency of the survey regarding tasks of teaching.

Transposing the scale for learning gain to teaching gain, as a measure of developing *new* habits, we adjusted the reading scale of the gain as reported in Table 67.

Table 67: Reading scale for teaching gain (based on learning gain of Hake, 1998).

$\boldsymbol{g}$ **value**	**Development Trend**	**Description**
$\boldsymbol{g} \geq 0.7$	High teaching gain	*Teacher deals tasks of teaching rarely used before. A deep revision in habits took place, and many changes occurred.*
$0.3 \leq \boldsymbol{g} < 0.7$	Medium teaching gain	*Teacher is involved in changing practices in a slow growing, gradually developing process. The process of developing new habits is started, and some changes are already present in teaching practices.*
$\boldsymbol{g} < 0.3$	Low teaching gain	*Teacher did not substantially change habits of mind and practice. The practice of "new" tasks of teaching is limited.*

We calculated the $\boldsymbol{g}$ value for each sampled teacher. For teacher #3, we focused on the development trend concerning the process between two different academic years (2020/21 and 2021/22).

4.1.5.2 Part two: analysis of qualitative data

Qualitative data analysis involves an inductive process (Palinkas et al., 2015; Tashakkori and Teddlie, 2009). As a conceptual framework for our qualitative analysis, we considered adopting the constant comparative method (Glaser, 1965; Kyriakides et al., 2010). This method involves breaking down the data into discrete "incidents" (Glaser, 1965) and coding them into categories, eventually identified by the researcher as "significant to the project's focus-of-inquiry" (Kyriakides et al., 2010).

Our main categories are the tasks of teaching (Ball et al., 2008; Etkina et al., 2017), with their sub-categories concerning specific tasks (Table 51).

We investigated our qualitative data in two manners:

1. pre-post comparison of the same kind of data, referred to a specific category;
2. addressing data to each specific category.

We employed this analysis based on data collected for each teacher and each category.

We had to combine the qualitative analysis of multiple sources of data. Each source was suitable for our investigation goals. Considering each source as a category-inquiry data we focused our attention on the ones that were mostly multifaceted.

As "multifaceted category-inquiry data", we defined data that gives evidence of many aspects of the process implemented, such as the assessment written tests or teaching notes. Among qualitative data, teaching artifacts better satisfy this investigation requirement.

Concerning Formal/Informal discussions, we referred to them reporting some statements as a significant example. We translated the conversations into English, trying to bypass losing information in the translation process between the two languages.

We purposefully chose the most informative conversations concerned:

- description of teaching practices;
- description of students' feedback as the effect of a practical adopted;

We organised the data collected to represent each category chosen and highlight the process of changing teaching practices. Of course, the way proposed is not unambiguously defined. The same data could be relevant to outline different categories, not only those established in this work.

4.1.6 Limitations of the Methodology

There are several limitations in the methodology that we used for this study. We decided to use a multi-phase mixed method design to describe better the process of changing and developing *new* habits. We also considered the possibility of a phenomenological case study research (Creswell and Clark, 2017; Vagle, 2014) to "develop a composite description of the essence of the experience for all of the individuals" (Creswell and Clark, 2017).

We resolved our choice towards the mixed-method design, because it is recommended to cross-validate and check the qualitative and quantitative data we collected in the research. Distinguishing two different ways of treating data, we must consider the limitations emerging from collection and analysis, both qualitative and quantitative ones.

The Teachers' Survey about Task of Teaching was administered as an online survey, with many advantages, such as time-saving for teachers and researchers. The limitations were whether the teachers could accurately assess themselves regarding their teaching and whether they accurately reported that. There was no guarantee that the respondents in the survey accurately assessed themselves regarding the teaching and accurately reported it.

Lastly, most teachers decided to use the English version of the survey. Only one teacher asked for the Italian translation. On one side, maintaining the description of tasks of teaching in the same language as their definition in literature (Etkina et al., 2017) means guaranteeing the uniformity of the referring framework. Differently, the Italian translation could lose some meanings but resulting more understandable and referable to the didactic practice of these teachers.

Moreover, we referred to the Classroom Observations to gain information for the pre-test. Classroom observations themselves could lead to the "Hawthorne effect" (Sedgwick and Greenwood, 2015): it is natural that when people are aware that they are being observed, they tend to perform better, and this can affect the findings of the study. Therefore, the survey's compilation as a pre-test for our study could overestimate the sampled teachers, affecting the teaching gain measure.

In qualitative data treatment, we needed to establish trustworthiness (Merrian and Tisdell, 2016). According to the features of our purposeful sampling, the use of multiple qualitative data sources overlapping each other, we are confident in sustaining our analysis process's credibility, transferability, and confirmability (Merrian and Tisdell, 2016).

4.2 Teachers' Case Studies

Describing the process of developing habits means talking about the stories of teachers. Each story is a sequence of frames, snapshots of their professional disposition, knowledge, and skills (Etkina et al., 2017).

In the following descriptions, we summarise the main features of these eight stories as an overview resulting from the analysis conducted. Here, we chose to report only what we could identify as the main aspects that were meaningful in teachers' Reflection Phase and guided them in their revision process.

As to reasonably ensure the confidentiality of the data and the confidentiality and anonymity of the subjects, there were no explicit references to teachers' name or their students, classes and schools in this section[7].

4.2.1 Teacher #1

Teacher #1 has been a permanent Maths/Phys teacher in a secondary school for scientific studies for almost six years. This position was gained after eight years of temporary tutoring at college instruction and nine years in other local secondary schools.

After the Master's degree and PhD in Maths studies, this teacher attended professional pre-service training for becoming a teacher, the so-called SSIS (this acronym stands for Scuola di Specializzazione per l'Insegnamento Secondario - Specialised School for Secondary Teaching; Dal Passo and Lau-

[7] We explicitly refer to teachers' names only for those who have been cited in References with their permission.

renti, 2017). This was a biennial instructional program for teachers' certification, activated from 1999 to 2009.

The school context of Teacher #1 is highly competitive, facing high performance and preparation levels from students' and teachers' points of view.

The Physics curriculum has been recently revised, and all Physics school teachers must implement it to guarantee school homogeneity. This is a formal constraint for teaching innovation and changes. The constraint is substantiated by disciplinary recovery courses activated during schooling periods. If one student has difficulty in Physics, they could attend these extra-curricular courses to overcome difficulties. The course is not prepared by the same classroom teacher but by another teacher in that school.

This means that the teacher's work must be aligned with the others in the content and the "regular types" of problems used for assessing and consolidating student content knowledge.

Teachers could decide on lab activities, but the school has only one Physics lab (for fifty classes), so it isn't easy to plan experiments regularly.

There are also other school projects for curriculum improvement; they are not mandatory, and every teacher chooses them according to their teaching needs

In this context, if a teacher wishes to change, they could sometimes feel isolated and have difficulty moving out of the homogeneity constraints.

Developing *new* habits would mean bypassing the homogeneity constraints, even if this bypassing is very difficult to sustain from a professional standpoint. It also would mean retaining a divergent attitude towards teaching practices (established by the context), believing that the new ones are more useful (from a teaching/learning efficacy point of view) than those used so far.

This teacher was engaged in this research project from its start. Originally, in the same school, there were also two other teachers interested in it. Unfortunately, when it was be possible to start the activities with them, COVID spread out, and during remote learning, those other two chose not to participate.

In Table 68, we reported the data collected during the research project for Teacher #1.

Table 68: Data collected for Teacher #1 (in **bold** with/by researcher).

Data collected Type	**Academic Year**		
	19/20	20/21	21/22
Classroom Observations	**16h**		
Teaching Activities		**20h**	80h
Discussions		50h	70h
Teaching Artifacts	1	9	15
Audio/Video recorded		8	
Survey	**1**		1

Starting from analysing the pre-post survey responses and calculating the teaching gain $\boldsymbol{g}$, we obtain an indication of the development trend of the process that this teacher activated in changing habits (Table 69).

This measure informs us a noteworthy change occurred in teaching practices. Despite the context constraints, this teacher substantially changed the way of teaching.

Table 69: Teaching gain for Teacher #1.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 39,6\% \pm 0,4\%$	$0.62 \pm 0,01$	Medium-high teaching gain
$\overline{x}_{post} = 77,4\% \pm 0,4\%$		

To convey a more detailed description of this process, we deeply investigated each task of teaching (Ball et al., 2008; Etkina et al., 2017) as a category for the qualitative analysis.

From a broad overview of the teacher's survey responses, we could highlight which category-tasks lead to information about the more significant area of changes (Table 70).

The most relevant categories of changing are those concerning the use of Multiple Representations (**5**), and the building of concepts through experimental practises (**6**).

To better document the process, we looked at the pre-post responses of the sub-categories, concurring in detailing each specific task of teaching.

The comparison between responses of each category-task is reported in the following tables (Tables: 72, 73, 74, 75, 76, 77). The colour scale defining the frequency Likert-scale of the survey (as in Table 59) is here recalled. Then, the mode value on the overall answers is shown in Table 71.

Teacher #1 acknowledged that it is very difficult to pinpoint students' p-prims (diSessa, 1993) and use them as resources (Hammer, 1996) for conceptual change (diSessa, 2014) in the process of building knowledge.

In a "transmissive" process of building knowledge, nothing ad-

Table 70: Broad overview of Teacher #1 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$2,00 \pm 0,29$	$3,50 \pm 0,14$	$30\% \pm 6\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,10 \pm 0,07$	$4,00 \pm 0,07$	$38\% \pm 2\%$
3.	Monitoring, interpreting, and acting on student thinking	$2,43 \pm 0,08$	$4,14 \pm 0,13$	$34\% \pm 3\%$
4.	Scaffolding meaningful engagement in a science learning community	$2,70 \pm 0,13$	$3,90 \pm 0,07$	$24\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$1,38 \pm 0,06$	$4,25 \pm 0,13$	$58\% \pm 3\%$
6.	Using experiments to construct, test, and apply concepts	$1,00 \pm 0,00$	$3,14 \pm 0,17$	$43\% \pm 3\%$

Never
Rarely
Sometimes
Very Often
Always

dresses this task. You think what you have to say, not what students think about or how to make visible their thinking. What is dominant is your thinking and process, not the students'.

Reading the transcriptions of the video-recorded lessons, this teacher became aware of how teacher-centred the process of building knowledge was.

Table 71: Mode Frequency Value for the survey's overall responses for Teacher #1.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

Table 72: Sub-categories Task 1, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

> *I even tried to include students in my discourse. I was unaware that I included them in my reasoning and not in their own reasoning. Of course, my reasoning was thoroughly formal and clear and correct. But it was not their reasoning. Thus, I noticed they could not replicate it as I asked them to.*

Likewise, the kinds of questions posed during the classroom discourses were teacher-centred.

> *I asked students to respond to my thinking process. I understood that they often did not respond to anything because they did not follow the reasoning that it was not theirs.*

This would mean changing the way of planning and designing lessons. It meant finding the time when students' ideas could unfold, emerge and be part of the process of building knowledge.

The main difficulties Teacher #1 encountered in this process were lesson-time management and classroom setting. The teacher made many efforts to overcome them, but met two constraints.

First, students were not usually to be engaged in active learning practices. Also, even if they got involved, they sometimes behave as if active participation means less *formal/effective* lessons (as already seen in a higher level of instruction, Deslauriers et al., 2019).

Second, the school management of Teacher #1 does not allow the use of working groups in classroom activities for preventing COVID infection. This restriction is still mandatory and limits the activation of sharing knowledge building in peers-works.

In the teacher's words, we recognised an unavoidable claim of need to change:

> *I need to expand our classroom discourses to activate students' participation! I have to stimulate discourses more than I was used to do before: it's become a teaching necessity.*

Teacher #1 changed the way of designing and sequencing learning experiences and activities. It appears with evidence by contrasting colours in tables 73 and 74.

Using Classroom Observations, we could depict how a learning sequence was normally addressed before the adoption of the ISLE approach.

The teacher presented the specific content topic describing phenomeno-

Table 73: Sub-categories Task 2, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

logical situations. Based on collected evidence, the description was portrayed without any experimental activities or reasoning. The focus was to a mathematical model of the phenomenon, as the teacher declared:

> *I ever preferred to give more emphasis to maths representations of physical phenomena. I always thought that was the most important thing I had to do in my lessons. Now, I'm confident many other things make students aware of physics knowledge.*

To understand how this teacher introduced new elements in the learning sequencing, we considered how the teacher is now preparing lessons. Figure 60 displays the teacher's draft notes.

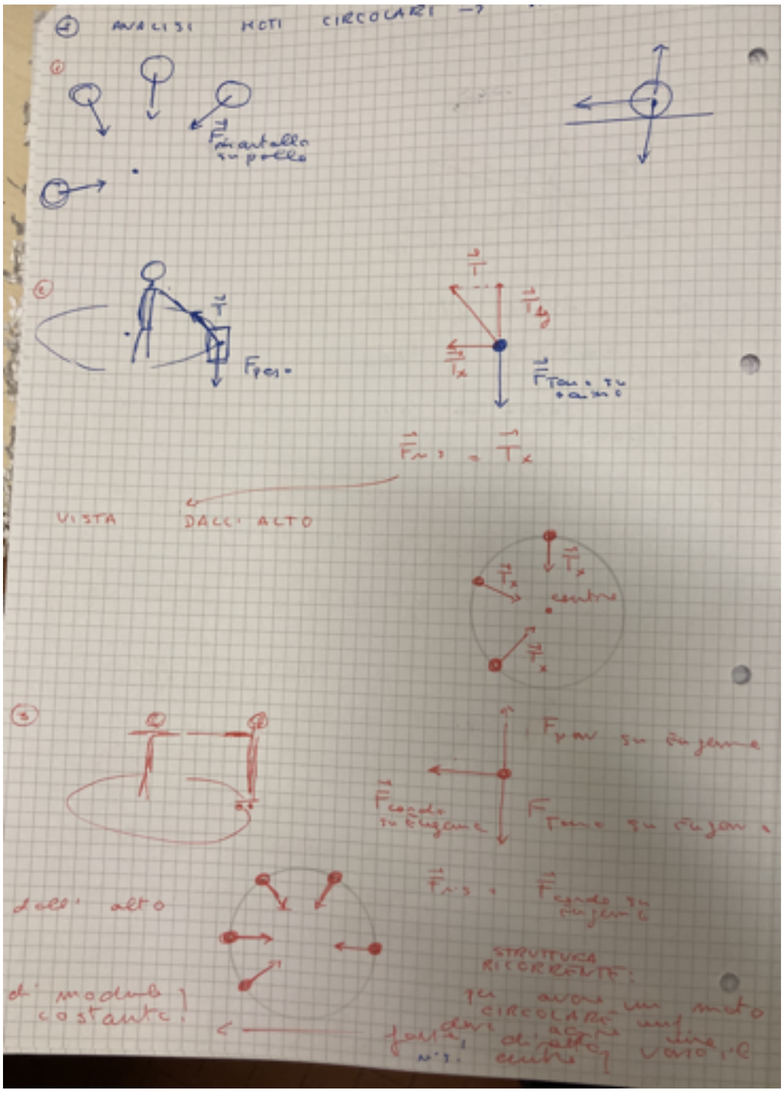


Figure 60: Photo of teacher's log notes regarding circular motion learning sequence.

The sequence designs the way of searching a pattern in the Observational Experiment that explores reason which is the cause of circular motion (Etkina, Planinsic, et al., 2019). The teacher's focus is on force diagram representation.

Stressing the use of motion and force diagrams in the conceptual description of phenomena is one of the changes the Teacher #1 made.

For example, in some activities developed, the teacher supported students in the process of forces' representation using the Desmos platform (DESMOS, 2022)[8].

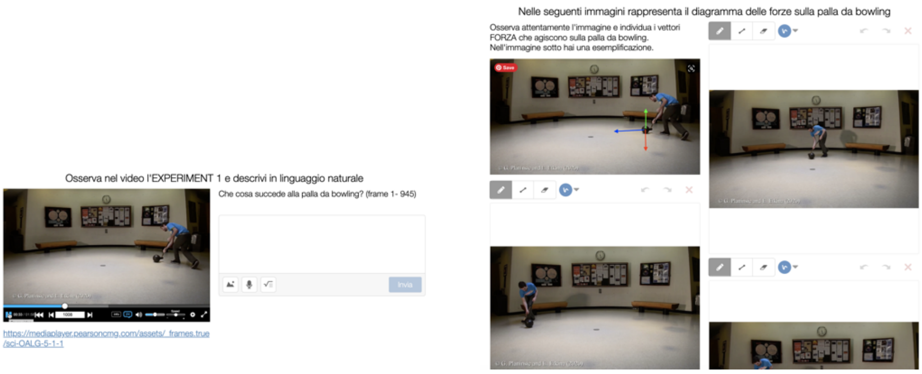


Figure 61: Screenshots of students' online activities for circular motion. After watching the video-observational-experiment, students had to draw a force diagram on chosen video frames.

The teacher revised content knowledge by changing lesson preparation and learning sequences.

> *I changed my content knowledge. I know Physics in a conceptual way that I did not really understand before. The first conceptual change was mine. Then in my students!*

The changes mainly regarded the adoption of multiple modes of representations and multiple strategies to build conceptual knowledge.

One effect of Teacher #1 changes was the structure of the written tests for assessing students' learning (Table 74).

Introducing multiple representations would mean sustaining students' learning and deep conceptual understanding. The teacher implemented writ-

[8]The activities performed are free to use (in the Italian version) at the following links: shorturl.at/aFJ49 and shorturl.at/hruNO.

ten tests changing quizzes (with respect to the previous ones used) to assess learning goals.

The previously written tests consisted of quizzes/questions to investigate the so-called "theory-based" knowledge and quizzes/exercises to investigate "application or problem-based" knowledge.

The first aimed to measure knowledge acquired, whereas the second measured the procedural application of the maths formula describing a physical law.

Table 74: Sub-categories Task 3, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

The new types of written tests are completely different. There is no distinction between the theory and application parts. Each exercise is based on real-life everyday phenomena that students could have experienced, seen, or recalled to something known (Fig. 62).

There are three key elements in this exercise we took as example:

1. asking students to represent force diagram;
2. asking students to switch between representations;
3. asking students to think of changing physical conditions.

1. Nel gioco degli scacchi, un cavallo di 30 g e una regina di 40 g, che sono a contatto , sono appoggiati su una scacchiera dove l'attrito è trascurabile. Marco spinge i due pezzi esercitando sul cavallo una forza orizzontale costante di 3,5 x 10^{-2} N.

   a. Disegna il diagramma delle forze agenti sul sistema costituito dal cavallo e dalla regina
   b. Determina l'accelerazione dei due pezzi
   c. Disegna il diagramma delle forze agenti sulla regina, e il diagramma delle forze agenti sul cavallo
   d. Determina la forza che il cavallo esercita sulla regina, e la risultante delle forze agenti sul cavallo
   e. Cosa succede se si scambiano di posto i due pezzi?

Figure 62: Example of *new* exercises in written test regarding Newton's laws.

The mathematical procedure of calculating the system's acceleration is present, but the exercises focus on many other aspects. For instance, students must think of a different system and reason on another force diagram representation.

> *Changing the way of assessments, asking more "why", "represent", and "reason" than "what" or "how many", my students were engaged in a deep learning process.*

This teacher recognised how assessing in a different manner is relevant to engage students in meaningful learning.

Analysing the sub-categories for Task 5 (Table 76) and Task 6 (Table 77), we notice without any doubt the deep change occurred in Teacher #1.

In detailing the change, it is clear that Teacher #1 became skilled in using experimental activities during learning sequences.

> *Demonstrative lab activities are useful because they show how to take, elaborate and use experimental data. These experiments show the phenomena and that these phenomena are real. But they do not help students build knowledge and never test hypotheses or design experiments. Observational, Testing and Application Experiments are completely different. When I use them, they work on students' building concepts. I did not always need to go to a laboratory room. My classroom is a good setting for using online video experiments.*

Teacher #1 was undoubtedly involved in the development of *new* habits. If, in the beginning, the activities were trials and only one class was engaged in the new teaching practice, now this teacher applies this practice in all the classes for Physics teaching.

> *I'll nevermore come backwards. I feel I have a powerful way of teaching Physics, and this is the first time I'm sure it works with my students. During these three years, I worked very hard. But I needed to do it because it gave me the self-consciousness that I could successfully teach Physics in an effective way.*

Despite school constraints, despite the large amount of work for producing *new* materials and resources for lessons and activities, Teacher #1 continues to develop productive habits.

Table 75: Sub-categories Task 4, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	Pre	Post
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

4.2.2 Teacher #2

Teacher #2 has been teaching Maths and Physics since 2006. After eight years of a temporary position in many secondary schools, she has been permanently employed in a high school for scientific studies, the oldest for sciences in Trieste (this year is the centenary).

To become a teacher, she attended the SSIS professional training courses (Dal Passo and Laurenti, 2017) after a Master's Degree in Maths Studies. For a long time, she recognised having difficulty teaching Physics for her lack of content knowledge preparation[9]. And the pre-service professional training

[9]The Maths Masters' Degree program has only one mandatory course in Physics, that is Newtonian Physics.

Table 76: Sub-categories Task 5, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	Pre	Post
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 77: Sub-categories Task 6, pre-post item-coloured responses Teacher #1.

Specific tasks or qualitative sub-category	Pre	Post
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

she attended did not sustain her as she thought it needed to.

She attended many courses for in-service Physics teachers, such as those concerning thermodynamics and quantum mechanics. Thus, she tried to overcome the missing preparation by getting involved in many programs.

She recognised to have devoted so much time to Physics training as she did not in Maths, becoming more skilled in Physics teaching than in Maths.

She is now the leader chief of her school's Department of Maths and Physics teachers. This is an important role for her: coordinating school projects, managing activities for many classes and promoting programs which lead to innovation in teaching Maths and Physics. This also happened for this research project.

This scientific high school has a long tradition in Physics studies. There are four Physics laboratories with many ancient instruments and new recently bought. The experimental activities are mostly demonstrative, guiding students to verify well-known physical laws.

Even if the school Physics curriculum firmly invites active learning practices using laboratories, it is very difficult for teachers to prepare and perform lab activities more than twice per year per class.

This teacher engaged many other colleagues in this research project, as reported in Table 78. Still, she was the only one who continuously worked throughout the project during these three years.

This data highlights the features of this school context, where teachers are willing to engage and participate in *new* activities. This supportive context helps teachers' development of *new* productive habits, as we will shortly try to spotlight.

Table 78: Research project teachers' engagement.

Activity	Year	# Teachers	# Classes	# Hours
Classroom Observations	19/20	4	4	40h
Teaching Activities	19/20	5	5	60h
	20/21	2	3	55h
	21/22	3	7	71h

Teacher #2 has been involved in the research project since its beginning, as reported in Table 79. She was very interested in the leading goals, mainly for overcoming the great disaffection towards Physics studies she observes year after year[10].

Table 79: Data collected for Teacher #2 (in **bold** with/by researcher).

Data collected Type	Academic Year		
	19/20	20/21	21/22
Classroom Observations	**8h**		
Teaching Activities		**25h**	**16h**
Discussions		20h	14h
Teaching Artifacts	2	3	3
Audio/Video recorded		2	
Survey	**1**		1

The teacher's expertise and professional practice are acknowledged by her

[10] As reported in Chapter 2, this trend is confirmed by the descriptive statistical analysis of the survey administered in this school during the academic year 2019/20, to measure students' attitudes towards Physics.

pre-test survey responses' high normalised mean value percentage ($\geq 50\%$). What is quite denoting is the smaller differences between pre and post-test, corresponding to a low teaching gain (Table 80).

Table 80: Teaching gain for Teacher #2.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 51,4\% \pm 0,2\%$	$0.25 \pm 0,01$	Low teaching gain
$\overline{x}_{post} = 63,5\% \pm 0,4\%$		

By inspecting category-tasks, we investigated what featured the process of development *new* habits. Table 82 and Table 81 convey a more detailed description of the process, focusing on the mode value and broad development trend through the incremental ratio.

Table 81: Mode Frequency Value for the survey's overall responses for Teacher #2.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

We strengthened our attention by analysing the category-task with the low incremental ratio (**6**) and the highest incremental ratio (**5**).

The analytical results for specific tasks and sub-caterogies are reported in Appendix A (Tables 108, 109, 110, 111, 112, 113).

The learning sequence for concept building of Teacher #2 follows a well-defined scheme (Fig. 63):

Table 82: Broad overview of Teacher #2 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$3,00 \pm 0,20$	$3,50 \pm 0,14$	$10\% \pm 5\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,30 \pm 0,05$	$3,00 \pm 0,08$	$14\% \pm 2\%$
3.	Monitoring, interpreting, and acting on student thinking	$2,43 \pm 0,08$	$3,14 \pm 0,10$	$14,3\% \pm 2\%$
4.	Scaffolding meaningful engagement in a science learning community	$2,90 \pm 0,06$	$3,40 \pm 0,05$	$10\% \pm 2\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$2,63 \pm 0,11$	$3,50 \pm 0,15$	$17,5\% \pm 2\%$
6.	Using experiments to construct, test, and apply concepts	$2,29 \pm 0,07$	$2,57 \pm 0,08$	$5,7\% \pm 2\%$

1. a slideshow presentation made by the teacher which presents contents in a designed scheduled plan;
2. application of theory in practical guided exercises and problem-solving (prepared materials with chosen exercises);
3. assessment phase (oral/written).

During the Content-Design Phase, we invited the teacher to change this scheme, introducing ISLE-based activities. What happened was the adoption of an overlapping scheme between the *old* activities and the *new* ones. The resulting scheme had a mixed design, where the *old* was never substituted by the *new* but only integrated.

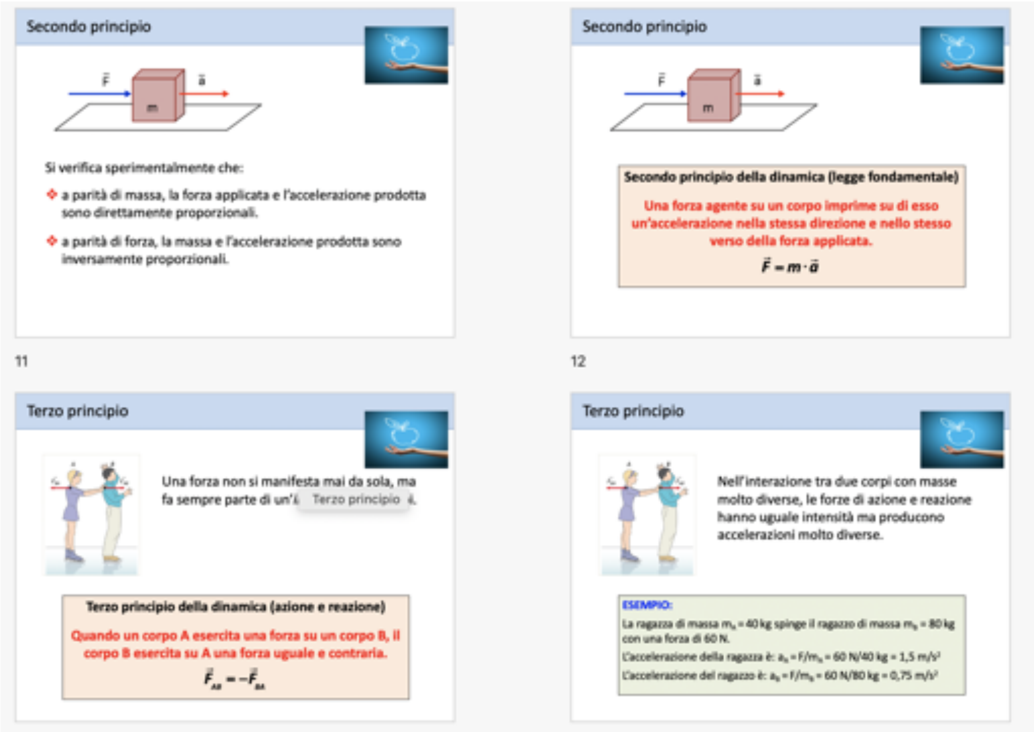


Figure 63: An example of some slides of the slideshow presentation used by Teacher #2 during her lesson.

Therefore, we guided the teacher to focus the attention on how *new* activities could activate deep understanding and meaningful learning. We audio-recorded two remote-distance lessons where students were engaged in two Desmos activities regarding dynamics of incline plane[11].

The activities were designed to help students to switch between representations and to reason (Fig. 64). During the activities, students were actively engaged. The high level of student engagement fascinated the teacher.

In particular, she was surprised by two main aspects:

- recognising student thinking process in switching between representations;

[11]The Italian version of the activities is ready at the following links: shorturl.at/kpvxy (part I), and shorturl.at/efxV5 (part II).

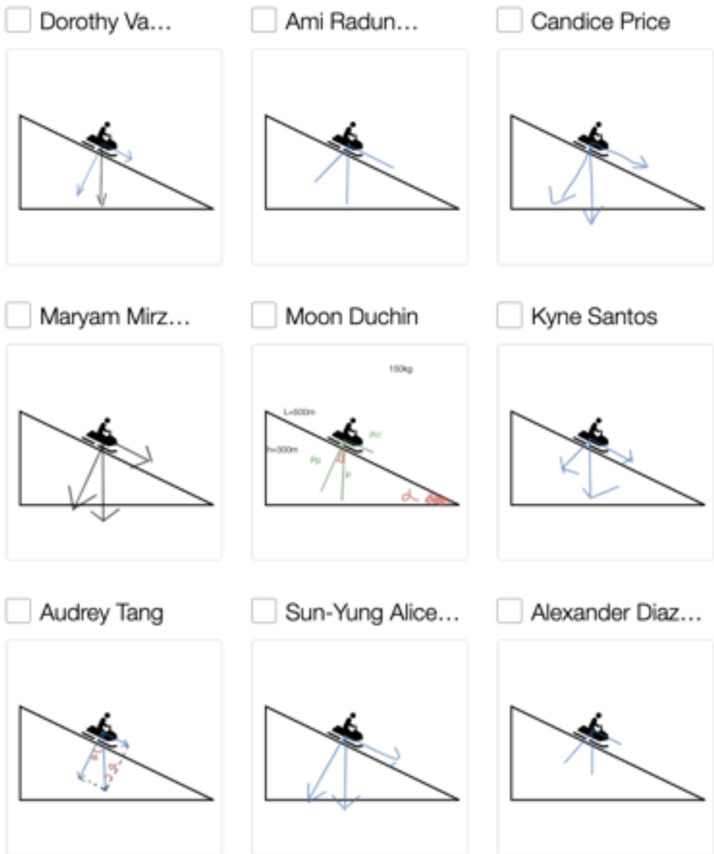


Figure 64: Students' responses in Desmos activity (the names are fictitious). Students had to draw a force diagram.

- the activity unravelled the "untold" or "obscure" in the concept-building process.

Another important aspect was delineated listening to audio-recorded lessons. During the activities, students asked questions and participated much more in classroom discourse than usual.

> *I noticed how students' questions changed. Students were actively engaged in the process of understanding, leading them to try explaining and reasoning in a way I did not see before.*

Motivated by those improvements in the classroom, Teacher #2 often implemented these kinds of activities in her teaching practices, encouraging students to use multiple representations.

Her process of developing *new* habits extends growing up. She needs to explore *new* schemes of using experimental activities for conceptual building, letting students at the centre of the process[12]. She is now trying these kinds of activities in her classes, becoming more aware and self-confident in the change.

Her characteristic disposition towards innovation and training sustain her process of changing and the process of improving students' attitude towards Physics.

During these years, she gradually individuated features in students' process of reasoning[13]. Looking through the learning processes, she was encouraged to find and explore a different way of teaching.

[12]During the academic year 2022/23, we promoted a lab activity ISLE-based in all the school classes, kindly supported and helped by the coordinating work of this teacher. We prepared five different lab activities, one per grade (see footnote 14 on Chapter 3).

[13]This has been reported in the analysis of student conceptions "Analysis of problem-solving students' sheets", in Chapter 2.

4.2.3 Teacher #3

Teacher #3 is now a permanent Physics teacher in a secondary school for professional and technological studies. During the research project, he had a temporary position as Maths and Physics teacher in a high secondary school for ancient classic studies for Slovenians who live in Italy.

He started teaching three years ago, after his Master's Degree in Physics Education and History of Physics[14]. So, he is a novel teacher with a theoretical background in Physics Education, which sustained him to move his first steps in teaching practices.

Despite the other teachers involved in this research project, in his former education, he was trained towards learning about Physics teacher PCK (Etkina, 2010; Magnusson et al., 1999), how students build Physics knowledge and what is conceptual change (diSessa, 1993; Hammer, 1996; Levrini and diSessa, 2008) and how epistemological beliefs influences this knowledge (Elby, 2001). This highlights his ability to build and reflect on his teaching practices under these frameworks.

In fact, during his first year of teaching, he laid the foundation of his PCK by making a lot of effort to cover all the patterns in the Phys-Maths interplay in his instructional practices (Bologna and Peressi, 2022b; Lehavi et al., 2017), promoting classrooms' discourses for argumentation skills development (Bologna, Leban, et al., 2022; Kuhn and Crowell, 2011) and assessing knowledge also with no-traditional exercises and problems (Bologna

[14]He started his studies in Physics Education during the apprenticeship and the Bachelor's Thesis Degree in Physics, implementing the use of an ancient galvanometer for educational purpose (Leban et al., 2020).

and Leban, 2022).

He dedicated many efforts to defining the features of his teaching under two intentionalities:

- he would not teach as he learnt Physics;
- he would teach, encouraging students' centrality in the learning process.

He realised very soon that there was a consistent difference between studying Physics and teaching it.

> *I learnt Physics in a traditional way, with frontal lessons, no interactivity, no more labs activities, and more Maths, everywhere Maths. I feel this was a limit to overcome for my professional development.*

Focusing on the mathematisation of Physics contents was a limit he wanted to overcome thinking to build his teaching practice.

In the secondary school where he taught, students attended this school to avoid scientific subject matters. This context constraint supported, even more, the need to come over the mathematisation process in the conceptual building as a unique way of presenting content.

> *I needed to open my mind and try to find something different in terms of conceptual Physics knowledge building.*

The first problem encountered was the lack of teaching tools. Quickly emerged the urge to create and prepare new materials because there were no available textbooks, exercises, or anything else that could help and support learning for his students (neither in Italian or Slovenian language).

Engaged in this research project responded to his need to build his teaching profile. Since he started to teach, he has participated in it, as reported in Table 83.

Table 83: Data collected for Teacher #3 (in **bold** with/by researcher).

Data collected Type	**Academic Year**		
	19/20	20/21	21/22
Classroom Observations			
Teaching Activities		24h	122h
Discussions		33h	48h
Teaching Artifacts		6	9
Audio/Video recorded		6	
Survey		1	1

What is remarkable is how he adopted the ISLE approach slowly during the first year and the second academic year, fully in the classes of 11^{th} grade, whereas in the ones of 12^{th} grade and the last ones only for some activities.

This clearly emerges by looking at the teaching gain (Table 84). The pre-test's normalised mean value percentage is slightly higher than expert teachers ($\geq 55\%$). This is due to his former preparation heavily influencing how he shaped his habits for Physics teaching (Etkina et al., 2017).

His teaching gain suggests what happened in these last two years. Teacher #3 nurtured the habits (in terms of disposition, knowledge and skills) developed during his educational training to maintain and improve them in developing his teaching practices. Table 85 shows the mode value for the overall survey's responses. Whereas, Table 86 gives an overview of responses

Table 84: Teaching gain for Teacher #3.

Normalised Mean Value Percentage	**g Value**	**Development Trend**
$\overline{x}_{pre} = 55,6\% \pm 0,6\%$	$0.42 \pm 0,01$	Medium teaching gain
$\overline{x}_{post} = 74,4\% \pm 0,4\%$		

in the survey concerning tasks of teaching.

Table 85: Mode Frequency Value for the survey's overall responses for Teacher #3.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

Therefore, we could refer to his learning process as consolidating productive habits, as could be seen in the detailed tables with the specific tasks of teaching (see Appendix A, Tables 114, 115, 116, 117, 118, 119).

In the first category-task (Appendix A, Table 114), there is by the Teacher #3 a lower score in the post-test than in the pre-test one. In this negative trend, he recognised a sort of formative pre-disposition when he started to teach. The pre-disposition was a consequence of the theoretical imprinting of his studies towards the specific task of anticipating students' beliefs for moving their intuitive, spontaneous knowledge into the normative one. For this specific aspect, this pre-disposition was not really confirmed by teaching practices, even if it is still present (the mean value is comparable with the other category/task).

Table 86: Broad overview of Teacher #3 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$4,75 \pm 0,13$	$4,00 \pm 0,20$	$-15\% \pm 5\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,20 \pm 0,08$	$3,70 \pm 0,09$	$30\% \pm 2\%$
3.	Monitoring, interpreting, and acting on student thinking	$3,43 \pm 0,18$	$3,57 \pm 0,14$	$3\% \pm 5\%$
4.	Scaffolding meaningful engagement in a science learning community	$3,00 \pm 0,12$	$3,80 \pm 0,10$	$16\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$2,50 \pm 0,20$	$4,00 \pm 0,13$	$30\% \pm 5\%$
6.	Using experiments to construct, test, and apply concepts	$1,86 \pm 0,15$	$3,3 \pm 0,22$	$29\% \pm 6\%$

It is relevant to notice that in the process of developing teaching habits, he was not sustained by his school colleagues but by the community of teachers involved in the research project. Sharing ideas and difficulties and exchanging materials and experiences supported his incoming towards becoming a Physics teacher.

There are two main aspects characterising the practice of this teacher, well-depicted by the incremental ratio of Table 86 addressing tasks of teaching (**2-5** and **4-6**):

1. the learning sequence employed in the conceptual building based on Observational and Testing Experiments;

2. the use of Multiple Representations to enact students' reasoning skills. We could underline these features by analysing the teaching artifacts for preparing his lessons. Figure 65 extracts teacher's notes.

Figure 65: Teacher's notes on conceptual building of constant velocity motion in one dimension.

The switching between representations supports the content development during the lesson. This is a key characteristic also in the learning activities performed using the Desmos platform related to Circular Motion, Work and Energy, and Kinematics[15].

> *I understood that all these instructional practices enact a way of building knowledge deep and durable. It is not the temporary knowledge acquired by memorising formulas.*

The difficult part was the assessment. It is difficult to assess students in written tests, creating exercises which do not assess memorising procedures but involve representations and reasoning about them.

> *We have to change completely the way of thinking about how to assess students' knowledge. This is still something I have to improve.*

Lastly, Teacher #3 transcribed the video-recorded of his lessons[16]. By listening again to classroom discourses, he was encouraged to improve his questioning (which kind of questions are used to guide students) during the scaffolding of students' concept-building process. He noticed he needed to let students talk in classroom discourses more than he realised to do during his lessons' hours.

[15] These activities are in Slovenian language and available at the following links: shorturl.at/jlmxY - Kinematics, shorturl.at/dgmN7 - Circular Motion, shorturl.at/pqwKY - Work and Energy.

[16] He made by himself the transcriptions because the video-recorded lessons were in Slovenian language.

4.2.4 Teacher #4 and Teacher #5

Teacher #4 and Teacher #5 belong to the same secondary school for ancient and linguistic studies. At the beginning of the research project, another teacher was engaged and involved in Classroom Observations. The spread of COVID's impacted her choice to continue the activities during the remote learning and when it could be possible to return to classrooms.

There are some differences between classes that have a curriculum based on ancient studies and to linguistic ones. Teachers underline the difference in students' motivation to study: ancient-curriculum classes are usually more motivated than the others, with high levels of performance and preparation.

Eventually, students attending this kind of school are not inclined towards scientific and mathematical studies, even if it is not unusual that some attend Medicine, Engineering or other scientific faculty for college instruction. They are well-prepared for "hard" studying.

This high school has a small, old Physics laboratory, unused by teachers. All teaching activities are performed in the classrooms without any equipment.

During the research project, the two teachers had classes with the same instruction grade. Therefore, it could be possible to work side-by-side with them, comparing activities and outcomes. In detail, they both worked in Clinical-practice phases on the following content topics:

- Inclined Plane;
- Work-Energy process (Bologna, Leban, et al., 2022);
- One-dimension Kinematics and Force-Motion conceptual relationship.

As it happened with other teachers, it would not be possible to follow the teachers' process of development *new* habits in the same class, with the same students. We would stress this fact for these teachers as we consider it relevant to the process that each of them underwent.

4.2.4.1 Teacher #4

Teacher #4 is a permanent Maths and Physics teacher. She started her teaching experience nineteen years ago, the first nines in a temporary position. She attended the SSIS preparation and certification program for teaching after her Master's Degree in Maths studies.

Her involvement in the research project is reported in Table 87.

Table 87: Data collected for Teacher #4 (in **bold** with/by researcher).

Data collected Type	**Academic Year**		
	19/20	20/21	21/22
Classroom Observations	**23h**		
Teaching Activities		**15h**	**16h**
Discussions		20h	22h
Teaching Artifacts	1	4	6
Audio/Video recorded		1	
Survey	**1**		1

Her teaching practices are well-planned. The Learning Unit usually follows a pattern that could be summarized in four steps:

1. open discussion with the classroom introducing a specific content topic;

2. mathematisation model of the phenomena described;
3. problem solving and exercises about the content;
4. written/oral assessment.

During her lessons, she constantly refers to the textbook, even if sometimes she stresses the limitation of the one adopted in her school. Nonetheless, she thinks it is very important for students to read and interrogate the textbook after classroom activities.

> *No matter how I want to make the learning sequence taking another way, the textbook is the content reference, and I cannot choose anything else.*

A remarkable feature of this teacher is her disposition towards students' involvement in classroom discourses. She addresses the aim of sustaining students' classroom talking by posing questions guiding their investigation.

Then, she let them discuss, finding contrasting positions or agreements, focusing on what is important and what is not. This took a great part of the lesson timing. Then after reviewing ideas, she moved towards concept building and grounded the knowledge with mathematics.

When she realised that the students were "*tired*" of the maths process, she stopped immediately and switched to another representation.

All of the features of how she shapes her teaching practices are well-depicted in the broad overview by category tasks (Table 88, and Appendix A, Tables 120, 121, 122, 123, 124, 125), looking at the test mean values. Whereas, in Table 89 the mode value is reported.

The feedback from her post-test was widely positive. The activities en-

Table 88: Broad overview of Teacher #4 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$2,50 \pm 0,14$	$4,25 \pm 0,24$	$35\% \pm 6\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,60 \pm 0,05$	$4,30 \pm 0,13$	$34\% \pm 3\%$
3.	Monitoring, interpreting, and acting on student thinking	$2,57 \pm 0,11$	$4,71 \pm 0,11$	$43\% \pm 3\%$
4.	Scaffolding meaningful engagement in a science learning community	$3,00 \pm 0,07$	$3,90 \pm 0,13$	$18\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$2,63 \pm 0,06$	$4,88 \pm 0,04$	$30\% \pm 2\%$
6.	Using experiments to construct, test, and apply concepts	$1,29 \pm 0,07$	$3,00 \pm 0,18$	$34\% \pm 4\%$

Table 89: Mode Frequency Value for the survey's overall responses for Teacher #4.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

couraged her to promote teaching practices that could sustain her development of *new* habits of mind and practice. Therefore, her teaching gain is a medium-high value (Table 90).

After the cognitive apprenticeship and the beginning of a new academic

Table 90: Teaching gain for Teacher #4.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 49,6\% \pm 0,4\%$	$0.67 \pm 0,01$	Medium-high teaching gain
$\overline{x}_{post} = 83,4\% \pm 0,6\%$		

year, she came back to her "survival" habits. (Etkina et al., 2017).

Her process of development *new* habits of mind and practices was constrained by the "survival" restraints of rooted practices, difficult to overcome because it would mean making *new* materials, *new* sequence learning, notes for students to read and interrogate instead of the textbook.

This teacher did not overcome her "survival" teaching practices, limiting the activation of the development of habits of maintenance and improvements. The reason could reside in difficulty in the use of materials in English.

Without proper language skills, she needs to have the support of someone who translates and prepares teaching artifacts. However, this in-service training specified her disposition towards the students' centrality in the learning process.

Finally, she did not participate in the community of practices. Combining these two overlapping conditions (no language skills and no community), what happened evidently underlined that the importance of community support for change.

4.2.4.2 Teacher #5

Teacher #5 is quite a novice teacher in Maths and Physics after a fragmented career among temporary positions in middle schools, teaching Maths and Science for three years, and in high secondary schools, teaching Maths for eight years.

When she joined the research project, it was her first year of teaching both Maths and Physics in secondary schooling (Table 91 reports her engagement in the research).

She intentionally decided to take part in the project for sustaining the building of her Physics teaching profile, lacking experience and practice.

Table 91: Data collected for Teacher #5 (in **bold** with/by researcher).

Data collected Type	**Academic Year**		
	19/20	20/21	21/22
Classroom Observations	**26h**		
Teaching Activities		**10h**	**10h**
Discussions		16h	19h
Teaching Artifacts	3	3	3
Audio/Video recorded			
Survey	**1**		1

After her Master's Degree in Maths, she attended the SSIS certification program for teaching in middle and high schools. Then, she could not have the possibility to deepen disciplinary insight from a pedagogical content knowledge point of view since she started her new position three years ago.

Unlike the other teachers, she had to build *ex-novo* habits toward Physics teaching. She already had a long experience teaching Maths and developed suited habits for this teaching.

What happened at the beginning of her Physics teaching was a blending of habits developed in Maths teaching and the *new* ones developed in Physics teaching.

What we could immediately notice by Classroom Observations was that she structured learning sequences around mathematical modeling of the Physics phenomena.

During her lessons, she spent a great deal of time deriving mathematical expressions for physics laws. The classroom discourses were mostly teacher-centred, with low student participation only when they requested deeper explanations or further content knowledge.

The way she assessed student learning outcomes mirrored her teaching approach. Her written graduation tests consisted of two parts: one with theoretical questions and the second with exercises of formula's application and manipulation (Fig. 66 and Fig. 67).

(1) Definisci il lavoro nel caso generale, poi illustra i tre casi particolari che abbiamo evidenziato con dei disegni e dei semplici esempi.

(2) Spiega cosa significa che una forza è conservativa e fornisci almeno due esempi di forza conservativa e un esempio di forza non conservativa. Quale importante grandezza fisica si può definire in caso di forza conservativa?

(3) Enuncia il teorema dell'energia cinetica.
(4) Definisci l'energia potenziale gravitazionale.

Figure 66: Example of theoretical questions in written test (in Italian).

We would underscore the verbs used in the questions:

1. "*define* the work"...

2. "*explain* what does it mean "conservative force"..."
3. "*enunciate* kinetic energy theorem..."
4. "*define* gravitational potential energy..."

Each question calls on students' factual declarative knowledge without any reasoning concerning physics concepts.

Furthermore, if we examined the types of of exercises (Fig. 67), for example we found:

(8) Una noce di cocco di $1200\,g$, inizialmente ferma, cade da un ramo di un albero a $20\,m$ da terra e arriva a terra con una velocità di $16\,m/s$.
(a) Calcola l'energia potenziale iniziale e finale.
(b) Calcola l'energia cinetica iniziale e finale.
(c) L'energia meccanica è conservata? Calcola la perdita di energia meccanica a causa delle forze di attrito.
(d) Calcola la forza di attrito media che ha agito nel percorso di caduta.

Figure 67: Example of exercises queries in written test (in Italian).

The verb *calculate* is repeated many times, and the unique Physics request concerns energy conservation but does not ask to motivate the answer.

The teacher reflected on the lack of student feedback during classroom discourses and the increasing difficulties in students' written tests solution.

When we started the tutoring and coaching phases in the cognitive apprenticeship, she realised how it was important to (according to tasks of teaching, Etkina et al., 2017):

- anticipate students' challenges related to conceptual and qualitative reasoning;
- Designe and sequencing learning experiences that also include productive representations;
- Elicit student understanding and help them express their thinking via multiple modes of representation;

- Use representations, examples, and models consistent with each other and the theoretical approach to the concept she wants students to learn.

The awareness soon became practice, which, day by day, she consolidated through a continuous reflection on herself. What happened in the process of of development of Physics teaching habits is well depicted by the overview of category-tasks in Table 92, and by the mode value in Table 93.

Table 92: Broad overview of Teacher #5 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$1,50 \pm 0,14$	$3,00 \pm 0,20$	$30\% \pm 5\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$1,40 \pm 0,05$	$3,10 \pm 0,10$	$34\% \pm 2\%$
3.	Monitoring, interpreting, and acting on student thinking	$2,00 \pm 0,14$	$3,00 \pm 0,14$	$20\% \pm 4\%$
4.	Scaffolding meaningful engagement in a science learning community	$1,30 \pm 0,05$	$3,10 \pm 0,14$	$36\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$2,00 \pm 0,11$	$4,00 \pm 0,11$	$40\% \pm 3\%$
6.	Using experiments to construct, test, and apply concepts	$1,00 \pm 0,00$	$1,00 \pm 0,00$	$0\% \pm 0\%$

The process guided the teacher towards defining her professional identity as a Physics teacher. This development of the professional identity is relevant to her teaching gain, which came about as an incremental effect of the reflective process upon her practices (Table 94).

Table 93: Mode Frequency Value for the survey's overall responses for Teacher #5.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

Table 94: Teaching gain for Teacher #5.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 30,4\% \pm 0,4\%$	$0.40 \pm 0,01$	Medium teaching gain
$\overline{x}_{post} = 58,2\% \pm 0,6\%$		

What still makes her reflect on her Physics teaching is the lack of integrating experimental activities and building concepts based on the experimental evidence (this is exactly what emerges if we examine Table 92, category-task **6**; more detailed information is in Appendix A, Tables 126, 127, 128, 129, 130, 131). She needs to change her way of building learning sequences and be more self-confident about her skills in performing experiments.

4.2.5 Teacher #6

The process of developing *new* habits of Teacher #6 is quite different from the others. The difference mainly resides in how it was possible to implement the research project with the school's teacher during the COVID emergency.

In fact, unlike other schools, it was not possible for the researcher to interact and participate in classroom activities both in the presence of or in remote learning.

A firm interest in this teacher to discuss her teaching practices was the key feature which allowed her to change drastically. Table 95 describes the teacher's involvement in the research project.

Table 95: Data collected for Teacher #6 (in **bold** with/by researcher).

Data collected Type	**Academic Year**		
	19/20	20/21	21/22
Classroom Observations			
Teaching Activities			**12h**
Discussions		20h	23h
Teaching Artifacts			7
Audio/Video recorded			
Survey	**1**		1

Teacher #6 has background in Astronomy Studies. She has almost twenty years of teaching experience in Maths and Physics, gaining a permanent position after attending the SSIS certification program (Dal Passo and Laurenti, 2017) sixteen years ago.

She teaches these subjects in a secondary school for Social and Humanities studies, where students are commonly less interested in sciences and technological content. Also, the school curriculum requires teachers to treat fewer topics in a framework with less mathematisation.

The disciplinary department of her school includes teachers belonging to two other kinds of secondary school, which are part of the same secondary institute: a school for ancient and modern linguistic studies and a school for music ad choirs studies.

All three schools have the same Physics curriculum and the same problems with students' motivation to face off. But when we presented the research project in 2019/20, only this teacher was interested in it[17].

Even though she had a long experience in teaching, she would reflect upon her practices, trying to deeply understand why she felt a sort of professional dissatisfaction towards her Physics teaching.

When she became engaged in the research project, she believed it was the chance to overcome her professional dissatisfaction, to discover the reasons for it and to implement a change. She was ready for a deep insight into her practices.

What happened was the concurrence of two elements: on one side, the possibility of knowing a different way of teaching Physics, and on the other, a question arose from a student.

This event was so important that she decided to write a detailed memory[18]

[17]We would remarkably underline that Teacher #6 is now promoting the adoption of the ISLE approach in her school, engaging her colleagues in a revision of their teaching practices.

[18]The teacher's memory was written in English, and it is available, with teacher permission, at the following link: shorturl.at/qCGN2

when she tried to underpin and focus on how the change occurred.

> *In this writing, I would like to describe a metamorphosis in high school physics teaching, which I happened to go through, not intentionally but luckily. It all began with a shocking moment caused by a student's question. The answer made me realise how shallow and limited my teaching objectives were, most focused on solving equations related to unrealistic situations. It has been quite a nightmare to move from "Describing Physics Equations" to "Leading Interactive Meetings", where students are provided with phenomena to investigate through inductive reasoning. Eventually, I met ISLE, and it all began to make sense!*

The *metamorphosis* that she describes is clearly visible in the teaching gain we measured through the survey about tasks of teaching (Table 96).

Table 96: Teaching gain for Teacher #6.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 31,4\% \pm 0,4\%$	$0.56 \pm 0,01$	Medium-high teaching gain
$\overline{x}_{post} = 69,6\% \pm 0,6\%$		

The question posed by an eighteen years old student, after three years of Physics curricular studies, was very simple:

> *Prof... I do not understand... What do we study Physics for?*

What is important to note here is what happened after that.

[...] It took me some months to find the perfectly matching answer. Eventually, I succeeded. I found it only when I focused on the actual knowledge I was passing on to students and no longer on something that "is well known by everybody". The answer I came up with sounds exactly like this: "For becoming fond of how point like objects, perfect gases and point-like charges behave, not to mention the high level of competence you acquire in substituting letters with numbers and rearranging equations". [...] It would make sense to him since it summarises very clearly what my students and I have been involved in, in my Physics classes. It represents the pattern underneath my teaching.

The question had moved the teacher inside her habits, making them visible in an unexpected manner:

[...The given answer] also represents where my lessons have always led to, even if I was not aware that I was actually planning it, even if I had always thought that my teaching objectives had to do with the understanding of some natural phenomena and how some technological devices work.

Being aware of the need for change made the teacher revolutionise her teaching practices.

I am still going through this process, and it seems endless [...]

The process is visible when we analysed pre-post survey-specific tasks (Table 97) and the mode value of the frequency for the overall responses (Table

98). The high value of the incremental ratio in all the category-tasks underpins how she developed *new* dispositions, knowledge and skills. And this happened just in one one academic year (the details of specific tasks are reported in Appendix A, Tables 132, 133, 134, 135, 136, 137).

Table 97: Broad overview of Teacher #6 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$2,50 \pm 0,14$	$5,00 \pm 0,00$	$50\% \pm 3\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$1,70 \pm 0,13$	$3,30 \pm 0,13$	$32\% \pm 4\%$
3.	Monitoring, interpreting, and acting on student thinking	$1,57 \pm 0,14$	$2,86 \pm 0,10$	$26\% \pm 3\%$
4.	Scaffolding meaningful engagement in a science learning community	$1,40 \pm 0,08$	$4,30 \pm 0,13$	$58\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$1,38 \pm 0,06$	$2,63 \pm 0,20$	$25\% \pm 4\%$
6.	Using experiments to construct, test, and apply concepts	$1,28 \pm 0,10$	$3,29 \pm 0,18$	$40\% \pm 4\%$

Table 98: Mode Frequency Value for the survey's overall responses for Teacher #6.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

Firstly, she tried to change one learning sequence about the conceptual building of the electrostatic phenomena[19], starting from Observational Experiments.

> *It is amazing, unbelievable how much more my students learned about the characteristics of the space surrounding a charged body, even if mostly from a qualitative point of view. Maths was there, of course, but still, it was not well integrated into the whole process. But... one step at a time!*

Secondly, she encountered many inconveniences, such as the lack of materials and textbooks. Nonetheless, she is now devoting all efforts to developing these *new* habits:

> *What I can say for sure, for the time being, is that trying to introduce an investigative approach is definitely worth the effort from every point of view: more motivation in preparing your lessons, increased fun in class, more focused students, meaningful situations for getting to know your students better and to trust them... Probably, sometimes, you will also find yourself reorganising your knowledge of Physics in a more significant, consistent and accessible way or... learning Physics for the first time!*

What led her to this deep revision was the need to change and the desire that she had something *new* to learn to improve her teaching.

The changes in her teaching also met the innovation purpose of a school project involving her classes, the so-called "Sezione Rondine"[20]. This is a

[19] How the sequence learning was set up is described in detail in the teacher's memory.

[20] "The Rondine Classes": https://rondine.org/sezione-rondine/

pilot program of the Italian Instruction Governance for developing students' wellness, growth-mindset, letting them able to overcome difficulties and conflicts in a global world and be peace-maker.

The ISLE approach she implements in her "Rondine" class satisfies all the program requirements and what the training course for "Rondine" methodology had asked for pilot teachers[21].

[21] This fact led teacher #6 to promote other teachers adopting the ISLE approach for Physics teaching/learning also in the other pilot "Rondine" classes in the country region Friuli-Venezia Giulia.

4.2.6 Teacher #7 and Teacher #8

Teacher #7 and Teacher #8 belong to the same institute for secondary instruction. This institute is devoted to training towards technical and professional jobs, and it includes three different kinds of vocational schools: Tourism, Economy and Informatics, and Social and Healthy Assistance courses.

Technical and Professional secondary schools have been recently interested in instructional reform (D.M. 99, 15/07/2022[(22)]) which followed another recent one (D.M. 61, 13/04/2017[(23)]).

The reform ought to increase the focus of these schools to integrate knowledge and practical skills through personalised educational learning, flexibility and more lab activities.

The two teachers who participated in the research project had to face the news brought by the reform. In detail, they had to integrate their teaching practices in a manner promoting:

- student-centred learning environment;
- learning sequence (the so-called Learning Units) based on laboratory practice and, if possible, highly interdisciplinary.

Their professional development was encouraged by the reform they had to enact.

Then, there is another feature which characterised their context of teaching. Every day, in their classes, they face students with low motivation towards studies and many behavioural problems. Classroom management is often heavy, and lesson conduction is difficult, challenging, and demands

[22] https://www.gazzettaufficiale.it/eli/gu/2022/07/26/173/sg/pdf

[23] https://www.gazzettaufficiale.it/eli/gu/2017/05/16/112/so/23/sg/pdf

many resources.

Lastly, but not less importantly, Physics is a curricular subject only for the first years in technical courses, whereas, in the professional one, it is part of the Integrated Sciences curriculum. This difference affects teaching choices concerning content topics to teach, methodology practices and how to assess students' progression.

Teacher #7 and Teacher #8 strictly work together to overcome these issues and to improve their teaching to face continuous incoming challenges.

This collaboration also occurred when we presented our research project. Except for the Clinical-practice phase implementation in each teacher's class, they discussed, planned, and reflected together, as it would be in a school community of practice. Therefore, in this particular case, the development of *new* habits for each teacher is the development of *new* habits for the entire community[24]

4.2.6.1 Teacher #7

Teacher #7 is a Physics teacher with a Master's Degree and a PhD in Physics studies. After training and three years of teaching in Maths/-Phys and Informatics temporarily, he won a permanent teaching position in Physics through a public recruiting selection. He has been holding this job for almost fourteen years.

During this long period of time, he devoted a great deal of effort to building his teacher profile, becoming a member of the Italian Association

[24]As the result of this development process, these teachers decided to start a scientific team-working group project called G.Ri.D, Gruppo per la Ricerca Didattica (Group for Didactics Research) in their school.

of Physics Teaching (AIF, Associazione per l'Insegnamento di Fisica) and taking part in many in-service training programs also in the international area (Bussani et al., 2019).

All these experiences have shaped his PCK and his interest in teaching Physics with clear intentionality:

> *Promoting students' interest toward the scientific practice and doing Physics.*

This intentionality straightforwardly emerges in the two papers he wrote to share with a wider Physics teachers' community his teaching experiences (Bussani, 2020; Bussani and Comici, 2023).

He considered participating in this research project as an opportunity to empower and sustain his teaching target (Table 99).

Table 99: Data collected for Teacher #7 (in **bold** with/by researcher).

Data collected Type	**Academic Years**		
	19/20	20/21	21/22
Classroom Observations	**12h**		
Teaching Activities			**8h**
Discussions		4h	15h
Teaching Artifacts	4		3
Audio/Video recorded			1
Survey	**1**		1

The process of developing *new* habits is still ongoing, as the teaching gain indicates (Table 100).

Table 100: Teaching gain for Teacher #7.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 47,8\% \pm 0,4\%$	$0.23 \pm 0,01$	Low teaching gain
$\overline{x}_{post} = 60,0\% \pm 0,4\%$		

During the Clinical-practice phase concerning the Work-Energy process[25] operating in children's toys, his classes were engaged in activities substantially different with respect to the ones he normally ran. He appreciated the collaborative building of knowledge, the environment of sharing ideas and the emphasis on Observational and Testing experiments without - what he claimed - "*any formal teacher's explanation*".

Exploring these *new* practices, he was motivated by the purpose of changing the way he usually engaged students in doing Physics. Meanwhile, he is "*testing the ground*", revising his practices and re-thinking the activities that he utilizes in his classes (as the overview on category-tasks suggests - Table 101; the detailed information about the specific tasks are reported in Appendix A, Tables 138, 139, 140, 141, 142, 143). Whereas, Table 102 shows the mode frequency value.

The change implies revising how to build a learning sequence: not focusing on practical activities such as collecting data of measurements and then analysing data (Bussani, 2020; Bussani and Comici, 2023), but enhancing these practices to an epistemic process, as the ISLE process is (Brookes et al., 2020). This means investigating phenomena in the same way scientists

[25]The activity is described (in the Italian language) and available at the following link: shorturl.at/fHKS7

Table 101: Broad overview of Teacher #7 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$2,75 \pm 0,24$	$3,25 \pm 0,13$	$10\% \pm 1\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,60 \pm 0,07$	$3,00 \pm 0,07$	$8\% \pm 2\%$
3.	Monitoring, interpreting, and acting on student thinking	$3 \pm 0,16$	$3,14 \pm 0,17$	$3\% \pm 5\%$
4.	Scaffolding meaningful engagement in a science learning community	$2,40 \pm 0,10$	$3,70 \pm 0,11$	$26\% \pm 3\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$2,13 \pm 0,10$	$2,75 \pm 0,11$	$13\% \pm 3\%$
6.	Using experiments to construct, test, and apply concepts	$1,57 \pm 0,11$	$2 \pm 0,14$	$9\% \pm 4\%$

Table 102: Mode Frequency Value for the survey's overall responses for Teacher #7.

	Mode Value	
	Pre-test	Post-test
All Category-tasks	$39,1\% \pm 0,2\%$	$41,3\% \pm 0,2\%$

do, making hypotheses, predicting outcomes, and testing predictions.

This teacher is realising the need to turn his learning sequence into an epistemic process and not only into factual practices. And he is really aware that moving towards this change means developing *different* habits.

4.2.6.2 Teacher #8

Teacher #8 is a Science teacher teaching Physics in the Integrated Science curriculum. She has a Master's Degree and a PhD in Chemistry. The way she became a teacher is quite different from the others. She attended a training program certification called TFA (the acronym for Tirocinio Formativo Attivo, which could be translated as Active Training Apprenticeship; Dal Passo and Laurenti, 2017).

This national pre-service program was activated twice, in 2012 and 2014. It was a program substantially different from the SSIS one, providing many training hours in cognitive apprenticeship in classrooms and a formative training in pedagogical and discipline insight courses. Unlike the SSIS program, after the final TFA's examination for a teaching qualification, a teacher had been admitted to temporary teacher position lists and selections for a permanent position.

Teacher #8 acquired two different teaching qualifications: one for Maths and Sciences in middle school instruction and the other one for Chemistry and Integrated Sciences for high schools.

She temporarily taught Maths and Sciences and Chemistry for three years, and now she succeeded in a permanent position five years ago.

Her teaching practice was very creative. She spent many hours planning, inventing, and exploring all that is possible to use in her classes to engage her students in the process of active learning, as we could observe.

She got involved in the research project to become confident in Physics teaching that she considered needing to improve (Table 103).

Table 103: Data collected for Teacher #8 (in **bold** with/by researcher).

Data collected Type	Academic Year		
	19/20	20/21	21/22
Classroom Observations	**6h**		
Teaching Activities			**10h**
Discussions		4h	15h
Teaching Artifacts	2		3
Audio/Video recorded			2
Survey	**1**		1

What occurred this year was a consolidating process of teaching practices that she was exploring mainly by trial and error. The teaching gain confirms the development trend towards productive habits reflected in the tasks of teaching.

Table 104: Teaching gain for Teacher #8.

Normalised Mean Value Percentage	***g* Value**	**Development Trend**
$\overline{x}_{pre} = 37,4\% \pm 0,2\%$	$0.40 \pm 0,01$	Medium teaching gain
$\overline{x}_{post} = 62,6\% \pm 0,6\%$		

The detailed overview under each category-tasks shows how she is purposefully addressing these challenging processes (Table 105, and detailed information in Appendix A, Tables 144, 145, 146, 147, 148, and 149). Whereas Table 106 details the mode value for the pre-post survey responses.

She was convinced by the activity her students did in the Clinical-practice

Table 105: Broad overview of Teacher #8 survey's responses by category-task.

	Category-task	**Mean Value**		**Incremental ratio (%)**
		Pre-test	Post-test	
1.	Anticipating student thinking around science ideas	$2,25 \pm 0,13$	$4,25 \pm 0,13$	$40\% \pm 4\%$
2.	Designing, selecting, and sequencing learning experiences and activities	$2,10 \pm 0,07$	$3,40 \pm 0,14$	$26\% \pm 3\%$
3.	Monitoring, interpreting, and acting on student thinking	$2,00 \pm 0,08$	$3,43 \pm 0,16$	$29\% \pm 4\%$
4.	Scaffolding meaningful engagement in a science learning community	$1,70 \pm 0,05$	$2,70 \pm 0,11$	$20\% \pm 2\%$
5.	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$1,63 \pm 0,07$	$2,50 \pm 0,18$	$18\% \pm 4\%$
6.	Using experiments to construct, test, and apply concepts	$1,71 \pm 0,07$	$3,14 \pm 0,17$	$29\% \pm 4\%$

Table 106: Mode Frequency Value for the survey's overall responses for Teacher #8.

	Mode Value	
	Pre-test	Post-test
All Category-tasks		

phase. This activity "*led her out of schemes*", more than she could imagine possible to perform in her classes with "*those students*".

In a framework of conceptual blending (Gregorcic and Haglund, 2021), we developed a kinesthetic activity regarding one-dimension Kinematics (Fig.

68) ISLE-based[26].

Figure 68: Moments of the activity in the gym.

The teacher recognised what helped achieve the learning outcome:

- switching between representations (patterns, motion diagram, graphs), Fig. 69;
- engaging multiple settings for developing learning sequences (class, gym, garden, computers' lab);
- assessing knowledge using alternative tests based on collaborative working groups.

Her words better synthesised what happened in her teaching practices:

I was really aware of what was necessary to task for effective teaching practices. But when I realised that nothing is better than

[26]The activity has been presented as a communication at the SIF Congress 2022; the presentation and the materials (in Italian language) are available in the folder: short-url.at/cnrT5

this, there were no more constraints to face. I had no more excuses.

Figure 69: Materials and representations of motion diagram during the activity in the garden.

4.2.7 Community of practice

Many teachers engaged in this research project often emphasized the importance of belonging to a community of practice. They highlighted two main issues:

- the relevance for themselves as Physics teachers;
- the relevance for instruction.

They would not develop *new* habits if they thought they were "perfect teachers". Instead, they were troubled and worried about the great effort they employed daily in their classrooms and practices and the small effect they underpinned on their students. Their shared dissatisfaction was a lever to punch the change.

Then they realised the change they were experiencing was the same, in other schools, other classes, and other teachers were trying to pursue. The shared goals help them to overcome difficulties (and due to the COVID pandemic, more difficulties than usual; Bjurholt and Bøe, 2022; Marzoli et al., 2021; Mazzola et al., 2022; Porru et al., 2022).

Acknowledging the value of the community developed through this research project, we shared a detailed report with all the school management directors at the end of the planned activities[27].

With this report, we wanted to stress how the collaborative work between teachers of different high schools provided opportunities for developing productive habits. We also spotlighted how many students were indirectly engaged in the process of Physics learning innovation. Figure 70 shows the

[27]The original report - in the Italian language - is available at the following link: short-url.at/CIJSW

total number of students involved in the work of their teachers.

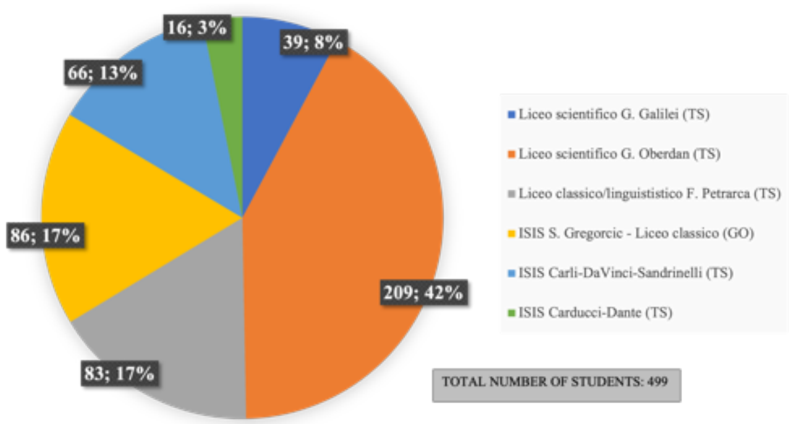


Figure 70: Students involvement in the research project 2019-2022.

Lastly, the relevance of instruction stands in disseminating practices this project had started. Teachers involved in their process of developing *new* habits are now actively engaged in sharing what they are practising with their colleagues.

That's happened because developed habits are productive for themselves and their students and others.

4.3 Developing Teachers' Habits - Summary

The aim of developing teachers' habits was the way we addressed to answer the two research questions:

(RQ3): *To what extent do teachers' practices change after the participation in such program?*

(RQ4): *To what extent do changed teaching practices improve students' attitudes toward Physics?*

In the following, we'll try to summarise the findings of our analysis, targeting the two research questions.

4.3.1 Targeting Research Question #3

According to the coding scheme we assumed as key for the analysis (Table 66) of our data, we made a correspondence between the research questions to address and the tasks of teaching which could target the goals.

Each task was defined as a category of investigation, providing information about the process of developing *new* habits. We refer not to "general" habits but to those a teacher is encouraged to adopt teaching Physics in the framework of the ISLE approach. This framework leads teachers to move away from the only application pattern of Phys/Maths interplay towards a comprehensive use of multiple representations which "are for sense-making as much as answer making" (Etkina, 2015a, p. 674)[28].

In the meantime, when participating in a learning sequence based on the ISLE process (Fig. 54), the students are actively engaged in doing Physics and learning to reason in an epistemologically authentic inquiry process (Brookes et al., 2020; Chinn and Malhotra, 2002). The tasks of teaching required to enact this learning process shape the teacher's PCK to foster classroom discourses, ensuring and supporting the development of students' argumentation skills (Brookes et al., 2020; Kuhn and Crowell, 2011; Wang and Buck, 2016).

We analysed the process of developing *new* habits that occurred to the

[28]The predominance of an application pattern of Phys/Maths interplay mainly focuses on "answer making" processes (Bologna and Leban, 2022; Bologna and Peressi, 2022b).

eight sampled teachers. Each of them experienced changes in some aspect of their teaching. Of course, it is not meaningful (neither from a research perspective) to compare the stories, the cases and their teaching gains. We depicted an ongoing process with its features, not in terms of teacher performance or efficacy of teaching.

It is interesting to estimate the impact of the tasks related to the research questions. This evaluation is obtained by the mean value of the incremental trend of each task per teacher impacting the same research question (Table 107).

Table 107: Effects on the research question of teachers' changes.

Research Question	**Task of teaching**	**Mean of Incremental Trend Percentage**
To what extent do teachers' practices change after the participation in such program?	Anticipating student thinking around science ideas	$24\% \pm 3\%$
	Designing, selecting, and sequencing learning experiences and activities	$27\% \pm 1\%$
	Monitoring, interpreting, and acting on student thinking	$22\% \pm 2\%$
	Scaffolding meaningful engagement in a science learning community	$26\% \pm 2\%$
	Explaining and using examples, models, representations, and arguments to support students' scientific understanding	$29\% \pm 2\%$
	Using experiments to construct, test, and apply concepts	$24\% \pm 2\%$
	Whole mean	$25\% \pm 3\%$

The mean percentage is not a measure of how the research question (RQ3) has been answered. It indicates how, on average, the teachers implemented changes in their tasks of teaching, which is the proxy for the revision of their

PCK. Thus, it could be considered a measure of the effect of teachers' revision that happened because of engaging in the development of *new* productive habits.

A 25% mean incremental trend in teaching practices has pinpointed the overall effect on teachers' change. These teachers really started to revise their Physics teaching. And this was the requirement of our research question.

4.3.2 Targeting Research Question #4

Despite the high number of students involved in classroom activities (N=499), we could not administer the surveys about attitudes towards Physics to all, as we planned at the beginning of the research. We faced many limitations, such as obtaining permission (from school management) to administer the survey.

Therefore, we could only collect the responses of a limited sample (N=96) at the end of our project and in a few classes. The data collected refer to different schools and different grades. Not all teachers administered the attitude scale survey to their students, or they let them be free to compile.

Here we report the plot of the descriptive statistical analysis for the whole matching sample, comparing it with the whole sample analysed in Chapter 2 (Fig. 71). We also compare the two whole samples by gender (Fig. 72, 73).

We could partially be confident this result shows a better students' positive trend towards Physics than before teachers started to develop *new* habits.

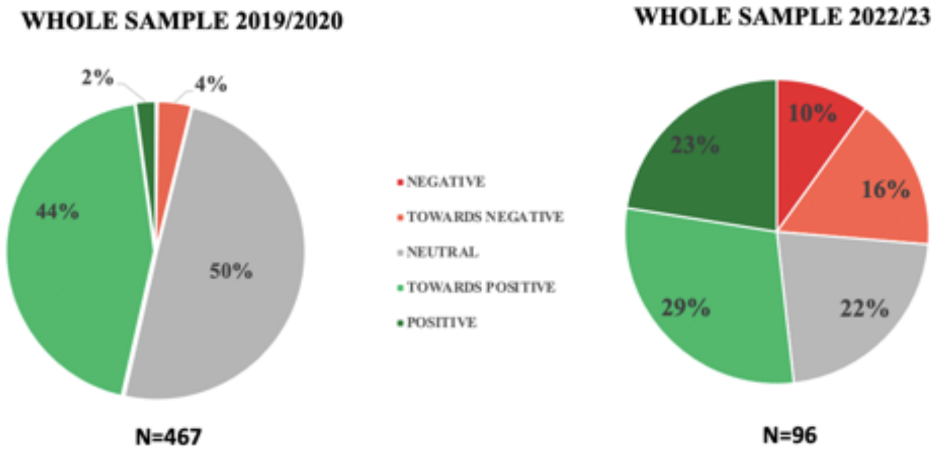


Figure 71: Attitudes towards Physics: comparing results for the whole sample (on the left academic year 2019/20, on the right 2022/23).

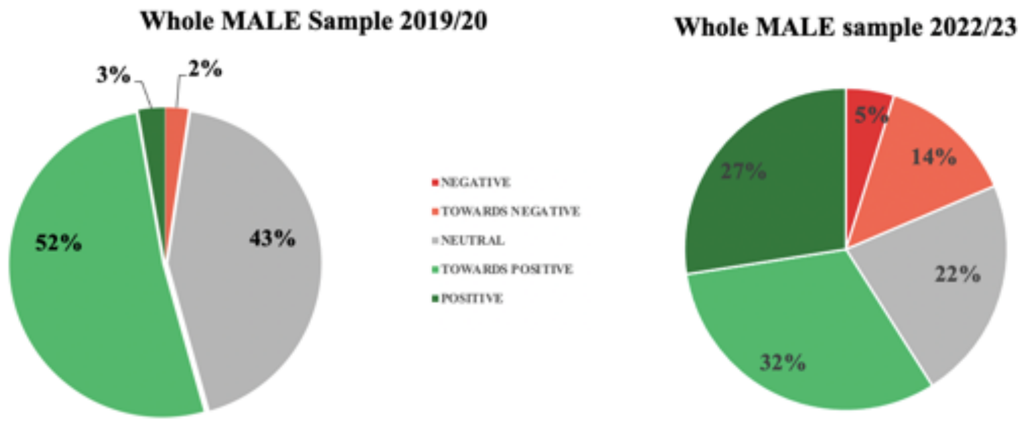


Figure 72: Attitudes towards Physics: comparing results for the whole male sample (on the left academic year 2019/20, on the right 2022/23).

By enlarging the community of practice, many students would benefit from the change activated in teaching practices involving their teachers. Therefore, we expect to observe an increasing trend towards positive attitudes to these students.

* * *

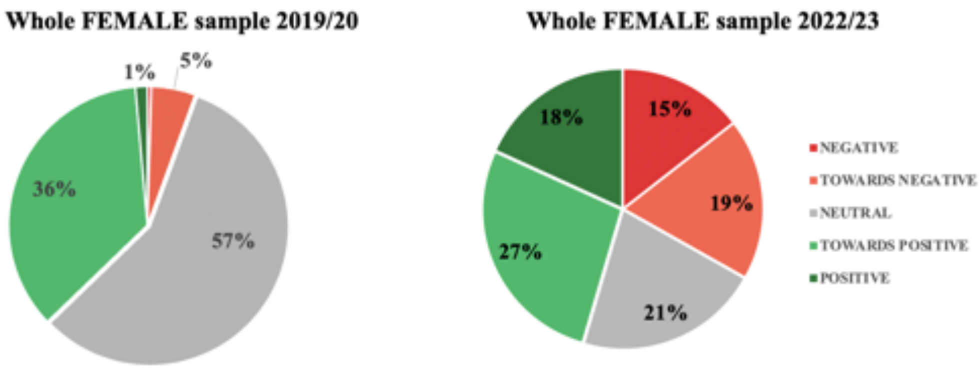


Figure 73: Attitudes towards Physics: comparing results for the whole female sample (on the left academic year 2019/20, on the right 2022/23).

Chapter 5

Discussion and Conclusion

Never before has the Italian system of instruction faced the need to undertake many efforts to introduce the development of scientific and mathematical thinking in the educational process[1].

This challenge agrees with the Recommendations of the European Union Council. These Recommendations foster the development of Competences for Lifelong Learning, including one in STEM disciplines (European Council, 2018).

The promotion of these Competences means:

- students achieve new learning outcomes that were not the goals of education before;
- teachers engage in specific teaching tasks that were not a part of their practices before.

The scientific competence includes the development of a positive attitude

[1]This is a very recent claim of the physicist Nobel Price Giorgio Parisi, who is working with a selected group of experts and the Italian Ministry for Instruction and Merit to planning the introduction of Maths and Physics since the kindergarten schooling (interview realised 01/11/23 - shorturl.at/eOY58).

"of critical appreciation and curiosity, [...] in particular as regards scientific and technological progress in relation to oneself, family, community, and global issues" (European Council, 2018, p. 9). This competence is achieved through learning outcomes such as the ability and willingness to explain the natural world using a large body of knowledge and methodologies, including observation and experimentation, to identify questions and draw evidence-based conclusions. These outcomes mean that the students develop logical and rational reasoning, learn how to test hypotheses, and to change their ideas when they contradict new experimental findings (European Council, 2018; MIUR, 2012).

The new teaching tasks involve an explicit use inquiry-based pedagogies in classrooms (European Council, 2018). These pedagogies help teachers engage students in active learning processes (Fazio et al., 2021).

Our study makes the following contributions to Physics Education:

1. Experimental evidence of the deficiencies of conceptual development and attitudinal changes toward Physics of Italian secondary students and the teaching practices of Italian Physics teachers.
2. A theoretical approach to choosing an appropriate framework to guide teachers' professional development to help teachers bring their instructional practices in alignment with the Recommendations of the European Union Council.
3. Experimental evidence of the effectiveness of professional growth of the teachers who participated in the professional development program governed by this framework and of the effects that the newly adopting teaching practices had on the attitudes towards Physics of their

students.

Contribution 1 stems from the preliminary studies of Italian physics students and their teachers that we conducted to formulate our research questions, and contributions 2 and 3 are based on the studies that we conducted to answer the following research questions:

RQ1: *How to choose a teaching/learning approach to address students' attitudes and conceptual coherence and help teachers meet the challenges of the 21st Century education?*
RQ2: *How to develop a professional development program that helps Physics teachers to adopt and implement the approach?*
RQ3: *To what extent do teachers' practices change after the participation in such program?*
RQ4: *To what extent do changed teaching practices improve students' attitudes toward Physics?*

The first question regards the choice of the teaching/learning approach that might better help students achieving the new learning outcomes. This approach needs to address the goal of overcoming deficiencies of conceptual development and attitudinal changes toward Physics of Italian secondary students and the teaching practices of Italian Physics teachers.

The second research question concerns teachers' involvement in adopting the ISLE approach (Etkina, Brookes, et al., 2019), promoting their professional development. Among many educational professional development programs, and among Italian experience in teachers' training, we identified the conceptual model suitable for Physics teachers' program in the development of habits through cognitive apprenticeship (Etkina et al., 2017).

The last two research questions regard the effect on teaching practices and learning outcomes of the adoption of a *new* approach through the development of *new* productive habits (Etkina et al., 2017).

Below we discuss the answers to these research questions, the implications of this study for Physics instruction in Italy (in terms of recommendations), its limitations, and future directions for research.

5.1 Research Question #1

The first research question was: *How to choose a teaching/learning approach to address students' attitudes and conceptual coherence and help teachers meet the challenges of the 21st Century education?*

The insight into students' and teachers' conceptions led us to search for a teaching/learning approach that could help both students and teachers. On one side, that approach should be able to help students overcome their conceptual difficulties (Ekici, 2016), low confidence in Physics learning (P. Gardner, 1985; Sheldrake et al., 2019; Testa et al., 2022), and help them develop reasoning skills (Aguiar, 2016; Kuhn and Udell, 2003; J. Osborne et al., 2013; Tippett, 2009). On the other side, it should help teachers become skilled in helping students achieve those goals.

We called this approach *Early Physics*, not intended as an approach to be adopted in early instruction of Physics, but by analogy with an approach in Maths Education called *Early Algebra* (D. W. Carraher and Schliemann, 2018; Malara and Navarra, 2018; Navarra, 2022).

We regard *Early Physics* as a teaching domain based on representative, relational and experimental activities. Students are gradually guided to recognise analogies, meanings, structures, relationships, and whatever they need to pass from qualitative to quantitative conceptualisation in a coherent conceptual framework.

In the conceptual design, we considered the natural language as the semantic facilitator in describing Physics phenomena and their representations. Switching and exchanging between disciplinary languages in learning sequence development is the main feature of this approach.

This core feature fits well with the conceptual framework we pinpointed as a reference: the use of Multiple Representations as a reasoning tool (Van Heuvelen, 1991; Zou, 2000). From a cognitive perspective, the use of Multiple Representations supports cognitive enhancement concerning the process of externalisation (Ainsworth, 2008; A. M. Collins et al., 1991; Cox, 1999), students' negotiation of representation meaning (Prain and Tytler, 2013) and reasoning activation process (Cox, 1999; Stenning and Oberlander, 1995).

From an epistemological point of view, Multiple Representations are related to the different functions of scientific explanation (Yeo and Gilbert, 2017), supporting conceptual understanding (Ainsworth, 2008; Munfaridah et al., 2021; Opfermann et al., 2017).

Then, we investigated which inquiry approach could better satisfy the conceptual requirement.

In the ISLE approach (Etkina, Brookes, et al., 2019), we found all of the facets that we wished to have in the *Early Physics*, both from cognitive and epistemological perspectives. The cognitive perspective is integrated into two facets: the use of Multiple Representations and an inquiry practice which could activate and regulate a complete learning cycle (Kolb, 1984; Zull, 2004).

The epistemological perspective is woven into the approach, which is an epistemologically authentic inquiry-based learning environment (Brookes et al., 2020; Chinn and Malhotra, 2002), where "students should learn physics by thinking like physicists; by engaging in knowledge-generating activities that mimic the actual practices of physics and using the reasoning tools that physicists use when constructing and applying knowledge" (Brookes et al., 2020).

In the ISLE learning environment, the role of natural language is a semantic facilitator. That is exactly what we hoped to build into the *Early Physics* approach, which undoubtedly motivates our choice.

Now, we need to substantiate this choice with respect to our research question. The recent work of Danielle Buggé (Buggé and Etkina, 2020) on the short and long-term effect of the ISLE approach on high-schools Physics students' attitudes strongly supports our choice.

Buggé found that the attitudes toward physics of the students who are exposed to ISLE learning during their Physics courses do not decrease by the end of the course (Buggé and Etkina, 2020).

This is a contrast-tendency with respect to traditionally taught Physics courses where students' attitudes tend to decrease (Adams et al., 2006; Cahill et al., 2018; E. F. Redish et al., 1998; Wilcox and Lewandowski, 2017),as we also observed in our schools' context (Bologna and Peressi, 2021a, 2021b).

The ISLE approach "to learning and instruction does not cause the learners any harm" (Buggé and Etkina, 2020, p. 236). This finding supports and confirms our choice of this approach.

Concerning conceptual coherence, in our literature review, we highlighted the need for an immersive and not spotty experience on the teaching/learning side. This requirement ensures the growing improvement of students' scientific reasoning and thinking. This requirement is substantial in guaranteeing a coherent conceptual building.

In the ISLE framework, the progression in conceptualisation building goes step-by-step with the investigation process, supported by the increase in the use of reasoning tools (Etkina, Brookes, et al., 2019). The conceptual coherence allows students to learn without conceptual discrepancy and activates conceptual change (diSessa, 2014) that the students need for deep learning and deep Physics understanding.

ISLE students demonstrate "consistency and coherence in model-based and evidence-based reasoning in making predictions and interpreting results" (Etkina et al., 2018). Many studies have claimed consistency and coherence in evaluating ISLE students' development of scientific reasoning (Etkina et al., 2018; Etkina, Karelina, et al., 2010; Rosengrant et al., 2009) and also using traditional PER assessment (Etkina, 2015a).

Therefore, to answer this research question, we chose the ISLE approach by recognising in it all the requirements we were looking for describing an *Early Physics* framework: an approach where the natural language is the semantic facilitator in describing Physics phenomena and their representations, and students do Physics in an authentic inquiry-based learning environment.

5.2 Research Question #2

The second research question was: *How to develop a professional development program that helps Physics teachers to adopt and implement the approach?*

Among many possible approaches to the creation of a professional development program, we chose the theoretical framework that focuses on the development of teachers' habits (Etkina et al., 2017). This framework helps develop and sustain Physics teachers with already-formed habits to develop other habits through reflecting, reviewing and adopting *new* tasks of teaching (Ball et al., 2008; Etkina et al., 2018), emphasising the developmental need to overcome "survival" habits. This is not a fragmented experience in time and modality. To change habits, a training teachers' program must set up, sustain, and perpetuate conditions for forming productive habits (Etkina et al., 2017).

Etkina's and colleagues' framework focuses on the cognitive apprenticeship (A. Collins and Kapur, 2014) as a path to forming productive habits of mind and practice (Etkina et al., 2017). This focus is reflected in the name of the framework – DHAC – Development of Habits through Apprenticeship in a Community.

Traditionally, cognitive apprenticeship starts with the apprentices experiencing learning environments that model proficiency. In a professional development program this would mean bringing teachers to a designated site and engaging them in the activities that simulated student learning physics through the ISLE approach and reflecting on their experiences.

But this would take a lot of time which the teachers did not have. We overcame the teachers' time constraints by taking part in their teaching work. We did not ask teachers to find time to come to us, but instead, we accompanied them in their teaching process that they were still employing daily. When it was possible, the researcher co-taught in the classroom using the ISLE approach and the teacher participated and reflected afterwards. Otherwise, researcher coached teacher preparing learning sequence, activities, materials and what teacher needed to use ISLE in classroom; teacher performed learning paths and then reflected with the researcher.

In this context of cognitive apprenticeship, the learner was the teacher, and the researcher embodied the role of the facilitator in the adoption of the *new* approach.

Therefore, we engaged teachers in a cognitive apprenticeship based on clinical practice in their school context, in their classes, and with their students. What makes different this cognitive apprenticeship among the one used in pre-service training teachers are two aspects:

- the *Monitoring Phase* is mainly a *Diagnostic Phase* of teachers' classroom practices and leads to teachers' reflection on their teaching;
- the *Reflection Phase* strongly pervades all the other phases, because leads teachers to leave *old* tasks of teaching and acquire *new* ones.

This process nurtures the development of habits of mind and practices. But we also needed to develop habits of maintenance and improvement (Etkina et al., 2017).

Therefore, we needed to create teachers' community of practice. The learning community serves multiple roles in teaching programs (Etkina et al., 2017; Etkina, 2015a). In our program, for the purpose of our project research, we highlighted that the most important role of the community of practice was to sustain teachers in their challenge of changing habits.

We achieved this goal by:

- creating a "physical" place where teachers with researchers could share ideas, difficulties, outcomes and perspectives;
- promoting and planning together activities carrying out professional training towards teaching innovation practices;
- reducing the overwhelming effect of the Physics teacher's isolation;
- preparing materials, resources and whatever is necessary for new teaching practices dissemination;
- documenting teachers' good practices with reports and papers and applying to conferences of Physics teachers.

Adopting the approach developed in another country and with all the materials in a different language (English language), the community of practice sustained teachers' practices by sharing translated materials into Italian.

This community also fulfilled the role of curricular mediator/facilitator, discussing and reflecting on the Italian Physics curriculum and the ISLE one (Brookes et al., 2020). This process helped to choose and validate the ISLE activities/materials that satisfied the Italian Physics instruction requirements.

5.3 Research Question #3

The third research question was: *To what extent do teachers' practices change after the participation in such program?*

We engaged eight teachers in this developmental program. Each of them had different professional background and teaching experience. The program that we proposed was not limited by the differences in teachers' preparation and prior experiences. It activated a process of change in all of them. We investigated this process using a study of mixed-method design.

Before the beginning of the program of the development of *new* habits, we made teachers aware of the finding of a study that we had conducted (also engaging them) investigating Italian Physics teachers PCK (Bologna and Longo, 2022). This was the starting point for leading the teachers to reflect on their teaching.

Then we tried to document what happened in the process of the development of *new* habits by writing detailed their stories about the background and evolution of every teacher.

Most of the participating teachers recognised the effect of the participation in the professional development program in the change in their disposition towards the use of Maths in Physics.

This disposition's change was sustained by the change in their knowledge of Physics content in a way that "they understood Physics concept in a way they never experienced before".

The knowledge change strengthened their skills in using experimental activities in their classes. The Maths modelling came after the conceptualisation based on Observational and Testing experiments (Etkina, Brookes, et al., 2019).

We tried to "measure" the increase in the teachers' engagement and improvement in this professional program defining the *teaching gain*. This measure is based on the widely used *Hake's learning gain* (Hake, 1998). We aimed to find evidence of how the teachers changed their tasks of teaching by adopting the ISLE approach.

All the measurements of our teachers' teaching gain displayed the activation of a change process. By mean value frequency of tasks of teaching used percentage among all the teachers, teachers changed their way of teaching by at least 25% with respect to their previous practices.

However, it is impossible to summarise in very few words what happened to each teacher; this is part of the professional (and even personal) story they shared doing this project. What is relevant is that most of them are encouraging their colleagues to the need to change, even if every day they face context limitations or teaching constraints such as the lack of exercises ISLE-based on their textbooks (this is one of the most frequent statements they say).

5.4 Research Question #4

The fourth research question was: *To what extent do changed teaching practices improve students' attitudes toward Physics?*

At the beginning of our research project, we developed a scale to measure students' attitudes towards Physics. We intended to have an instrument context-based, referring to Italian instruction, teaching/learning practices and curriculum topics. We statistically validated this scale and analysed the sample used for a first insight into Italian students' attitudes (Bologna and Peressi, 2021a, 2021b).

We considered this first analysis to be a snapshot, which could inform us about our students. The worst findings in this first overview were two: a great percentage of students with a neutral trend towards Physics (this means they did not know if they like/dislike, they were substantially indifferent to Physics study), and a growing disaffection towards Physics of the female sample group. The growing disaffection also featured the male sample group a fewer less evident.

The gender differences we found administering our scale were consistent with the studies conducted at the college level in introductory physics courses (Wilcox and Lewandowski, 2017) and high-school ones (Buggé and Etkina, 2020) as a pre-test before ISLE courses. It is important to emphasise that after exposure to the ISLE learning environment, female students practically unchanged their scores "compared to their male counterparts at the end of the school year" (Buggé and Etkina, 2020, p. 235).

In this first investigation, we encountered two limitations. First, it was not possible to administer the attitude scale to all the schools involved in our research project. The main cause was the spread out of the COVID pandemic and the difficulties in re-organising all schools' activities.

However, the instrument developed could help us monitor whether a change would occur in students' attitudes at the end of the research project. And this was what we tried to do. But, even in the end, we faced some limitations.

Only one-fourth of the students exposed to the ISLE approach compiled the attitude scale survey. Nonetheless, the analysis of the data collected from this reduced sample was very interesting.

Comparing the findings of the two analyses (pre and post ISLE exposure), we highlighted three features:

- the decreasing percentage of the neutral trend (also in the sample by gender);
- the positive trend increased in a larger percentage compared to the previous one;
- the increase of the negative trend.

All these findings led to the same conclusion: something has changed. What the teacher did during Physics lessons was not indifferent to the students anymore. They felt that they liked or disliked Physics; they knew that they could freely answer teachers' questions without the fear of being wrong; they made hypotheses based on observations instead of only solving mathematical equations in the problems with no real-life context. What we are here reported is not only based the analysis of the poor sample collected (N=96), but also based on the informal conversations with the teachers that confirmed these findings.

We could also hypothesise a reason for the growth of the negative trend. They students were not used to being engaged in active learning. They held less inclination towards experimental practices because they did not usually participate them. This effect has been recently studied also at the college level (Deslauriers et al., 2019).

For sure, we need more data for a statistically relevant comparison to better measure the effects teachers' changes on student learning. We need to study not only the attitudes but also students' conceptual coherence in the process of knowledge development.

5.5 Implication for Instruction

According to this study's findings, we can identify three meaningful implications for instruction.

1. The overview of students' and teachers' conceptions led us to motivate the need to change the process of learning/teaching Physics in the context we investigated. Our efforts to collect and give evidence-based results could encourage our proposal of promoting a change widely, not only locally.
2. Developing an *Early Physics* approach and promoting its adoption in classrooms, we encountered some constraints. One is how knowledge is built and organised in Italian Physics textbooks. As an implication for instruction, we would suggest a deep reflection and revision of how Italian Physics textbooks could support teachers' development of *new* habits as now they present content knowledge in a way unsuitable for this development.
3. One of the most important follow-ups of our research project is the creation and development of the teachers' community of practice. We recognise this as a crucial point that makes the change durable and persistent (Etkina et al., 2017). The collaborative work between teachers

of different high schools helped them meet the challenge of developing productive habits. This finding should be considered in future programs of teachers' in-service training as a foundation feature.

5.6 Recommendations

In this research, we tried to draft the conceptual and theoretical framework for an *Early Physics* approach. The main result of this study is that we firmly recommend that teachers adopt the ISLE approach in an *Early Physics* framework. We explored its adoption in the Italian context of secondary schooling, confirming its validity and potentiality from a cognitive and epistemological perspective in all kinds of secondary instruction.

Then, we involved teachers in a deep revision of their PCK, promoting an in-service training program based on cognitive apprenticeship and the set-up of a community of practice. This led us to a second recommendation. The goal of the community of practice is to support teachers in their disposition towards being "prepared and willing to be lifelong learners and take an inquiry stance towards their teaching" (Etkina et al., 2017, p. 3). That is a necessary condition to be a teacher in a continuously changing world (Hammerness et al., 2005; L. Shulman and Sherin, 2004).

If we, as teachers, want to prepare students for this world with these features, we must face and shape the same attitudes towards our learning. And this recommendation is for teachers.

5.7 Limitations of This Study

Drawing conclusions about the findings, we have to consider three main limitations of this study.

First, my role as researcher and teacher overlapped in the implementation phase. As a teacher, I could have influenced the specificity of my role as a researcher when I was in classes during lessons with the sampled teachers. This limitation does not concern the repeatability of the cognitive apprenticeship we defined in this research work.

It was impossible to identify how and to what extent these blending roles affected teachers' development of habits. Sometimes I consider this a resource because teachers viewed me firstly as a colleague and then as a researcher. This facilitated our mutual work during the research project.

Second, some teachers needed more supportive scaffolding and some less. Thus, the scaffolding process was personalised and could not be generalised to any teacher. This means that the teaching gain could have been not the result of the same exposure to a unique cognitive apprenticeship program but to to some personal circumstances.

Third, our research design faced COVID restrictions. This affected many aspects that we planned at the beginning of this project:

- we limited classrooms observations;
- the pre-test attitudes scale survey was administered only in one secondary school and not in all the schools involved in the research project; the post-test only in few classes of different schools;
- the kind of learning activities we could design and realise in classes had

to be revised to fit remote learning environments;

- the disaffection of some teachers, who decided to leave the research project for the difficulties faced with remote learning mode.
- the limitation of audio recordings due to the use of masks and safe distance between students.

These limitations and the ones regarding the methodology used in our research design could help us pinpoint the possible future work to answer the research questions better.

5.8 Future Work

Due to the limitations described, we could only partially complete our research work and used the methodological tools we planned to answer our questions. Thus, we would revise some aspects of the study to be able to give better and more robust answers to our research questions.

First, we would systematise the data collection from the attitudes scale survey in all the classes where teachers are developing *new* habits. We would use these data as a pre-post test in long-term exposure under teaching innovation (that means the same teacher in the same class for at least three years).

Second, to help sustain teachers in the community of practice in developing habits of maintaining and improving, we need to prepare more resources for teaching materials available in the Italian language.

This is of vital importance because, in the process of change, teachers need to be relieved from designing all of the activities and be supported in their practices. Then, we would systematically survey the teachers on their tasks of teaching to monitor the teaching gain. These changes would become a way to sustain teachers' reflection and revision under their teaching practices.

Third, we would substantiate the adoption of the ISLE approach to revise the Italian Physics curriculum in secondary schooling and lower levels of instruction. A deeper conceptual study should lead us to underpin better how students develop scientific abilities (Etkina, Heuvelen, et al., 2006) and how teachers have to support their students to develop the epistemological resources necessary to engage with these science practices productively (Buggé, 2020).

Fourth, we are looking for a new research phase including wide dissemination and contamination of good practices which we started with this research project.

We hope we can conduct another in-service training program for those Physics teachers who need to change their unproductive habits. In the meantime, we work with the undergraduate Physics students: we would like to increase their passion for the teaching profession and for the research in Physics Education.

* * *

As a teacher, this research work has surely changed my Physics teaching habits.

* * *

Appendix A

Comparison between pre-post teachers' responses, according to the six category-tasks of teaching (Ball et al., 2008; Etkina et al., 2017).

Table 108: Sub-categories Task 1, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 109: Sub-categories Task 2, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 110: Sub-categories Task 3, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 111: Sub-categories Task 4, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 112: Sub-categories Task 5, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 113: Sub-categories Task 6, pre-post item-coloured responses Teacher #2.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 114: Sub-categories Task 1, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 115: Sub-categories Task 2, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 116: Sub-categories Task 3, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	Pre	Post
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 117: Sub-categories Task 4, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	Pre	Post
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 118: Sub-categories Task 5, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	Pre	Post
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 119: Sub-categories Task 6, pre-post item-coloured responses Teacher #3.

Specific tasks or qualitative sub-category	Pre	Post
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 120: Sub-categories Task 1, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 121: Sub-categories Task 2, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 122: Sub-categories Task 3, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 123: Sub-categories Task 4, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 124: Sub-categories Task 5, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	Pre	Post
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 125: Sub-categories Task 6, pre-post item-coloured responses Teacher #4.

Specific tasks or qualitative sub-category	Pre	Post
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 126: Sub-categories Task 1, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 127: Sub-categories Task 2, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and helping them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 128: Sub-categories Task 3, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 129: Sub-categories Task 4, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 130: Sub-categories Task 5, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 131: Sub-categories Task 6, pre-post item-coloured responses Teacher #5.

Specific tasks or qualitative sub-category	Pre	Post
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 132: Sub-categories Task 1, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 133: Sub-categories Task 2, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 134: Sub-categories Task 3, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	Pre	Post
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 135: Sub-categories Task 4, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	Pre	Post
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 136: Sub-categories Task 5, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	Pre	Post
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 137: Sub-categories Task 6, pre-post item-coloured responses Teacher #6.

Specific tasks or qualitative sub-category	Pre	Post
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 138: Sub-categories Task 1, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 139: Sub-categories Task 2, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 140: Sub-categories Task 3, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 141: Sub-categories Task 4, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 142: Sub-categories Task 5, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 143: Sub-categories Task 6, pre-post item-coloured responses Teacher #7.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

Table 144: Sub-categories Task 1, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Anticipating specific student challenges related to constructing scientific concepts, conceptual and quantitative reasoning, experimentation, and the application of science processes		
Anticipating likely partial conceptions and alternate conceptions, including partial quantitative understanding about particular science content and processes		
Recognizing student interest and motivation around particular science content and practices		
Understanding how students' background knowledge both in physics and mathematics can interact with new science content		

Table 145: Sub-categories Task 2, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Designing or selecting and sequencing learning experiences that focus on sense-making around important science concepts and practices, including productive representations, mathematical models, and experiments in science that are connected to students' initial and developing ideas		
Including key practices of science including experimentation, reasoning based on collected evidence, experimental testing of hypotheses, mathematical modelling, representational consistency, and argumentation		
Addressing projected learning trajectories that include both long- term and short-term goals and are based on evidence of actual student learning trajectories		
Addressing learners' actual learning trajectories by building on productive elements and addressing problematic ones		
Providing students with evidence to support their understanding of short- and long-term learning goals		
Integrating, synthesising, and using multiple strategies and involve students in making decisions		
Prompting students to collectively generate and validate knowledge with others		
Helping students draw on multiple types of knowledge, including declarative, procedural, schematic, and strategic		
Eliciting student understanding and help them express their thinking via multiple modes of representation		
Helping students consider multiple alternative approaches or solutions, including those that could be considered to be incorrect		

Table 146: Sub-categories Task 3, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Employing multiple strategies and tools to make student thinking visible		
Interpreting productive and problematic aspects of student thinking and mathematical reasoning		
Identifying specific cognitive and experiential needs or patterns of needs and build upon them through instruction		
Using interpretations of student thinking to support instructional choices both in lesson design and during the course of classroom instruction		
Providing students with descriptive feedback		
Engaging students in meta-cognition and epistemic cognition		
Devising assessment activities that match their goals of instruction		

Table 147: Sub-categories Task 4, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Engaging all students to express their thinking about key science ideas and encourage students to take responsibility for building their understanding, including knowing how they know		
Developing a climate of respect for scientific inquiry and encourage students' productive deep questions and rich student discourse		
Establishing and maintaining a "culture of physics learning" that scaffolds productive and supportive interactions between and among learners		
Encouraging broad participation to ensure that no individual students or groups are marginalised in the classroom		
Promoting negotiation of shared understanding of forms, concepts, mathematical models, experiments, etc., within the class		
Modelling and scaffolding goal behaviours, values, and practices aligned with those of scientific communities		
Making explicit distinctions between science practices and those of everyday informal reasoning as well as between scientific expression and everyday language and terms		
Helping students make connections between their collective thinking and that of scientists and science communities		
Scaffolding learner flexibility and the development of independence		
Creating opportunities for students to use science ideas and practices to engage real-world problems in their own contexts		

Table 148: Sub-categories Task 5, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Explaining concepts clearly, using accurate and appropriate technical language, consistent multiple representations, and mathematical representations when necessary		
Using representations, examples, and models that are consistent with each other and with the theoretical approach to the concept that they want students to learn		
Helping students understand the purpose of a particular representation, example, or model and how to integrate new representations, examples, or models with those they already know		
Encouraging students to invent and develop examples, models, and representations that support relevant learning goals		
Encouraging students to explain features of representations and models (their own and others') and to identify/evaluate both strengths and limitations		
Encouraging students to create, critique, and shift between representations and models with the goal of seeking consistency between and among different representations and models		
Modelling scientific approaches to explanation, argument, and mathematical derivation and explain how they know what they know. They choose models and analogs that accurately depict and do not distort the true meaning of the physical law and use language that does not confound technical and everyday terms		
Providing examples that allow students to analyze situations from different frameworks such as energy, forces, momentum, and fields		

Table 149: Sub-categories Task 6, pre-post item-coloured responses Teacher #8.

Specific tasks or qualitative sub-category	**Pre**	**Post**
Providing opportunities for students to analyse quantitative and qualitative experimental data to identify patterns and construct concepts		
Providing opportunities for students to design and analyze experiments using particular frameworks such as energy, forces, momentum, field, etc.		
Providing opportunities for students to test experimentally or apply particular ideas in multiple contexts		
Providing opportunities for students to pose their own questions and investigate them experimentally		
Using questioning, discussion, and other methods to draw student attention during experiments to key aspects needed for subsequent learning, including the limitations of the models used to explain a particular experiment		
Helping students draw connections between classroom experiments, their own ideas, and key science ideas		
Encouraging students to draw on experiments as evidence to support explanations and claims and to test explanations and claims by designing experiments to rule them out		

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