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PHYSICS

THE ROLE OF HABITS IN PHYSICS PROBLEM SOLVING AND POSING AMONG ITALIAN HIGH-SCHOOL TEACHERS: A COGNITIVE AND SOCIO-CULTURAL PERSPECTIVE.

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The map is not the territory, and
the name is not the thing named.

(Gregory Bateson, 1979)

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Abstract

This study investigates the relationship between curricular materials and problem solving practices in Italian high-school Physics education. A quantitative taxonomic analysis of 212 problems drawn from Italian high-school textbooks and ISLE-based materials was conducted using the Revised Bloom's Taxonomy to map the cognitive demand of traditional problems and compare it with that of non-traditional tasks. Results indicate that over half of traditional problems elicit implementation of already known mathematical manipulation, while ISLE-based problems engage higher-order thinking skills more consistent with authentic scientific inquiry. The study then examines how this skewed problem distribution shapes teachers' problem solving practice. In-service teachers participating in a professional development programme were engaged in a creative activity that invited them to redesign traditional problems into non-traditional ISLE-based ones. Analysis of session transcripts and questionnaires reveals a persistent tendency toward procedural, calculation-driven approaches, as well as scarce flexibility. The detected habits are understood through a bourdieusian lens as manifestations of a field-specific habitus, mediated by textbook culture and reinforced through teaching practice. This work contributes to Physics Education Research by highlighting the mismatch between curricular problem solving and the cognitive characterization of authentic scientific reasoning and by providing empirical grounding to inform curriculum reform, design of educational materials, and teacher professional development.

Chapter 1. Introduction

1.1. Problem solving in Physics Education Research

Problem solving has always been regarded as one of the main components of Physics learning. Students are expected to consolidate their understanding of physical concepts and develop scientifically authentic reasoning also through problem solving. Through decades, research in physics education has developed theories and models that attempt to describe students' reasoning patterns, problem solving strategies, and how different tasks foster these skills. This body of work has evolved from cataloguing the differences between expert and novice problem solvers to paying increasing attention to the underlying knowledge structures that drive those differences, moving towards cognitive and social studies. Research on problem solving generally aims to develop an accurate description of the knowledge structures and cognitive reasoning patterns that characterize effective scientific thinking, to inform curricula design and the production of educational materials that can actively promote expert-like reasoning.

The discussion on Problem Solving has always been central to Physics Education Research (PER) and remains ongoing. In an effort to cover those contributions that have revealed to be most enlightening and useful to the advancement of the field, this section is structured in two interconnected themes. We begin by examining how researchers have approached the categorisation and differentiation of physics problems themselves. With the advancement of PER, many different types of problems have been developed. Research-informed tasks are often designed to mirror the work of an expert scientist and foster authentic scientific reasoning or target common students' difficulties. Tracking different ways to define a category of physics problem allows to begin an investigation of the nature of reasoning that problem solving requires. We then turn to the question of how students and experts approach these problems, reviewing the literature on solving strategies with a focus on the role of knowledge organization and contextual factors that influence problem-solving behaviour.

1.1.1. Classification of physics problems

With problems being such an important component of almost every Physics course, teachers and researchers have developed different strategies to characterize and classify the types of problems employed by different teaching approaches. Different criteria can be used to classify problems: content, representation format, complexity, and cognitive demand are some examples.

Textbooks typically cluster problems that are similar in content, so that problems that require the same (or similar) base of factual knowledge to be solved are close. Problems and exercises are presented in a dedicated section at the end of the chapter, which is usually partitioned following content-based criteria that mirror the order in which the content was presented in what namely is called the "theoretical" section of the chapter. This structure allows teachers and students to quickly identify the appropriate problems to be assigned as homework or to be solved during class. This choice is not neutral, but it appears as natural. Textbooks often accessorize end-of-chapter problems with an indicator of the complexity of the problem, like a symbol or number of stars or point-ball for increasing difficulty. These conventions make it so most of the time students are able to predict what equations they will have to use to solve the problem (because of the content-related indications) and how many steps it will take to get to the expected quantitative result.

Another dimension along which problems can be classified is their representational format. Different semiotic resources can be used to present a physics problem: natural language, diagrams, graphs, mathematical expressions and many others. Several researchers have proposed frameworks that categorize problems according to their format or the variety of representations used in the problem's statement. Kohl and Finkelstein focused on the influence of representations on students' performance for much of their research and identify four types of representational format: math, pictorial, graphical, and verbal (Kohl & Finkelstein, 2005). Studies show how students' success rate varies across representationally different versions of the same problem, often referred to as "isomorphic" pairs of problems (Kohl & Finkelstein, 2006; De Cock, 2012).

Italian researchers working on representational format classification of physics problems have largely cited and built on the international (mainly American) literature rather than studying Italian materials and students' performance specifically.

The most direct approach to the classification of problems based on their difficulty is measuring the success rate of students' attempting to solve them. This is usually quantified by the number of students who successfully solve each problem or by defining a summative quantitative descriptor for each student, identifying different levels of expertise such as "novice problem solver" and "expert problem solver", and quantifying how many students of each class are able to solve the problem (Ince, 2018). Other studies define the classification criteria after having exposed novices and experts to the problems and having asked them to identify categories of problems (Chi, Feltovich, & Glaser, 1981).

Taxonomies of physics problems

Students' success and the quality of their solutions can be an indicator of the difficulty of a certain problem, but the information it provides about the group of students could be considered more relevant than the information about the problem itself. Moreover, teachers and researchers often need tools to evaluate a problem's probable difficulty without administering it to students first. Therefore, we need to move away from the difficulties a student encounters when solving a problem, which is an empirical outcome of the observation of their solution strategy.

We use "cognitive demand" to refer to a property of the task which is related to the type of thinking it requires or that its representational format elicits. Because cognitive demand is not directly observable, researchers have developed structured frameworks to make it measurable and communicable, called taxonomies of educational objectives. Many subject-specific taxonomies have been developed by the PER community. Most of these draw from a broader, discipline-independent framework: the Taxonomy of Educational Objectives, developed by Benjamin S. Bloom and his collaborators in 1956, widely known as Bloom's Taxonomy (Bloom, 1956). This tool provides a hierarchical structure to classify educational objectives or tasks. The first version of the taxonomy described six categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Each of these is then broken into sub-categories. In 2001, Bloom and his research group published the Revised Bloom's Taxonomy, an extension of the original framework (Krathwohl, 2002). The new taxonomy addressed a weak point of the original version: the Knowledge category embodied both the action and the object, as it included both the act of recalling information and a characterization of the type of information. This superposition did not allow to differentiate the cognitive process of remembering and the nature of the knowledge recalled. This flaw was eliminated in the Revised Taxonomy by allowing these two aspects to form separate dimensions: the *object*, providing the basis for the Knowledge dimension, and the *action,* forming the basis for the Cognitive Process dimension. The Revised Taxonomy has become a common tool in all discipline-specific education research, including PER. Its most common application is its representation as a table that allows to lay out the two-dimensional space defined by the taxonomy and collocate tasks in its cells:

	Factual Knowledge	Conceptual Knowledge	Procedural Knowledge	Metacognitive Knowledge
Remember				
Understand				
Apply				
Analyse				
Evaluate				
Create				

Table 1.1. The Taxonomy Table. Columns represent the Knowledge domain, rows the Cognitive Process domain.

Since the use of the taxonomy is strictly related to the verb used to state the task or the objective in a text, researchers often define disciplinary-relevant verbs to fill the taxonomy and limit the risk of mis categorization of problems (Gates & Pugh, 2021). We chose the Revised Bloom's Taxonomy to classify Physics problems and defined a Disciplinary-relevant Taxonomy Table to facilitate its use. The taxonomy and the motivation behind our choice are discussed further in Section 2.1.1.

Unsatisfied with more general frameworks, Physics education researchers have designed discipline-specific taxonomies, such as the Taxonomy of Introductory Physics Problems (TIPP) (Teodorescu, C, Feldman, & L, 2013). The instrument is based on the New Taxonomy of Educational Objectives (NTEO), a non-disciplinary-specific two-dimensional taxonomy with *systems of thinking* as one dimension and *domains of knowledge* as the other dimension (Marzano & Kendall, 2007). The developers of TIPP selected NTEO as their preferred framework rather than Bloom's because they argue that the former combines knowledge domains with cognitive processes, and that Anderson's revised taxonomy does not explicitly refer to problem solving. The strengths and limitations of the Revised Bloom's Taxonomy we detected while utilizing it as a classification tool are discussed in the Results section of Chapter 2.

Formal taxonomies are not the only way to differentiate physics tasks without submitting them to students first. Chinn and Malhotra focused on the definition of the characteristics of *authentic inquiry* in contrast to simpler, non-scientific tasks (Chinn & Malhotra, 2002). The authors do not define a structured classification scheme but identify the cognitive processes that differentiate epistemologically authentic inquiry tasks from simple tasks that do not mirror the work of scientists. These differentiation criteria were then applied to textbooks tasks and researcher-developed tasks. The study shows how research effectively produces problems that aim to elicit scientifically authentic reasoning (Chinn & Malhotra, 2002).

The need for classification of Physics problems arises from the variety of tasks that teachers and researchers develop for students. Research and experience show how solving standard end-of-chapter problems and exercises does not help students develop higher-level thinking skills, conceptual understanding, and scientific abilities (Kim & Pak, 2001). The failing of traditional quantitative exercises led researchers to design alternative tasks that ultimately demonstrate to be more effective. A notable example of researcher-defined categories of problems is reported in the next paragraph.

Non-traditional problems

The Investigative Science Learning Environment (ISLE) approach for the learning and teaching of Physics is an example of an approach to curriculum and materials design that addressed this issue. The philosophy at the core of the ISLE teaching method is that students learn by mirroring the work of trained physicists. The framework was developed by professors Eugenia Etkina, Gorazd Planinšič, and David Brookes, and the results of the most influential research papers are summarized in the book «Investigative Science Learning Environment: When learning Physics mirrors doing Physics» (Etkina, Planinsic, & Brookes, 2019). Together with a wide offer of educational materials such as assessment rubrics and experimental activities, ISLE proposes ten new problem types. These *non-*

traditional problems are designed specifically to help students develop expert-like reasoning and cannot be solved only by searching for an equation. The ten problem types are briefly described in Table 1.2.

Type of problem	**Keywords**	**Description of task**
Raking tasks	Rank, compare	Rank the values of a certain physical quantity for different situations, in descending or ascending order.
Choose answer and explanation		Choose the correct answer and the correct matching explanation (cause-effect or mechanistic) in order to get full credit.
Choose measuring procedure	Procedure, method	Choose (or propose) the correct (or the best) experimental procedure that will allow them to measure/determine a certain quantity.
Evaluate reasoning or solution	Evaluate, a friend says […], agree, discuss, comment, compare and contrast	Critically evaluate the reasoning of some (imaginary) people or evaluate the suggested solution to a problem (given either in words, graphs, diagrams, or as an equation). Students have to recognize productive ideas (even when they are embedded in incorrect answers) and differentiate them from unproductive ideas.
Make judgement (based on data)	Decide, reject, justify, (in)consistency	Make a judgment about one or more hypotheses, based on data or other forms of evidence that are given in the problem, sometimes taking uncertainties into account.
Linearization		Write an equation that describes the relevant situation, rearrange it to obtain a linear function.
Multiple possibility problems	Tell all, say everything you can, give examples	List as many quantities as they can that can be determined based on data given in the problem, or tell everything they can about the physical attributes of the objects that appear in the text, or the relations between them.
Jeopardy problems	Invent a problem, pose a problem	Convert a representation of a solution into a problem statement. If the solution is given in the form of an equation, they need to understand the meaning of the quantities and their units.
Design an experiment or pose a problem	Design, invent, write your own, pose	Design an experiment, an experimental procedure, or a device that will allow them to measure/determine certain physical quantities or that would meet specific requirements. Students have to pose a problem that involves certain objects with given characteristics.
Problem based on real data		Solve problems that are based on real data, obtained in real- life situations, often using easily available equipment and/or equipment that is typically used in student labs.

Table 1.2. The ten non-traditional problems proposed by the ISLE framework.

Non-traditional problems are included in the end-of-chapter sections of the ISLE-based textbook «College Physics: Explore & Apply» (Etkina, Planinsic, Rutberg, & Van Heuvelen, 2026).

1.1.2. Solving strategies

Alongside a typological analysis of physics problems, researchers have taken an interest in describing how students develop and engage in problem solving strategies. Classification schemes and taxonomies characterise physics problems based on their written presentation, identifying structural features and cognitive demand. On the other hand, research on solving strategies turns to what happens in the solvers' mind, examining the processes and reasoning patterns students employ when solving a problem. These two lines of inquiry are deeply intertwined: the features that are used to categorize problems directly influence how those same problems are approached.

Studies on the expert/novice gap in Physics problem solving

The gap between expert and novice problem solvers has been studied extensively in an effort to develop tools and construct curricula that help students become more expert-like in their approach to physics problems. This line of research emerges from broader work in cognitive science and education which aims to describe knowledge organization and its application in problem solving contexts. The differences between experts' and novices' approaches goes beyond a gap in factual knowledge: experts are able to select the appropriate solution strategy thanks to interconnected conceptual schemas that allow them to probe many solutions to find the most suitable for each problem; while novices tent to rely on algorithmic procedures and rarely vary their strategy (Chi, Feltovich, & Glaser, 1981). Understanding how students develop, or fail to develop, expert-like solving strategies has become a central concern of PER, informing the design of curricula, assessment tools, and educational materials.

One of the first studies of students' approaches to problems was that of Chi and her colleagues, also mentioned in Section 1.1.1. The study investigated students' classification criteria by asking them to differentiate problems based on how they would go about solving them (Chi, Feltovich, & Glaser, 1981). The participants were divided in two groups, experts and novices, and developed two classification schemes: experts noted the physical principle(s) needed to solve them, while novices focused on the surface structure of the problem, in particular on the representations used. The observation that novice problem solvers lack the knowledge base and strategic skills to qualitatively analyse a problem and plan a solution is a common result in PER (Maloney, 2011).

Larkin and her colleagues presented physics problems to experts and novices and conducted think-aloud protocols (Larkin, 1983). The researchers reproduced the performance of the two groups with computer programs and identified the main difference in approach: while experts favour a working-forward strategy, the novices use a working-backward process. This working-backward strategy is well known to anyone who has experience in working with introductory Physics students and is often referred to as *plug-and-chug*: identifying the unknown variable, searching for an equation containing it, seeing if all other quantities are known, and repeating until the last variable can be determined with equations. Many studies confirm that the majority of students do not approach physics problems in a strategic manner and skip qualitative representation of the problem (Walsh, Howard, & Bowe, 2007).

Research on quantitative problem solving (i.e. the use of mathematics in physics) focuses not only on which procedures experts and novices *select*, but also on how they *use* the selected equations to solve problems. In particular, a study by Kuo and his colleagues attributes part of the difference in the reasoning patterns of an expert and a novice solver to the use (or lack of use) of symbolic knowledge (Kuo, Hull, Gupta, & Elby, 2013). The use of symbols and their connection to physical quantities was also probed by Hegde and Meera. In their study, they conducted semi-structured interviews with students with the goal of describing the microstructure of student thought process during problem solving (Hedge & Meera, 2012). Their findings show how the same scaffolding leads to different results for different students, and that the same strategy can be either successful or unsuccessful depending on various factors beside the expertise of the solver.

Epistemic Games and the resources model of students' cognition

The comparison of expert and novice approaches does not only highlight the difficulties that students often have but focuses on the differences in knowledge and knowledge organization of the two groups. Research shows that knowledge structures can inhibit access to useful skills in the context of problem solving (Sabella & Redish, 2007).

Tuminaro and Redish argue that research focusing on the expert/novice gap does not necessarily help understand how students make the transition and start to approach physics in an expert-like manner (Tuminaro & Redish, 2007). Starting from this consideration, they developed a framework that describes students' behaviour by identifying organizational structures of knowledge students use, called *epistemic games*. An epistemic game is «a coherent activity that uses particular kinds of knowledge and processes associated with that knowledge to create knowledge or solve a problem». The framework stands on the *resource model* of student thinking, that was developed by Hammer and gained much attention in subsequent PER literature (Hammer, 2000). In this model, knowledge elements (resources) combine dynamically in associative structures that are activated by control structures in response to environmental stimuli. The core elements of the model are: the basic elements of knowledge, the way those elements are linked (*knowledge structures*), and the way those linked structures are activated in different circumstances (*control structures*), and are all equally referred to as *resources*. The notion of basic knowledge elements draws heavily on Di Sessa's concept of phenomenological primitives, or *p-prims* (Di Sessa, 1993). In the resource model, p-prims constitute the finest grain of the knowledge hierarchy: they are the raw intuitive material from which more elaborate and coherent knowledge structures are built through instruction and experience. P-prims are drawn from everyday experiences, and they are cued by contextual factors, not unlike other resources. A description of the dynamic activation of p-prims and other resources is specifically the goal of the epistemic games framework (Tuminaro & Redish, 2007). It offers a way to account for how these fine-grained intuitive elements are recruited and coordinated and why the same underlying knowledge can lead to such different outcomes across different problem solving contexts.

The game is "epistemic" in the sense that it is a process that produces new knowledge by combining the cognitive resources associated with the game itself, following a specific *epistemic form*, the structure that guides inquiry. To determine these structures, the authors analysed numerous hours of video data of students solving problems in groups. The six locally-coherent structures they identified are: i) Mapping Meaning to Mathematics, ii) Mapping Mathematics to Meaning, iii) Physical Mechanism Game, iv) Pictorial Analysis, v) Recursive Plug-and-Chug, vi) Transliteration to Mathematics

(Tuminaro & Redish, 2007). These are examples of possible schemes, and do not represent the whole horizon of possibilities that students have when approaching a problem. As discussed in Section 1.1.1, research in Physics education has designed many types of problems that elicit different reasoning patterns that could be not accounted for in these six e-games.

Epistemic games quickly became a reference framework for any researcher probing students' problem solving behaviour. Nonetheless, the effectiveness of Redish and Tuminaro's framework in describing how students move while solving a problem has sometimes overshadowed its bounds, which the authors clearly state but that are often overlooked. While an e-game can be an excellent description of how students solve problems, it does not include its "boundary conditions" in the sense that the framework does not inquire how students choose which strategy to employ (which e-game they choose to play) and what they consider a good answer in Physics (how they decide the game is done). Redish and Tuminaro recognize that students' expectations about physics problems affect the entry and ending conditions of a e-game, and that these expectations are built through experience in the classroom. In the authors' case, the students that were observed participated in a reformed introductory course where all homework activities, lectures, discussions and laboratories were someway non-traditional. Another understated limitation is that of the 60 hours the researchers had videotaped, they selected for detailed analysis only the episodes that contained some discussion of mathematical issues, reducing the data set to 11 hours of video (Tuminaro & Redish, 2007).

Environmental factors such as teaching practice and epistemological framing of a Physics course surely affect the resources that students think are relevant to a specific situation, and therefore the epistemic game they recognize as successful. This dimension of the resources model reconsiders students' difficulties and unsuccess as a result of the activation of counter-productive resources. This theoretical consideration should result in instructional practice that focuses on modifying the resources students activate and that is aware of its influence on students' epistemologies (Sabella & Redish, 2007). The six epistemic games that the authors identified can serve as blueprints of processes to look for when inquiring students' reasoning but are not a conclusive theoretical result, in the sense that they don't constitute a model of human behaviour nor categories of solving strategies per se (Tuminaro & Redish, 2007). The intention of the original authors was to provide a conceptual tool that could guide researchers while coding students' behaviour to relate it with contextual factors, including instructional practice. In the authors' own words: «The specific resources and games we describe are not the only ones students use or play. Our intention is to introduce a new kind of structure for analyzing students' thoughts on problem solving. […] We expect that the description of student problem solving behavior in terms of epistemic games will be useful both in understanding how to teach strategies and metacognition in problem solving and in analyzing group behavior in the context of problem solving» (Tuminaro & Redish, 2007). The epistemic games framework should not be understood as a tentative taxonomical description of student thinking, but rather as a tool to describe reasoning patterns.

Metacognition and skills in problem solving

Many features influence how a problem is approached, but the choice is not defined by knowledge capital and contextual factors alone. Selecting a solution strategy in one's repertoire also requires metacognitive knowledge and skills. Research shows that expert problem solvers typically demonstrate a higher ability to overcome intuitive responses than novices (Gette & Kryjevskaia, 2019). Informed by dual process theories of reasoning (see Section 3.2.1.), this result suggests that problem solving requires analytic processes to identify one own's intuitive thoughts and to engage in effortful logic-based evaluation of such thoughts (Dulger & Ogan-Bekiroglu, 2025). These factors can be considered "internal", in contraposition to external factors such as teaching style, but are still influenced by the way tasks are presented to the solvers: not all problems necessarily require a deeper inquiry, simpler exercises can be effectively resolved without challenging intuition. Metacognition is one of the skills that reformed instruction aims to develop in students and that demonstrates to be crucial for problem solving.

1.2. Blind spots: contextualizing physics problem solving in the school context

Problem solving has been approached by researchers with different methods and described by numerous theoretical frameworks built on empirical studies. Some of these frameworks have been described in Section 1.1. For much of this research, the cognitive dimension of problem solving has been the main focus. Only more recently the relationship between problem solving, understood as a learning practice, and the school, the context in which it takes place, began to emerge as a central topic in PER. A growing number of frameworks have been highlighting the affective, epistemic, and social dimensions of problem solving. Students' beliefs about Physics, their positioning towards different tasks, the expectations placed upon them, and their engagement in activities all influence how they approach and solve problems. Research has shown that students' responses are shaped by their teachers' assessment and teaching practices, such as the use of standardized tests and multiple representations while teaching (Kim & Pak, 2001).

Despite the depth of this literature, a gap persists. These factors that undoubtably shape students' problem-solving practices have been studied primarily as marginal variables acting on outcomes, rather than as central features of a system. Contextual variables such as teaching style, materials, and task framing are often treated as noise or assumptions rather than influent actors. This work suggests a move from this perspective, shifting the framing of the school context from a backdrop to a system where teachers, students, educational materials, and institutions continuously influence one another.

Adopting an ecological lens allows us to begin mapping how these elements influence one another. If we focus on four main nodes, A) the teachers, B) the students, C) the subject, and D) the institutions, each of these is connected and influenced by the others and many sub-nodes such as families, peers, editorial materials, the scientific community. Focusing on any single element of the network should not require setting the others aside. Investigating the relationships between individual elements remains valuable, but the analysis must acknowledge the wider net of influences. This perspective has gained traction in general educational sciences theory and several neighbouring disciplines in the last decades, drawing from Physics' own theory of complex systems. A notable example is Edgar Morin's undertaking of an epistemology of complexity that addresses the limitations of reductionist and separatist analysis (Morin, 1977-2004).

This thesis focuses on the relationships between teachers and problem solving, understood as one of the sub-nodes of the disciplinary pole. Specifically, it investigates whether and how Italian high-school teachers' practices are influenced by textbooks. This focus does not imply that the other elements of the system are irrelevant nor ignored. We assume that the dispositions of teachers have a direct effect on students: the way a teacher selects, solves, and presents problems and exercises inevitably shapes how their students will approach them and the discipline in general. Social dimensions are accounted for by considering teachers both as individuals and a community that shares collective practices. Pressures and influences coming from institutions and the scientific community also act as forces on teachers' professional identity and guide their teaching practices.

Within this net of relationships, the textbook has a crucial role. It is not a passive tool simply used by teachers and students as a repository of content. Rather, it acts as an artifact that encodes the values, epistemological positions, and norms of an entire disciplinary community. We think of it as a materialisation of what the majority considers Physics is, what counts as a problem and what counts as a solution. In this sense, the textbook participates in the shaping of teaching habits.

The relationship between teachers and textbooks in Italy is mediated by editors and takes the shape of a recursive loop. In Italian high schools, teachers are the ones that select the textbooks their classes will adopt. This choice is not individual, but collegial, so all teachers at a school department must adopt the same textbook. It is notable that while teachers select the volume, students are the ones studying on it and families pay for it. This means that editorial choices are constrained by what teachers are willing to adopt. So, editors and authors tend to favour production of materials that align with existing expectations and familiar formats. This mechanism results in an auto-reinforcing cycle: teachers' unwillingness to change shapes what the market has to offer; the market, in turn, fosters that inertia by not offering innovative materials.

To investigate this relationship, this thesis draws on a socio-anthropologic framework: the professional dispositions of teachers are examined through Bourdieu's concepts of *field* and *habitus*. From this point of view, the textbook is an artefact that reflects and reinforces the community's habitus: it embodies the cultural capital and actively participates in the development of teaching habits at once. These habits condition the relationship that students will develop with the discipline, and in our case, with problem solving.

1.3. Thesis overview

This thesis investigates the relationship between Italian high-school physics textbooks and the problem-solving practices of in-service physics teachers. To do so, it combines a quantitative analysis of the cognitive profile of textbooks, a theoretical discussion of teaching practice as a social phenomenon in which habits form and persist, and a qualitative study of the behaviour of Italian teachers participating in a professional development program.

Chapter 2 opens the empirical inquiry and answers the question of which cognitive processes are activated and what type of knowledge is required in standard Italian physics problem solving tasks. The analytical tool used to describe the cognitive profile of the selected textbooks, the Disciplinary Taxonomy Table, is rooted in the Revised Bloom's Taxonomy and facilitated the classification of problems found in the textbooks and compare them with a selection of non-traditional ISLE-based problems. The results reveal that the vast majority of problems in commonly used textbooks clusters in the lower cognitive levels, demanding almost exclusively procedural and mathematical execution.

Chapter 3 moves from these results and focuses on the consequences of the uniformity of problem solving tasks. How does this monotony influence the professional dispositions of teachers? The chosen lens to answer this question is that of habits. Therefore, the chapter builds an ecological account of habits as socio-cognitive structures, drawing from neuroscience, cognitive science, sociology, and frameworks in Physics Education Research. In particular, it frames teachers as a community that develops habits and that sustains relationships with students and other poles of the school system such as editorial materials and institutions. Sustained participation in the community leads to the acquisition of particular dispositions that define expertise within the group. To cover this node and move closer to existing PER frameworks, the chapter then describes the concepts of Adaptive and Routine Expertise and the DHAC model (Developing Habits through Apprenticeship in a Community) (Etkina, Gregorcic, & Vokos, 2017), which constitutes an account of how teaching habits form and are maintained.

Chapter 4 brings the theoretical framework of habits in contact with empirical observation. The central question guiding this chapter is: *to what extent can the* *professional habits of in-service physics teachers be detected through their engagement with non-habitual problem-posing tasks, and how do those habits shape their practice?* To investigate this, the chapter describes the collection of qualitative data during a teachers' training course specifically designed to place participants in a non-habitual situation. Surveys administered before and after the program, combined with coded transcripts of teachers' interactions, allow for an analysis of professional habits and their interference with teachers' approach to tasks that fall outside their habitual repertoire.

Chapter 5 presents and converges the findings of the preceding chapters. It opens with a synthesis of the results from quantitative, theoretical, and qualitative perspectives. The analysis supports one central argument: the cognitive profile of Italian high school textbooks is spiked in correspondence of algorithmic procedures, and this phenomenon actively participates in the formation of teaching habits that are very difficult to dismantle. The chapter discusses the limitations of this study and the implications for instruction and teacher education, to finally outline directions for future research.

Chapter 2. Problem solving tasks in Italian high-school textbooks

This chapter focuses on the description of the problems and exercises present in the most used Physics high school textbooks in Italy, answering the following research questions: *Which cognitive processes are activated and what type of knowledge is required in traditional problem solving tasks? How do they compare with non-traditional tasks?*

This analysis will allow us to address Italian teachers' habits more effectively. As discussed in Section 1.2, textbooks are very influential in teachers' daily practice and carry a set of assumptions that become natural to teachers and students alike. Therefore, knowing what kinds of problems Italian textbooks offer is crucial, and a thorough comparison with research-inspired tasks can highlight their limitations and show a viable alternative. This study employs non-traditional ISLE-based problems presented in Section 1.1.1. as an example of tasks designed to develop scientific abilities (Sarlah & Planinsic, 2023).

We analyse the cognitive demand of Physics problems using the Revised Bloom's Taxonomy, aiming to understand the kinds of knowledge and thinking skills each problem fosters. To address these aims, Section 2.1 presents the theoretical framework underpinning this section, deepening the analysis of the Revised Bloom's Taxonomy, as well as discussing the role of non-traditional ISLE-based problems in supporting scientific abilities. The following section focuses on the process of adaptation of the Taxonomy Table to make it disciplinarily aligned with our goals. Drawing from existing PER literature, a Disciplinary Taxonomy Table (DTT) was developed, and a token verb was allocated to each cell. Section 2.3 outlines how we assembled two sets of traditional and non-traditional physics problems and how the DTT was used to classify said problems. The traditional problems were sourced from commonly used Italian high-school textbooks, while the non-traditional problems come from the ISLE-based textbook "College Physics: Explore and Apply" (Etkina, Planinsic, & Van Heuvelen, 2019A) and from a previous teachers' training program (Bologna, Modugno, Longo, & Peressi, 2026A). Section 2.4 reports the quantitative analyses conducted on the distribution of tasks and problems within the two-dimensional space defined by the DTT. Section 2.4 offers a discussion of the findings, complemented by a retrospective evaluation of the problems generated during the previous teacher training program.

The main contents of this chapter have been presented in an oral contribution at the GIREP Conference in 2025 and will be published in a paper in 2026 (Bologna, Modugno, Longo, & Peressi, 2026B).

2.1. Theoretical framework

This section provides a more detailed description of the theoretical frameworks that guided this phase of the research. We start by detailing the Revised Bloom's Taxonomy, characterizing the Cognitive Process and Knowledge dimensions. A brief discussion of ISLE-based non-traditional problems will follow, with a focus on the intentions of the researchers that developed the ten new types of problems.

2.1.1. Revised Bloom's Taxonomy

The Taxonomy of Educational Objectives is a framework originally presented by a committee chaired by Benjamin S. Bloom in 1956 (Bloom, 1956). The revision of the original taxonomy was developed decades later by the same group and extended the spectrum of categories in a two-dimensional space (Krathwohl, 2002). The goals of the original structure did not change, and the Revised Taxonomy has been used extensively in PER to classify exercises and problems, determine the goals of curricula, and check the congruence of educational objectives, activities, and assessments in a course. The two dimensional taxonomy provides an effective way to classify educational activities by framing tasks in terms of the disciplinary content involved (Knowledge dimension) and a description of the reasoning process to be done (Cognitive Process dimension).

Bloom's revised taxonomy is not the only attempt at defining a framework for the classification of learning objectives and problems. Physics education researchers have developed many taxonomies and criteria to differentiate problems and learning activities according to the cognitive processes and knowledge domains, and the role of the student approaching a task (Hanàkovà & Kluvanec, 2016). The common goal of all taxonomies is an attempt at defining the cognitive demand of a selection of problems without the need of submitting the tasks to students. Looking into these frameworks, it is possible to recognize that the main difference is the external structure in which the single tasks are organized, while the processes identified are very similar across different models. This suggests that in the PER community there is an agreement on what are the cognitive processes used during physics problem solving. This conformity facilitated filling the Taxonomy Table with disciplinary-relevant token verbs, as discussed in Section 2.2.

The four knowledge categories of the Revised Taxonomy are: Factual knowledge, Conceptual knowledge, Procedural knowledge and Metacognitive knowledge. The definition of the categories is not hierarchical. In our case, the four categories are used describe the content that has to be known or processed in order to approach the problem or exercise. Following the intentions of the original authors, we intend the four categories to be characterized as:

- **Factual knowledge**: The basic elements of a discipline. For physics tasks, these include the definition of physical quantities and other fundamental elements such as symbols, notation conventions, mathematical operations, graphs, and diagrams.
- **Conceptual knowledge**: The interrelationship between the basic elements of a discipline. In the physical context, this category covers concepts such as proportionalities, qualitative similarities, models and assumptions, and general structures.
- **Procedural knowledge**: How to do something. This category relates to those techniques that a student must know to study Physics, including mathematical procedures, methods of inquiry, and experimental strategies.
- **Metacognitive knowledge**: Knowledge of cognition in general and awareness of one's own cognition.

The Cognitive Process dimension in divided in six levels:

1. **Remember**: Retrieving relevant knowledge to the present task.
2. **Understand**: Determining the meaning.
3. **Apply**: Carrying out an already known procedure.

4. **Analyse**: Detecting the composing elements of a given situation and detecting the relationships between said elements.
5. **Evaluate**: Expressing a judgement based on given or known criteria and standards.
6. **Create**: Putting separate elements together to form an original product.

The levels are in hierarchical order in the sense that the latter three are considered to be more complex and are often regarded as the most important outcomes of education. The six levels are divided in two sets: Lower Order Thinking Skills [LOTS] (Remember, Understand, Apply); and Higher Order Thinking Skills [HOTS] (Analyse, Evaluate, Create). The hierarchy still allows for overlaps and overtakes. For example, some of the cognitive processes associated with Understanding can be more cognitively complex than some processes associated with Analyse.

2.1.2. ISLE-based non-traditional problems and scientific abilities

The scope of this research was not only to investigate the cognitive demand of problems found in Italian textbooks, but to compare it with that of research-informed tasks. In particular, we aimed to better identify the characteristics of the ten non-traditional problem types proposed by the ISLE approach (Etkina, Planinsic, & Brookes, 2019A). The new problem types, already listed in Section 1.1.1., fit the scope of our analysis for many reasons. First, they were developed by researchers within the more general ISLE framework and are aligned with its intent of teaching physics by mirroring the work of a scientist. This directly translates to an explicit intentionality in eliciting scientifically authentic reasoning patterns and processes, even conveyed as cognitive demand in problem solving. Second, the ten types are already well defined and have been used extensively by teachers all around the world in the last decades. Third, the ISLE-based textbook is accompanied by an Instructor's Guide that provided us with a list of all non-traditional problems available, which facilitated the retrieving of data for the analysis (Etkina, Brookes, Planinsic, & Van Heuvelen, 2019B, 2019C). The textbook is designed for introductory Physics courses at the American college level and for the AP[1] course in

[1] Advanced Physics

high school education, and it is basically algebra-based. In the last few years, many Italian high-school teachers used materials from the textbook and experience shows that it is essentially aligned to the Italian high-school level (Bologna, Leban, Longo, Peressi, & Sorzio, 2024; Bologna, Buggé, & Gregorcic, 2025).

As discussed in the “Methods” section of this chapter, not all ISLE-based problems we analysed come from the textbook. A fraction of non-traditional problems were produced by Italian high-school teachers during a teacher’s training program, analogous to the one described in Section 4.1.1, that took place at the University of Trieste between 2023 and 2024 (Bologna, Modugno, Longo, & Peressi, 2026A).

The course, titled «Creative Atelier» engaged pre-service and in-service physics teachers in a creative activity that consisted in converting a traditional problem into a new, non-traditional one. We structured this activity on the design implementation described by researchers close to the authors of the ISLE textbook (Sarlah & Planinsic, 2023).

2.2. Design: the Disciplinary Taxonomy Table (DTT)

As already discussed, Bloom’s Revised Taxonomy is not subject-specific. To facilitate the categorization process, we decided to fill the Taxonomy Table with disciplinary-relevant token verbs that represent the task related to the specific position in the two-dimensional space. The choice of token verbs was informed by existing literature on the cognitive processes that characterize physical reasoning and previous uses of the Revised Taxonomy for Physics Problems (Gates & Pugh, 2021; Chinn & Malhotra, 2002). Semiotic resources (in our specific case, verbs) often have different disciplinary meanings and this is particularly true for Physics. For example, the verb *determine* can directly translate to *calculate* in a Physics student’s mind, while to a medical student it could mean *provide a diagnosis*, which requires different cognitive processes and knowledge.

The token verbs alone cannot fully embody the significance of a cell in the taxonomy table, which is why while using the DTT we always referred to the original definition of the categories of Knowledge types and Cognitive Process levels. The difference between cells can be subtle, especially between cells that sit on the same row but different columns. To better characterise some of the cells, we added nouns that state the object of the action required to the student. It is important to note that the token verbs are not uniquely defined and have an auxiliary role in the classification process, merely summarizing the main characteristic of each intersection of cognitive level and knowledge types. For this reason, future works could produce a different but equally valid collection of token verbs.

A distinction that showed to be crucial was that between the Apply-Procedural and Analyse-Procedural cells. Both positions indicate the performing of not-original procedures, often mathematical calculations. The location of each problem was based on whether the solution could be reached through simple *plug-and-chug* (fill a known equation with given numerical data and get a quantitative solution), in which case it would be allocated to the Apply-procedural cell, or a more complex manipulation of multiple mathematical expressions with a stronger involvement of the physical meaning of said expressions, which would lead to its positioning in the Analyse-Procedural.

The filled Disciplinary Taxonomy Table is presented here:

		Factual Knowledge	**Conceptual Knowledge**	**Procedural Knowledge**	**Metacognitive Knowledge**
LOTS	**Remember**	List, fill the gap	Recognize	Recall how to do	Check what you know
	Understand	Summarize	Classify, rank, identify (relationship)	Discuss (strategy or procedure)	Identify source of mistake
	Apply	Respond	Predict, estimate (value)	Calculate, determine	Employ learning techniques
HOTS	**Analyse**	Select, identify	Explain (relationship)	Calculate, determine (multiple steps)	Correct your mistakes
	Evaluate	Check, compare	Evaluate (relationship)	Evaluate efficiency (strategy or procedure)	Self-evaluation
	Create	Generate	Assemble	Design (strategy or procedure)	Communicate your reasoning

Table 2.1. The Disciplinary Taxonomy Table (DTT).

2.3. Methods

This Section covers the methodology of the study. First, a careful selection of 212 physics problems sourced from different textbooks and based on different criteria provided us with what we regard as a representative sample of both the Italian textbooks' offer and of the ISLE approach materials. The problems were then allocated an individual spot in the two-dimensional space charted by the DTT, using the token verbs as a reference to compare the tasks to.

2.3.1. Data collection

We analysed a total of 212 problems, divided in two sets. For the first set, we selected 129 problems from a selection of Italian high school textbooks (Amaldi; Halliday, Resnick, & Walker; Walker) and 54 non-traditional problems from the ISLE-based textbook (Etkina, Planinsic, & Van Heuvelen, 2019A). The second set consisted of 83 problems that were used and produced during a teacher's training program that aimed to introduce teachers to non-traditional ISLE-based problems and exercises (Bologna, Modugno, Longo, & Peressi, 2026A). The problems included in the first set are randomly selected within the whole course for each textbook (all volumes), while the problems used during the teachers' training program were manually selected by the participants and tutors. The specific selection criteria for each set are discussed below. The whole dataset is not content-bound and can be considered to be representative of the general offer of Italian textbooks and of the ISLE-approach.

First set

To retrieve a representative set of Italian traditional problems, we chose to use three of the most common Physics courses in Italy: the Amaldi course and the Halliday course, both edited by Zanichelli, and the Walker course, edited by Sanoma Pearson (Amaldi; Halliday, Resnick, & Walker; Walker). The first is the most common Physics textbook in Italy: the first edition of the book came out in 1947 and it has been modernized and revised every year since then. Rankings based on the official data of the Italian Ministry of Instruction and Merit (MIM, ex MIUR) show that books written and edited by Ugo Amaldi occupy the first six positions (Libri di Fisica Più Adottati, 2026). The latter two are commonly used adaptations of American courses. These textbooks were chosen to guarantee a more equal comparison with the ISLE-based course, also American.

A total of 75 problems were randomly selected: 45 from the Amaldi course, 20 from the Halliday course, and 10 from the Walker course. We randomly drew the problems from the end-of-chapter sections of the whole courses, avoiding the "conceptual questions" section wherever present. We chose to avoid these sections because we wished to specifically probe what editors consider to be problem solving tasks, which we understand does not necessarily cover the whole cognitive profile of the textbook. We will refer to this group as the traditional-problems-subset of the first set and denote it with the code T1.

To complete the first set of randomly selected problems, we selected 54 non-traditional problems from the ISLE-based textbook "College Physics: Explore and Apply" (Etkina, Planinsic, & Van Heuvelen, 2019A). These constitute the non-traditional-problems-subset of the first set and will be denoted as NT1. To source the problems, we used a compiled list of the non-traditional tasks proposed by the ISLE-based textbook to randomly select six problems per problem type (Etkina, Brookes, Planinsic, & Van Heuvelen, 2019C). We chose not analyse tasks of the tenth type, "problem based on real data", as they may be traditional problems or any of the other types, which does not guarantee the intention of eliciting a explicitly non-standard cognitive process. On average, 18% of the problems in the textbook are non-traditional, and they are scattered in every chapter, so the selection is not content-bound.

Second set

A second set of not randomly selected problems was added to the analysis to ensure the differences found in the first set were not exclusively due to their distribution over textbooks and the different targets of the traditional and ISLE-based textbooks (Italian high school vs. American introductory college courses). These problems come from a teachers' training program we carried out in the academic year 2023-24. The program aimed to activate teachers' creativity and skills, expanding their knowledge and acting on their habits related to problem solving in class (Bologna, Modugno, Longo, & Peressi, 2026A). The structure of the program is analogous to the one studied in the second part of this thesis and is described in detail in Section 4.1.1. The problems are the start and end product of a transformation process. Teachers started with the deconstruction of a standard problem taken from an Italian textbook and the rebuilding of a new one, which had to satisfy the conditions of a set non-traditional problem type. The transformed problem was then solved, commented on by experts and colleagues, and later definitively written down. This second set provided us with two subsets of closely related problems that differ in the framing of the task and the cognitive requirements but focus on the same physical content and context.

This set consisted in 41 traditional problems (T2) and 42 non-traditional ones (NT2). The traditional problems were manually selected from the same Italian textbooks used in the first set so that they would be easier to transform into a specific non-traditional problem type and are therefore not completely random (Amaldi; Halliday, Resnick, & Walker; Walker). Still, the tasks were chosen to cover many different areas of Physics so we can consider this set to not be content-bounded.

2.3.2. Classification

The DTT facilitated the classification process by presenting the token verbs to summarize the characterization of each cell of the Taxonomy Table. To allocate a problem, we read the full written text, identified the action verb, and compared it with those in the DTT. This allowed for a first classification. Then, since focusing only on the verb often misses the full essence of a query, so we examined the entire context to achieve a more accurate categorization (Gates & Pugh, 2021). During the classification process, we always referenced the definitions of the cognitive levels and knowledge types reported in the previous section. Triangulation was not possible at the time of the analysis; however, the main coder discussed the coding procedure with peers for the whole duration of the study. Some notes on the process of categorization are:

- Some Factual Knowledge is always required. To solve a problem, a student always needs to recognize symbols and terminology and have at least a basic knowledge of the models involved.
- One could argue that all problems that ask to *explain* and *justify* an answer feature some Metacognitive Knowledge. However, these clarifying requests are often secondary to a main task, and whenever that was the case, we did not consider them for the categorization.
- Selecting a unique position for each problem can be difficult. A good strategy is to compare different problems to better detect similarities and differences and refine the positioning of the problems.

- We recognize that most problem solving strategies involve some “remembering”, especially in the first phases. Understanding the context and planning a solving strategy can both be considered to stand in the first row of the Taxonomy Table.

This analysis focused on the main (higher) cognitive process elicited by the problem and the core knowledge recalled. Some nuances are inevitably lost because of this restriction. A deeper analysis could position each problem in more than one cell of the Taxonomy Table and identify multiple aspects of the same task.

At this point we were able to determine each problem’s position in the DTT. For each problem, we noted: the source (textbook or author); an internal reference (page and number of the exercise); the measurable verb(s) used to express the task(s); the problem type for non-traditional problems; the difficulty rating (if present); the main cognitive process required; and the main knowledge recalled.

Here we present two examples of the classification procedure: the first is a traditional problem taken from the first volume of the Amaldi course, the second is the non-traditional problem of the “Design an experiment” type developed by teachers during the training course (Bologna, Modugno, Longo, & Peressi, 2026A; Amaldi).

<table>
<tr><th>Problem</th><th>Measurable verb</th><th>Location in the DTT</th></tr>
<tr><td>The table shows the values of the instantaneous speed of a car, read on the speedometer at 15-second intervals. At a certain point the car begins to brake in sight of a traffic light. Calculate the mean acceleration of the car in the interval between
a) t = 15 s and t = 30 s;
b) t = 45 s and t = 75 s.
<table>
<tr><td>t [s]</td><td>0</td><td>15</td><td>30</td><td>45</td><td>60</td><td>75</td></tr>
<tr><td>v [km/h]</td><td>10</td><td>50</td><td>60</td><td>63</td><td>30</td><td>0</td></tr>
</table></td><td>Calculate</td><td>Apply-Procedural:
the problem can be solved by filling the known equation for the mean acceleration with quantitative data given by the problem and carrying out simple calculations.</td></tr>
<tr><td>You are studying for your driving license and you read that the highway code states that the minimum safe following distance (in meters) is your speed in km/h, divided by 10 and then squared. Design an experiment to test that braking distance is proportional to the square of the speed.</td><td>Design
(an experiment)</td><td>Create-Procedural:
To solve the problem, the student has to design an experimental procedure that will allow them to verify the given relationship.</td></tr>
</table>

Table 2.2 Examples of problem classification.

The same methodology was adopted for the analysis of traditional and non-traditional problems used during different Physics courses for engineering university students in Genoa (Angeli, et al., 2026).

2.4. Results

2.4.1. Measurable verbs distribution

The first correlation we inquired was that between the lexical variety found in the subsets and their coverage of the cognitive levels and knowledge categories. For each problem, we noted the verbs used to express the request as they were. Some problems have more than one request, and in these cases, as discussed before, the core request was considered for the categorization process. We are interested in seeing if the lexical range of a textbook's problems section is related to the variety in cognitive demand.

In subset T1, we counted 16 different verbs for 108 requests. Around 30% of the problems had more than one request. The most frequent verbs are "Calculate" [34/108], "How much/many" [28/108], and "Determine", making up 74% of all entries.

Subset T2 presents a similar situation: 16 verbs for 51 requests, meaning that only 19% of problems had multiple tasks. The most used are "Calculate" [16/51] and "How much...?" [13/51].

We find a wider lexical variety when analysing non-traditional problems. Subsets NT1 and NT2 respectively had 79 and 76 entries, meaning they had respectively 46% and 44% of problems with more than one task. No verb appeared with frequency higher than 13% in any of the two subsets. The problems taken from the ISLE-based textbook (NT1) use 29 different verbs, and the most frequent are "Determine" [10/79] and "Represent" [10/79]. The non-traditional problems produced during the teachers' training program (NT2) use 22 different verbs. The most frequent are "Rank" [8/76], and "Explain" [7/76].

2.4.2. Problem distribution

Having assigned to each problem its coordinates in the DTT during the categorization process, we are able to visualize our datasets in the two-dimensional space. Our analysis shows that 75% of traditional problems fall in the lower area of the taxonomy, while 78% of non-traditional problems elicit higher order thinking skills.

0-5%	
5-10%	
10-25%	
25-50%	
>50%	

Table 2.3 Colour Scheme for Tables 2.4-7

T1	FACTUAL	CONCEPTUAL	PROCEDURAL	METACOGNITIVE
REMEMBER	4%		1%	
UNDERSTAND	3%	3%		
APPLY		3%	56%	
ANALYSE		5%	24%	
EVALUATE	1%			
CREATE				

Table 2.4. Distribution of subset T1.

T2	FACTUAL	CONCEPTUAL	PROCEDURAL	METACOGNITIVE
REMEMBER		2%		
UNDERSTAND		12%		
APPLY	5%	5%	61%	
ANALYSE	2%	5%	5%	
EVALUATE		2%		
CREATE				

Table 2.5. Distribution of subset T2.

NT1	FACTUAL	CONCEPTUAL	PROCEDURAL	METACOGNITIVE
REMEMBER				
UNDERSTAND	9%	6%		2%
APPLY		2%	6%	
ANALYSE		9%	7%	4%
EVALUATE	15%	4%	13%	
CREATE	9%	2%	13%	

Table 2.6. Distribution of subset NT1.

NT2	FACTUAL	CONCEPTUAL	PROCEDURAL	METACOGNITIVE
REMEMBER				
UNDERSTAND	5%	5%		
APPLY		7%	2%	
ANALYSE		2%	12%	
EVALUATE	17%	10%	12%	
CREATE	17%	2%	10%	

Table 2.7 Distribution of subset NT2.

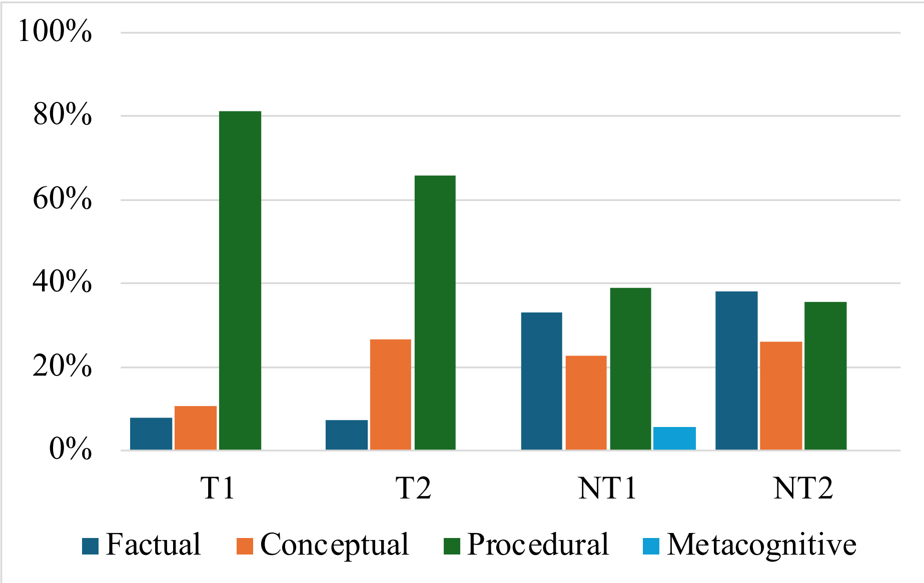


Figure 2.1. Coverage of the Knowledge dimension of the four subsets.

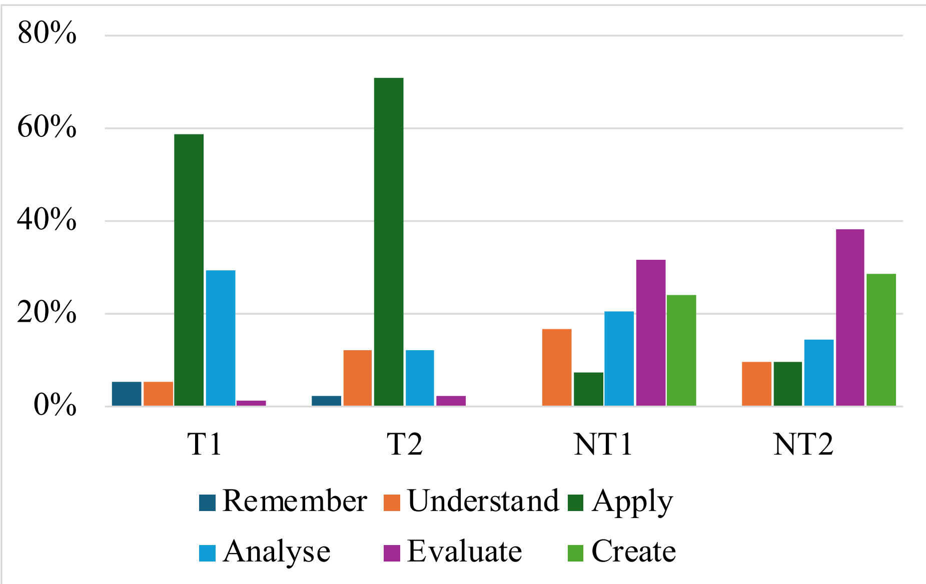


Figure 2.2. Coverage of the Cognitive Process dimension of the four subsets.

To visualize the distribution of the whole collection of problems, we compiled a table with all datasets combined. Table 2.6. showcases the combined cognitive profile, assembled considering all 212 problems. The total distribution sees exactly 50% of the problems in the lower order thinking area and 50% in the latter three levels. This splitting depends on the ratio of traditional and non-traditional problems taken into consideration, in our case respectively 54% and 46% of the total number of analysed problems.

COMBINED	FACTUAL	CONCEPTUAL	PROCEDURAL	METACOGNITIVE
REMEMBER	1%	<1%	<1%	
UNDERSTAND	4%	6%		<1%
APPLY	1%	4%	33%	
ANALYZE	<1%	6%	14%	1%
EVALUATE	8%	3%	6%	
CREATE	6%	1%	5%	

Table 2.8 Distribution of all data combined.

0-5%	
5-10%	
10-25%	
25-50%	
>50%	

Table 2.9 Colour Scheme for Table 2.8

2.5. Discussion of Chapter 2 results

2.5.1. Relationship between the lexical variety and the cognitive demand

Section 2.4.1 presents data on the lexical variety in the problems' requests across the four subsets. Traditional subsets show a markedly limited range: T1 only uses 16 different verbs over 108 requests (stated in 75 problems), and T2 uses 16 verbs over 51 requests. In both cases, a small cluster of expressions account for the majority of entries. It is notable that the most common requests all elicit the implementation of a mathematical procedure: "Calculate", "Determine" and "How much/many…?"

Non-traditional subsets display a wider variety: NT1 employs 29 different verbs over 79 requests, and NT2 employs 22 verbs over 76 requests. The proportion of multi-request problems also differs: around 30% in T1, 19% in T2, versus 46% and 44% in NT1 and NT2 respectively, suggesting that non-traditional problems tend to articulate more composite tasks.

This disparity appears to be mirrored by the distribution across cognitive levels. In both T1 and T2, more than half of the traditional problems fall in the "Apply" level, while for subsets NT1 and NT2 we see a more distributed coverage of cognitive levels. The same happens when looking at the knowledge dimension. Taken together, these observations suggest that the vocabulary used to formulate problem requests can be a surface-level indicator of a textbook's cognitive range: a wider cognitive profile is reflected in richer lexical usage.

2.5.2. Comparison of traditional and non-traditional problems

The analysis highlights clear differences between traditional and non-traditional subsets. As shown in the tables presented above, traditional textbooks mainly require Procedural Knowledge and concentrate heavily on the Apply level of the cognitive process dimension. Problems in the Apply–Procedural cell require students to execute familiar procedures. This result, combined with the frequency of mathematical requests shows the monotony of standard educational practice and the dry use of mathematics in high-school Physics. Out of the 116 traditional problems classified, only two fell in the Evaluate level, while the higher level, Create, was left completely empty. This shows that traditional textbooks provide few opportunities for students to develop higher-order thinking skills.

Table 2.2. shows that 56% of the randomly selected problems in subset T1 clustered in a single cell: 42 out of 75 problems could be solved simply by applying a known mathematical procedure to the given context. Considering the Apply-Procedural and Analyse-Procedural cells alone, we find 80% of problems from T1. Although the "Conceptual" column is the second most populated, its coverage remains limited, with little over 10% of the problems.

Figures 2.1. and 2.2. show differences between subsets T1 and T2. The second set was manually selected by the organizers of a teachers' training program so that the problems would be easier to transform into non-traditional ones. The analysis uncovers a preference for conceptual problems.

Non-traditional problems cover a wider portion of the Taxonomy Table. The distribution among the cognitive levels shows a shift towards higher order thinking skills, with 78% of problems in the Analyse, Evaluate, and Create levels. Problems in subsets NT1 and NT2 fill almost equally three of the four knowledge categories: Factual, Conceptual and Procedural. An important note is that many of the non-traditional problems that fell in the "Procedural" column regard experimental procedures rather than mathematical calculations like traditional problems, as they were of the "Make a Judgement (based on real data)" and "Choose a Measuring Procedure" types. The overlap with purely mathematical requests from the traditional subsets may constitute a weakness of the Revised Bloom's Taxonomy, as it does not differentiate abstract and experimental procedures.

This research also served us as a secondary analysis of the success of a teachers' training program we organized in late 2023 (Bologna, Modugno, Longo, & Peressi, 2026A). Coherence in the results of subsets NT1 and NT2 demonstrates that the transformation process was successful: the non-traditional problems developed by the teachers are aligned with those present in the ISLE-based textbook both on the Cognitive Process and Knowledge domains (see Figures 2.1, 2.2).

Our analysis confirmed that non-traditional research-informed problems fill the voids left by standard textbooks. The combined cognitive profile is more balanced than that of any individual subset: HOTS and LOTS levels are covered equally. A peak in the "Procedural-Apply" cell is still noticeable, driven by the high density of standard problems in the cell. This visualization shows how incorporating non-traditional into textbooks can be a way to better prepare students for scientific careers and develop scientific skills. In particular, solving ISLE-based non-traditional problems introduces students to the reasoning patterns that characterize an expert's work: moves like identifying variables to measure and to ignore, designing a measuring procedure and evaluating it, and assembling conceptual elements to build a model are all aimed at the acquisition of authentic scientific skills. The specific distribution showed by Table 2.8 is naturally dependent on the ratio of standard and non-traditional problems taken into consideration in this study. The current edition of the ISLE-based textbook has a smaller ratio than our total dataset: 72% of problems are not explicitly of a designed to be non-traditional. In our case 54% of the total number of analysed problems were traditional problems. Traditional problems proposed by the ISLE-based textbook have not been analysed, since our primary interest was to highlight differences between explicitly non-traditional problems and the present offer of Italian high-school textbooks.

Considering both the individual profiles and the combined one, we notice a lack of coverage of the first cognitive level, Remember, and the last knowledge type, Metacognitive. This result is common to standard and non-traditional problems. We identified several factors that could explain this result: the categorization prioritized the primary cognitive process and main type of knowledge required to solve each problem and, as discussed in earlier sections, these aspects are often secondary and therefore do not surface in the analysis. Another possible explanation is that the study did not include textbook sections labelled "questions" (or similar), where simpler exercises aimed at reinforcing definitions and disciplinary objects are more likely to appear, as well as items intended for self-assessment. We ignored these sections as they are not commonly regarded as strictly problem solving tasks and their intention vary according to each textbook.

2.5.3. Choice of the Revised Bloom's Taxonomy

This study allowed for an evaluation of the applicability of the Revised Bloom's Taxonomy in disciplinary-specific contexts, and in particular for the analysis of the cognitive profile of collections of physics tasks. The taxonomy proved to be an effective tool for our goals, especially after being detailed with disciplinary-relevant token verbs in the DTT. In particular, we noted that the Revised Bloom's Taxonomy:

- defines a sufficient number of cognitive levels and knowledge domains to categorize many different types of physics problems;
- frames cognitive processes and reasoning strategies recognized by PER as relevant in problem solving;

- the two-dimensional visualization in the Taxonomy Table offers an effective and immediate overview of the cognitive profile of a collection of tasks (such as a textbook) and allows to readily identify its weaknesses and strengths;
- it can be applied at different levels of analytical depth. It’s fine-grained enough to allow a nuanced examination of the various components of a single problem, making it possible to position the same item in multiple cells when conducting a deeper analysis (this was not done in our case). At the same time, the taxonomy can also be used at a broader scale to visualize and interpret entire datasets, providing a coherent structural overview that supports comparative and aggregate insights.

Even if the original framework is not tailored to PER needs of defining the characteristics of physics problems, Bloom’s Taxonomy is a well-known general frame that can be easily adapted to studies such as this one.

2.5.4. Closing remarks

This chapter set out to examine the cognitive demand of physics problems commonly used in Italian high-school textbooks, comparing them with a collection of non-traditional tasks. By mapping 212 problems into the Revised Bloom’s Taxonomy, we identified which knowledge resources and cognitive processes each set drawn on. The emerging picture for traditional textbooks is extremely monotone. An overwhelming majority of problems found in standard textbooks require to apply Procedural Knowledge: students are expected to mathematically manipulate given numerical values and obtain an exact quantitative result. These problems cluster in the Apply and Analyse levels of the cognitive dimension, leaving the higher levels Evaluate and Create nearly empty. The cognitive range students are exposed through routine textbook sourced work is therefore very narrow: the dominant task is to carry out a rehearsed mathematical procedure.

Non-traditional problems, by contrast, distribute more broadly across the taxonomy, engaging Conceptual and Factual Knowledge along with Procedural, and activating HOTS. These findings suggest that integrating such tasks into everyday practice could help fill the cognitive gaps left by commonly used textbooks, broadening students’ problem solving repertoires and supporting a more authentic engagement with Physics.

The narrowness of traditional problem-solving offer is a troubling observation: Italian high school teachers rely heavily on textbooks to source educational material, and repeated exposure to a particular type of problem shapes not only students' expectations of what physics problem solving looks like, but also teachers' habits and dispositions. A textbook that systematically omits higher order thinking tasks makes it harder for students to develop those skills and for teachers to recognize their absence and seek more effective alternatives.

Chapter 3. Habits as socio-cognitive structures: an ecological view

We colloquially refer to any kind of repetitive, automatic behaviour as a "habit". This broad definition is valid for both individual behaviours and collective social rituals. To analyse the role habits have in complex social environments such as schools and processes like problem solving, we must first define them. The aim of this chapter is to discuss habits in an interdisciplinary manner, drawing upon neuroscience, cognitive science, sociology, and educational sciences.

The investigation proceeds in three phases: first, we present cognitive and neurological evidence of habitual and automatic behaviours (Section 3.1). This will constitute the *individual level* of the description of habitual activity. Evidence from neurological and psychological contexts shows how repetition reinforces some mental associations that later dominate the decision making process. The identification of automatic behaviours or thinking patterns is not sufficient to understand the phenomenon of habit formation, as it has a strong social component: students and teachers study and teach physics within a specific social and institutional context, which strongly influences how they think and act.

The second phase of our investigation aims to describe how and why specific ways of thinking become habitual for teachers and students working in traditional high school (Section 3.2). This investigation of how communities develop collective preferred ways of thinking and influence the individual that participates in the community itself will help us understand the relationship between educational practice and the epistemic positioning of students and teachers.

The two levels, the individual one and the communal one, interact and influence each other in complex ways. Anthropologists, psychologists, scholars in social studies and many others have developed models that aim to describe the network of relations that connects an individual to the context it moves through. This chapter does not aim to provide an exhaustive neuroscientific nor sociological account of habit development, but to construct an interdisciplinary framework useful for understanding its influence on problem solving and problem posing strategies in Physics education.

Once formed, habits and routines are very stable, and their effect on workers' flexibility can serve as a measurement of their expertise. The framework presented in Section 3.3. defines Adaptive and Routine Expertise based on these premises. Finally, Section 3.4. illustrates the Developing Habits through Apprenticeship in a Community (DHAC) framework, developed by Eugenia Etkina and her collaborators specifically for physics teachers' training programs. This framework informed the design of the Creative Atelier discussed in Section 4.1.1.

3.1. Neuroscientific and cognitive description of mental habits

3.1.1. Habits as learned shortcuts in the brain

Ever since humans began reflecting on the nature of the mind and its interaction with the environment, thinkers have identified habitual, automatic, and instinctive patterns of behaviour as central features of mental activity. The idea that much of human behaviour operates outside deliberate control is present in Aristotle's writings and was central to Gautama Buddha's teachings. Similar philosophies appear often throughout the history of thought. The dichotomy between controlled, rational, goal-oriented thought and instinctive, automatic actions is the core of philosophical accounts of human thought from ancient times, through Descartes and Hume, to early psychologists such as James B. Watson and modern thinkers like Bergson.

Watson, an exponent of early behaviourism, focused his research on how behaviour can be shaped by external cues through learned stimulus-response (SR) associations (Watson, 1890). Habit development through repetition, often referred to as *conditioning*, has been one of the first interpretations of learning processes. Early theories considered the establishment of strong SR associations as an indication of successful teaching. With the shift from behaviourism to constructivism, we interpret habits as a by-product of learning, rather than its goal. Reward-based habit learning happens in stages. In the first phases, the learner is working towards a reward (food or approval), and their actions are goal oriented, non-habitual and purposeful. This behaviour is called action-outcome behaviour (AO). With extended training, the learner comes to repeating the tasked behaviour more automatically every time he perceives the learned cue. This built stimulus-response (SR) behaviour is resistant to the devaluation of the reward so that it persists even when the learner does not gain anything from performing the learned behaviour (Adams CD, 1981).

To approach the study of these automatic thought patterns and behaviours we start by listing their defining characteristics (Graybiel, 2008):

1. Habits are learned, as they are acquired through experience.
2. Habitual behaviours can present themselves over days or years and can become extremely fixed.
3. Fully developed habits are performed almost automatically, often without noticing and even without the individual being aware of the learned habit.
4. Habits often comprise a pattern of actions that are chunked together and performed in a sequential manner. These sequencies are often ordered and structured, so that the next action is immediately elicited by the previous one without pauses. The "opening move" of this sequence is usually prompted by an external stimulus.
5. Habits comprise of cognitive expression of routine (habits of mind) as well as motor expression of routine.

The shift from AO behaviour to SR behaviour when developing a new habit shows an additional defining characteristic (Kyle S. Smith, 2016):

6. Habits are performed not in relation to an immediate or anticipated reward but rather in relation to a previous goal.

We can now identify the habitual behaviour as the *performance of an automatic sequence of chunked actions (mental or motor) that has proved to be efficient in previous experiences with tasks similar to the present one.*

Developing habits can be extremely convenient for our brain, as reaction time decreases and accuracy in performing the task increases, saving the brain time and energy (Grundmann, et al., 2025). However, repetitively performing a task in a well-known manner limits the ability of switching strategy and makes dealing with unexpected results more difficult (Kim H. F., 2025).

Neurophysiological recordings have shown that distinct neural regions process cognitive flexibility and habitual stability. The brain continuously operates in two parallel ways: goal-oriented behaviour is processed in the regions associated with cognitive flexibility, and with repetition information shifts to caudal regions, that are associated with habitual behaviour (Kim H. F., 2025). The development of a habit does not substitute cognitive monitoring of the environment entirely, but research shows that when a habitual sequence of actions is triggered, activity in the neural areas associated with cognitive flexibility is significantly suppressed. These learned sequences not only suppress activity in areas of the brain but actively conflict with goal-oriented decision making (Frölich, Esmeyer, Endrass, Smolka, & Kiebel, 2022).

While it is clear that the development of habits is crucial in making life easier, cutting short decision-making time and minimizing cognitive fatigue with daily tasks of any complexity, it is also widely known that habits can be inefficient or even damaging. Breaking habits can be very difficult, especially when they develop in addiction or mental disorders. Following a pre-learned sequence mindlessly inhibits judgement and promptness and can lead to incidents. Developing habits increases accuracy at the expense of flexibility. While habits and skills share the optimization of accuracy and speed, one key difference lies in the flexibility of skilled performance versus the rigidity of habitual behaviours (Grundmann, et al., 2025). This trade off in cognitive load and flexibility is crucial when considering habit development in educational contexts: forming a habit can bring to accurate responses, but that does not necessarily mean that expertise is reached.

3.1.2. Processing in “autopilot”: controlled and automatic thinking

One of the first and most influential theories that describe different thinking styles is Schneider and Shiffrin’s work (Shneider & Shiffrin, 1977). They defined *automatic* processes as the activation of a sequence of nodes that “nearly always becomes active in response to a particular input configuration”, and that “is activated automatically without the necessity for active control or attention by the subject”. This definition anticipates what neuroscientific research later defined habitual behaviour. In contrast to automatic processes, *controlled* processes are defined as “a temporary sequence of nodes activated under control of, and through attention by, the subject” (Schneider & Chein, 2003). Psychologists and cognitive scientists later devised many different models starting from this central idea: these are referred to as *dual processing* theories (DPT). This family of theories all propose that human thinking operates through two separated systems: system 1 (S1) and system 2 (S2). The first relates to fast, automatic, and intuitive thinking, while system 2 processes are slower, deliberate, and controlled. Older elaborations of dual-processing theories imagined a shift from S1 to S2 according to the complexity of the task. It is now widely recognized that controlled and automatic processes are not mutually exclusive and most of the time the brain operates the systems simultaneously at different levels of cognitive control (Neys, 2018). The differentiation of the two systems does not necessarily reflect a biological separation in the structure of the brain[2] (Jansma, Ramsey, Slagter, & Kahn, 2001). Recent evidence supports the hypothesis that different neural regions are activated at different degrees in correspondence to habitual responses and goal-oriented behaviour, that could be identified respectively with automatic and controlled processes (Kim H. F., 2025).

While different DPTs have been devised, they agree on two main factors: i) the degree of learning (here understood as memory modification) is dependent on the amount and significance of controlled processes carried out during the activity (Schneider & Chein, 2003); ii) the type of response and the activation of automatic or controlled processes highly depends on contextual cues and the nature of the task (Fabio, Caprì, & Romano, 2019). These principles align naturally with the resources model introduced in Section 1.1.2. Within that framework, knowledge is organised in structures whose fundamental elements are selectively activated when deemed necessary; learning, in turn, can be understood as the progressive refinement of which resources are recalled in what order (Redish, 2004). This shift can be framed as the overriding of more intuitive, automatic

[2] Many early theories strived to describe an objective and scientific architecture of the mind, but dual processing theories are now treated as a framework for describing different thinking processes. Modern research aims to cover this gap through exchanges between neuroscience and cognitive science. Experimentation on human thinking is complex because of the many ecological variables involved.

responses (S1 thinking) in order to engage more elaborate and conscious thinking (S2). Dual processing theories have been extensively used in PER literature to describe cognitive behaviours of students, in particular to help them resolve reasoning inconsistencies (Kellar & Heron, 2025).

Unravelling the architecture of the human mind is too ambitious of a goal and a strict description of neurobiological and cognitive features of reasoning is beyond the scope of this work. Still, the arguments presented in this section provide us with important conclusions that inform and guide the analysis of the role of habits in physics learning environments:

- Evidence from neuroscientific and psychological settings support the definition of habitual behaviour (automatic processing) and its differentiation from other types of mental activity.
- Habits are learned through repetition and serve as shortcuts, minimizing reaction time and cognitive load, and increasing accuracy. This comes at an expense of cognitive flexibility.
- It is not possible to focus on the individual's approach to a task without considering the context and the nature of the task itself.

3.2. Socio-anthropologic role of habits

The development of automatic mental processes as discussed in the previous section frames habit formation as a causal effect of repetition of a task followed by a reward. This description accounts only for the individual dimension of habit development. Habits are learned and fostered in social contexts where the effect of others' acknowledgment and acceptance act as an unspoken reward. The social dimension of habit development is discussed with one of the most influential theories of social behaviour of the twentieth century: Pierre Bourdieu's.

Pierre Bourdieu was a French sociologist, anthropologist, and philosopher. His work addresses the distribution of power in complex modern societies, with a focus on how power in preserved through generations. Bourdieu's picture of social dynamics has overtaken disciplinary boundaries and his ideas have been employed to investigate the working of educational environments too (Nash, 1990). Simultaneously criticizing and drawing from Marxist philosophies, Bourdieu shapes his account of society as the study of a system of economic and cultural production, privileging symbolic capital. Applying the concept of capital to economic ("real"), social, and cultural resources enables an exploration of the conversion of one form of capital into another, effectively framing an economy of cultural practice.

Two of the most successful concepts defined by Bourdieu to study the structures of relations that construct a social system are the *field* and the *habitus*. The field is the network or configuration of objective relations between positions, while the habitus is the schemes of thoughts and dispositions on how to act that are developed in relationship with existing and past social structures (Grenfell, 1996). The habitus directs decision-making by organizing the way an individual thinks about reality, making a choice seem obvious or natural. The two are related so that the field structures the habitus, which in return is the embodiment of necessity of a field. On the other side, the habitus contributes to give meaning to the field, configuring the individual's disposition to the system. It is crucial to keep in mind that relations and structures are constantly being reformed and revalued in a complex dynamic manner.

The core of Bourdieu's theory is an urgency to question logical conformity, that is fundamental structures of thought. His view frames the State as an organization that applies constant symbolic violence onto its citizens. This symbolic violence works by defining the criteria for *objectivity*, which would otherwise be arbitrary, and by instilling mental structures. These cognitive structures are established through time and are also arbitrary but give rise to logical conformity, a silent agreement on what is "common sense" (Bourdieu, 1994). The relevance of this for the sociology of education is straightforward for Pierre Bourdieu: schools, being the means to cultural transmission, are agents for the reproduction of social classes (Bourdieu, 1974). In particular, the school is where a particular habitus is built and gives rise to, as he says, «patterns of thought which organise reality by directing and organising thinking about reality and makes what he thinks thinkable for him as such and in the particular form in which it is thought» (Bourdieu, 1971, p. 194-195). Such arguments have been applied in the broader context of the dynamics underlying the scientific community, especially by researchers working on feminist epistemologies (Cerroni & Simonella, 2012).

In the context of this work, we employ the field and the habitus to investigate how the school, understood as a non-place made up of physical spaces and relations, is related to the individual habitus of a teacher. In order to define the boundaries of our analysis, we propose a simplistic representation of the most significant components of the relevant field for our case (Figure 3.1). We consider four main nodes, representing the individual student, the teacher, the institution (school or university), and the discipline, in our case Physics. These four poles are related and influence one another: teaching practices, mandated curricula, textbooks, and departments mediate these relationship. A student is highly influenced by external actors such as their family, and is part of a community of peers with whom they share traits and behaviours. The same applies to the teacher. Both also maintain a meta-relation with themselves, indicated by the round arrow. The disciplinary pole summarizes practices, epistemologies, and behaviours that characterize the field and its respective community of experts. The textbook relates to this node of the network, as it defines the contents to be taught, the order in which to teach them, and the

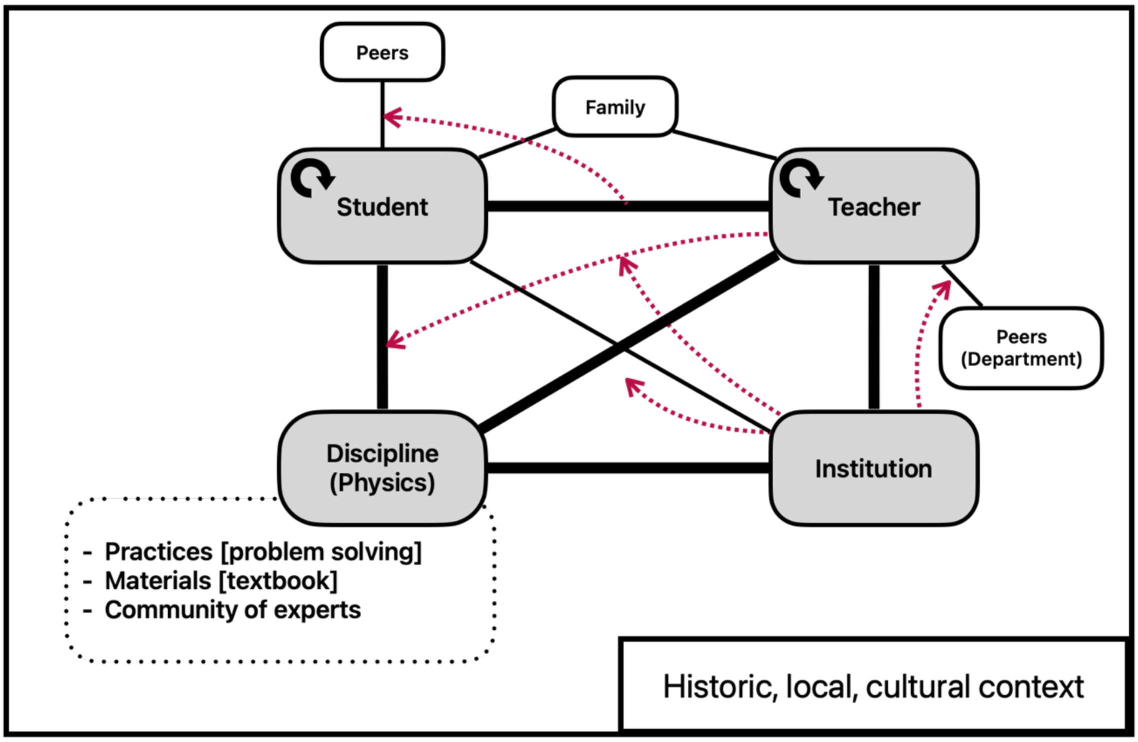


Figure 3.1 Representation of the field relevant in our case. Black continuous lines represent relationships, red dotted arrows suggest influences.

problems to solve. The red dotted arrows represent how actors in the field can influence the relationships that structure it: in particular, the teacher has an eminent role in the students' approach to the discipline he teaches, and this role is defined by the structure of the institution through explicit and implicit codes of conducts. Authorities and institutions also influence teachers' approach to a subject with training programs and defining mandated goals to reach and contents to teach.

This picture, although it is too simple to accurately summarize the everchanging structure of relations in a school, guides us in our study by showing the network of influences that make the relationship between Italian physics teachers and problem solving practices relevant. Every choice of a teacher influences and is influenced by this network. In particular, physics teachers' approach to problem solving will inevitably shape students' dispositions. That same approach is not casual, but it is shaped by socio-cognitive structures that are built on this network of relations. These structures are strengthened over time, and as more and more students learn them, some of them will become teachers and pass them over to new generations of students. This cluster of seemingly necessary or natural activities and cognitive processes is what constitutes the habitus in our case.

3.3. Adaptive and routine expertise

As discussed in Section 3.1.1, developing habits can bring to an increase in accuracy and speed which does not necessarily reflect expert-like traits (Grundmann, et al., 2025). The assumption that with skill acquisition performance becomes specialized, automatic, and effortless was challenged by many researchers in the 1980s (Eriksson, 2013). One of the most influential description of acquisition of skill and expertise is that of Hatano and Inagaki: they distinguish between routine and adaptive experts, starting from an investigation of learning of mathematics in a school setting (Hatano & Inagaki, 1986). The authors found that routine expertise, gained by extended and repetitive practice, does not lead to an increase in the understanding of conceptual knowledge. In contrast, Hatano and Inagaki noted that direct repetition should be avoided in favour of variability to develop what they named "adaptive expertise" (Hatano & Inagaki, 1986). A distinguishing characteristic of adaptive expertise is the ability to apply knowledge effectively in novel situations and atypical cases, recognising when it's convenient to applying the usual rules and principles is convenient and when it is not (Crawford et al., 2005). This flexible application of knowledge is strictly related to life-long and continuative learning as well as metacognitive effort. The adaptive expertise framework also abandons the assumption that becoming an expert requires years of accumulation of knowledge. The notion of characteristically adaptive applications of knowledge (cognitive processes) suggests that adaptive practices can be exhibited at any stage of instruction (Crawford et al., 2005).

Adaptive expertise is central in problem solving: the capacity to modify and adapt approaches to a task in response to shifting circumstances and the ability to explain the underlying principles that guide that same approach is an observed difference in expert and novice problem solving, as discussed in Section 1.1.2. In our study, we are interested in measuring Italian high school teachers' expertise in problem solving and posing. Chapter 2 described the current proposal of problems in Italian textbooks and revealed a striking monotony, which suggests the development of routine expertise. To continue the investigation of teachers' approach to problem solving practices, Section 3.4. addresses the development of the flexibility described by adaptive expertise in the context of the training of Physics teachers.

3.4. Developing Habits through Apprenticeship in a Community (DHAC)

The core conclusions of the latter two sections are: i) all instructional environments elicit the developing of a silent cluster of habits of mind and practice that become naturalized (habitus), ii) the ability to adapt one's approach to a situation (adaptive expertise) is crucial to problem solving. This section discusses how these results are integrated in the Developing Habits through Apprenticeship in a Community (DHAC) framework for teacher preparation, developed by Eugenia Etkina and other researchers close to the ISLE approach (Etkina, Gregorcic, & Vokos, 2017).

The premise of the DHAC framework for teacher training is: teaching is a habitual practice, all teachers will eventually develop habits, therefore, teacher preparation programs should attend to the efficient development of *productive* habits. For their purpose, the authors define a habit as "a mental association between a context cue and a response that develops as we repeat an action in that context for a reward" (Etkina & Planinšič, 2024). Research shows how a teacher's knowledge and beliefs affect their teaching practice and therefore their habits (Boudreaux & Elby, 2020). The authors include this observation in their framework by defining three main components that concur in the development and maintenance of a new habit: dispositions, knowledge, and skills.

- Dispositions are strong (often subconscious) beliefs or attitudes related to some aspect of teaching, that in concert with other factors, shape a teacher's behaviour and thought;
- knowledge of content, of the learning process, and subject specific teaching strategies;
- skills relate to technical and emotional abilities that a teacher needs to effectively lead a lesson.

The similarity of what the authors describe as "dispositions" and Bourdieu's more refined concept of habitus is obvious. Just like dispositions, knowledge affects what one notices and what ignores, and how decides to act. Expertise is characterised by knowledge and its organization, as discussed in Sections 1.1.2. and 3.3. Of course, skills are the last defining characteristic of a habit: to be able to perform a procedure (mental or practical) accurately and habitually, one needs the right set of skills.

After having defined a habit and its components, the authors provide examples of what they think are *productive* habits for a Physics teacher[3]. These practices are divided in habits of mind, habits of practice, and habits of maintenance and improvement. Inside this grouping, they divided habits of mind of a physicist and habits of mind of a physics teacher. Here we list some significant examples of productive habits (Etkina & Planinšič, 2024).

[3] The book "The Investigative Science Learning Environment: A Guide for Teacher Preparation and Professional Development" also describes non-disciplinary-specific habits, mostly relating to the general behaviour a teacher should have when doing a lesson (Etkina & Planinšič, 2024).

Productive habits of mind are those that characterize the typical thinking of a physicist or an expert physics teacher.

- approaching problem solving as a physicist and using mathematics in a Physics-specific way;
- being aware of the ‘surroundings’ as a source of teaching and learning Physics;
- habitually looking for natural phenomena that can be used to help students generate multiple explanations.

Habits of practice include habits that involve spontaneous decisions during lesson planning and the habits which lead to student learning.

- listening to students;
- approaching problem solving like a physicist;
- preparing each lesson while systematically focusing on three elements: goals, formative assessments, and sets of activities in which to engage students so that they achieve the goals, and being ready to change the course of a lesson if necessary;
- changing (or not) the path of the lesson based on what the student said;
- answering (or not) students’ questions and responding (or not) to students’ ideas.

It is important to notice how all of these habits are adaptive in nature: they require an evaluation of contextual cues and flexibility. In particular, they are strongly connected with epistemic empathy and responsive teaching (Bologna & Bembich, 2025). Epistemic empathy is the capacity for tuning into and appreciating learners’ intellectual and emotional experiences in constructing, communicating, and critiquing knowledge (Jaber, Davidson, & Metcalf, 2024). This alignment with students has a crucial role in recognizing the value of students’ ideas and following their lead even when they initially differ from conventional knowledge. Such behaviours are referred to as “responsive teaching”, an instructional approach to education that focuses on tailoring instruction to meet the diverse and evolving needs of individual students (Jaber, Dini, & Hammer, 2021). The ISLE approach naturally builds on the ideas of responsive teaching as it is the students who develop their explanations and design experiments to test those ideas through carefully designed activities. Therefore, teachers have to develop the right dispositions, skills, and knowledge to be able to conduct classes building on students' inputs (Dodlek, Planinsic, & Etkina, 2024).

Habits of maintenance and improvement are the habits that involve continuous learning on the part of the teacher as an individual and as a member of a community. Research shows that teachers that participate in a community of practice are more likely to use student-centred, active learning techniques (Tomkin, Beilstein, Morphew, & Herman, 2019). The availability of a community and active participation in it is crucial and needs to be a fostered even during pre-service teacher preparation programs (Etkina, Gregorcic, & Vokos, 2017).

These principles guided the design of the teacher training program described in the next chapter, that represents the context in which we tried to detect and study Italian physics teachers habits in problem solving.

Chapter 4. Habits and routines of in-service Italian physics teachers: empirical study

After having detailed the theoretical premises of this work, we move on to describe the design of the analysis. To be able to investigate the habitus of Italian high school physics teachers, we collected qualitative data on their teaching practice (with surveys) and observed behaviour in a teacher training program. Section 4.1. covers the design of the training course and the rationale behind the surveys. The data was analysed by looking at both the collective and individual level, and the methodology is described in Section 4.2. The chapter closes with a discussion of the results of this phase of the work.

4.1. Design

4.1.1. The teachers' training program

As argued extensively in the previous chapters, the environment is a central variable when discussing learning processes. This Section details the structure of the teacher training course we used for the analysis, the "Creative Atelier of Physics Problems and Exercises" (from here on, also referred to as "the Atelier").

The role of the Atelier is twofold: the first edition took place in the academic year 2023/24, and the problems produced during that edition constitute the second set of problems classified in Chapter 2. The design of the first edition and its development are the subject of my bachelor's thesis and a proceedings paper (Modugno, Bologna, & Longo, 2024; Bologna, Modugno, Longo, & Peressi, 2026A). The second edition of the course took place in spring of 2026 and is discussed in detail here. The contents, intentions, and activities of the two editions are identical, but during the second edition the main lecturer was Alessandro Ventura, a research fellow employed by the Physics Department of the University of Trieste.

The title of the course, Creative Atelier, is directly inspired by the Reggio Children Ateliers. The Reggio Emilia approach started as an educational program for preschool children and then expanded to include learning at all ages. The website defines ateliers as «environments promoting knowledge and creativity, suggesting questions and generating evocations; they are beauty that produces knowledge and vice-versa, the places where "the hundred languages" are enacted» (Reggio Children, 2026). Adopting this philosophy, the Creative Atelier of Physics Problems and Exercises was born as an opportunity for teachers to learn, transform, and adapt their resources in creative ways.

Stated goals

The main objective of the Atelier was to guide teachers in a reflection on their habits, in particular regarding the use of physics problems by presenting a viable alternative: ISLE-based non-traditional problems (described in Section 1.1.1). To address teachers' habits we referenced the DHAC framework for organizing teachers' training programs (see Section 3.4). We worked on their dispositions, knowledge, and skills in the following way:

- dispositions: the participating teachers were made aware of the urgency to develop scientific abilities and the inefficacy of traditional tasks in this sense;
- knowledge: the teachers were trained in the use of non-traditional problems and in recognizing the cognitive processes they entail;
- skills: the teachers learned a strategy to design non-traditional tasks.

In order to explicitly state the urgency of a change in their teaching practice, we presented teachers with an account of the requirements Italian authorities make regarding the development and assessment of scientific competencies and how they relate with the objectives of the ISLE approach (Modugno, Bologna, & Longo, 2024).

Structure of the program (second edition)

The second edition of the Atelier was hosted jointly by the universities of Genoa and Trieste in hybrid mode. The tutor presented the materials from his computer in a Microsoft Teams call, some participants met in Genoa (where an expert collaborator was always present), and others joined the online meeting. This organization made it possible to record all sessions using Microsoft Teams' tools. The program was part of a greater initiative conducted for the Piano Lauree Scientifiche (PLS) that spanned the whole academic year. During the first semester it consisted of two ISLE-based courses covering respectively content-specific and methodological aspects of physics teaching. The second semester offered another content-focused course and the Atelier, for a total amount of 39 hours of activities done.

The Atelier program spanned a total of 12 hours over the course of four three-hours-long meetings. The first meeting took place on the 26th of March, and the last one on the 3rd of June. Surveys #1 and #2 were submitted during the first meeting before starting the activities and took 20 minutes. The final survey was sent to the participants after the end of the last meeting. During each meeting, 2 or 3 non-traditional problem types were presented and worked on. All materials were shared with the teachers in a Google Drive folder. The following table presents summarizes the content distribution:

<table>
<tr><td rowspan="4">26th March 2026</td><td>Surveys #1 and #2</td></tr>
<tr><td>Introduction and discussion of the role of scientific abilities</td></tr>
<tr><td>“Jeopardy” problems</td></tr>
<tr><td>“Multiple possibility and tell all” problems</td></tr>
<tr><td rowspan="3">8th April 2026</td><td>Ranking tasks</td></tr>
<tr><td>“Evaluate” problems</td></tr>
<tr><td rowspan="2">“Make judgment based on data” problems</td></tr>
<tr><td rowspan="3">14th May 2026</td></tr>
<tr><td>“Choose a measuring procedure” problems</td></tr>
<tr><td>“Design an experiment” problems</td></tr>
<tr><td rowspan="3">3rd June 2026</td><td>“Linearization” problems</td></tr>
<tr><td>“Choose answer and explanation” problems</td></tr>
<tr><td>Problems based on real data</td></tr>
<tr><td></td><td>Survey #3</td></tr>
</table>

Table 4.1. Distribution of the ten non-traditional problem types over the four meetings. The discussion of “Make a Judgement based on data” tasks started, but was not completed, during the second meeting. It was reprised at the start of the third.

The creative activity: problem transformation

The main activity was the transformation of traditional problems into non-traditional ones (Modugno, Bologna, & Longo, 2024). The design of this activity is based on the implementation by Sarlah and Planinsic (2023). The steps of the transformation process are:

1. Solve: choose an appropriate (traditional) starting exercise and write its full solution.
2. Deconstruct: select significant information from the statement and the solution of the traditional problem.
3. Build: using the isolated information and looking at the characteristics of the chosen non-traditional problem type, write the new problem’s statement.
4. Solve: write the full solution of the new problem. If necessary, go back to step 3 and revise the problem’s statement. It can be useful to ask somebody else to solve the problem.
5. Ask for feedback: before using the new problem with students, submit it to colleagues.

During the Atelier, this activity was done in groups of 2-3 teachers. Each group started from a different problem to build the new one, which was then solved (step 3) by a different group. It was not always possible to complete this step of the activity because of time constraints. Every group-work session ended with each group presenting their product to the class and a discussion.

Participants

Enrolment in the teacher training program did not make it mandatory to participate to all four meetings. Therefore, the number of participants (and groups) varied each time. Table 4.2 summarises the number of teachers that participated to each meeting. The teachers did not know each other prior to the Atelier, and most of them had never encountered the ISLE approach for learning and teaching physics before. Teachers were invited to participate in the course through many channels: some were personal contacts of the tutors; others became interested in the ISLE approach during the national Didacta expo that took place in Florence in early march 2026. All participants were in-service physics teachers at the Italian upper secondary school level, but working in different types of schools and curricula.

Enrolling and attending teacher preparation initiatives like the Atelier is mandatory for all teachers in Italy, but the choice of the program and the time each teacher decides to invest is free. Therefore, all teachers were willing participants and were invited to take part to the research.

		26th March	8th April	14th May	3rd June
Number of participants	In-presence *	8+2 tutors	2+2 tutors	1+2 tutors	2+1 tutor
	Online	6	5	6+1 tutor**	3
	Total	16	9	10	6
Number of groups	In-presence	3	1	1	1
	Online	3	2	2 **	1

* the tutors in Genoa actively participated in the group-work. They had never carried out the transformation process beforehand.

** halfway through the third meeting, a group of university students graduating in Primary Education joined the activity guided by their professor. This group only worked on "Choose a measuring procedure" and "Design an experiment" problems.

Table 4.2. Number of in-presence and online participants for each session. The table also reports the number of groups assembled each time.

Tutors

As well as describing the teacher population, we think it's important to outline the tutors' backgrounds and their experience with the ISLE approach. The leading lecturer was Alessandro Pietro Ventura, a research fellow employed by the Physics department of the University of Trieste. Alessandro majored in History and Didactics of Physics from the University of Bologna and later became a licensed Physics and Mathematics high school teacher. He started working with ISLE when he was a bachelor student in Trieste and always continued taking part in initiatives aimed at spreading the ISLE approach to Italian schools. Alessandro also curated a workshop at the national Didacta expo in march 2026 that introduced the creative Atelier to teachers, which is how many participants became interested in the initiative (Atelier creativo di esercizi e problemi di fisica non tradizionali, 2026). The research group is guided by Valentina Bologna, who has been working in teacher preparation at the University in Trieste for more than ten years. Valentina is the main expert in the ISLE approach of the group and supervised the design and implementation of the first edition of the Atelier (Modugno, Bologna, & Longo, 2024). I was involved in the second edition of the Atelier mainly as a spectator, to collect qualitative data for this work. I am very familiar with the structure and the goals of the training program as I curated its design as part of my bachelor's thesis. I am also accustomed to the ISLE approach as I started working with it during my bachelor's years and continued through my master's in various ways. In early 2025 a collaboration between the research group of the University of Trieste and various professors of the Physics and Engineering departments of the University of Genoa started. Elena Angeli is the person in charge of the national initiative “Piano Lauree Scientifiche” for the Physics department of the University of Genoa and hosted the in-presence part of the Atelier in Genoa. Elena started working with ISLE recently and had never attempted the transformation process proposed by the Atelier, therefore she often actively worked with teachers during the activity. The in-presence meetings were also supported by the presence of a student tutor, who was not accustomed with the ISLE approach prior to this experience.

4.1.2. Design of surveys

In order to gain qualitative data on teachers’ prior habitual use of physics problems and their dispositions, we designed two surveys to be distributed before the start of the Atelier and one to be administered after the end of the program. All three surveys were administered in Italian. The translation from the original instruments for the second and the third surveys was performed using a conceptual translation model: the translation had to remain faithful to the ideas and concepts being probed by the tools, but be adapted to use words that teachers use usually (Ishimoto, 2013).

Survey #1

The first survey (see Appendix: Survey #1) is made up of 17 questions and covers the use of physics problems in the participants’ teaching practice. In particular, we are interested in probing how often teachers use problems during different phases of teaching: during class, as homework, etc. We also probed what are main sources for problems and whether the same source is used for written tests and standard use[4]. Two questions (15 and 16) are dedicated to the value that each component of the solution of a problem is given during assessment. These evaluations allow us to get a picture of what teachers deem as important or crucial when solving a problem and, therefore, what students pay more attention to when preparing for tests. The last question directly relates to the results of

[4] In Italy, the standard assessment strategy at the high-school level is a succession of oral and written tests throughout the whole school year, without mid-term or final exams.

Chapter 2 of this work and asked teachers to indicate how often some token verbs occur in the written statements of the problems they usually assign to students.

Survey #2

The second survey was also administered during the first meeting and required around 10 minutes to compile. The survey was designed starting from the tool to measure adaptive expertise in biomedical engineering students developed by Fisher and Peterson (Fisher & Peterson, 2001). The 42-item survey was developed to be used as a self-evaluation tool in higher-education settings and is informed by previous research in cognitive science. The questions have to be answered on a 1-6 Likert scale and cover four dimensions of adaptive expertise: i) multiple perspectives, ii) metacognitive self-assessment; iii) goals and beliefs, iv) epistemology. Our tool differs from the original one not only because it was rewritten to avoid referencing engineering education but also in its structure. In particular, the "goals and beliefs" section is duplicated and investigates not only beliefs on the nature of physics expertise but also teaching expertise. This will allow us to compare the attitude teachers have towards physics practice and the teaching physics. We designed the two "goals and beliefs" sections to have six pairs of isomorphic items, one regarding Physics and one on teaching practice:

	Goals and beliefs - Physics		Goals and beliefs – Teaching Physics
16	Challenge stimulates me.	24	When I'm teaching, challenge stimulates me.
17	I feel uncomfortable when I cannot solve difficult problems.	25	When I'm teaching, I feel uncomfortable when I cannot solve difficult problems.
19	Expertise can be developed through hard work.	28	One can become a better teacher through hard work.
21	To become an expert in Physics, you must have an innate talent for Physics.	29	To become an expert teacher, you must have an innate talent for teaching.
22	Experts in Physics are born with a natural talent for their field.	30	Expert teachers are born with a natural talent for teaching.
23	Even if frustrated when working on a difficult problem, I can push on.	31	When I'm teaching, even if frustrated when working on a difficult situation, I can push on.

Table 4.3. The six pairs of parallel items in Survey #2.

Another important modification is the "softening" of some of the questions. During a conversation with a colleague, some concerns emerged about the honesty of the teachers and their affective involvement. It emerged that keeping the original wording of some items could lead to skewed answers: teachers most likely would know which of the answers was the more expert-like and it could be hard for them to admit their insecurities or deficiencies. This is a risk that all self-assessment tools encounter. To limit its significance, one would need a large sample to dampen skewed answers, which was not available in our case. Another possible solution is that adopted by the developers of the Colorado Learning Attitudes about Science Survey (CLASS), where each question is formulated as both a self-assessment item and in the form of "How do you think an expert would answer?" (Adams, Perkins, Finkelstein, & Dubson, 2005). We chose not to adopt a similar strategy because we felt teachers would not benefit from a comparison with experts at this stage, not even as an individual meta reflection. We concluded that a possible solution would be to articulate the items so that they explicitly referenced the teacher's behaviour during class. With this rephrasing we intended to shift the perceived object of assessment from personal identity and expertise to observable professional practice: rather than asking teacher what they *know* or *think*, we asked them to reflect on what they *do*. This shift is in line with the scope of the study and we hoped it would reduce the perceived threat of the tool allowing teachers to respond more openly without feeling their professional competence was under scrutiny.

It should be noted, however, that these modifications introduce limitations. First, as already mentioned, the low number of participants in this study does not allow for a strict statistical analysis of the survey results. We mainly used the data collected for sustaining qualitative evidence. Second, the adaptations made to the original instrument mean that direct comparability with the validated tool cannot be warranted. The adapted survey should be understood as an exploratory instrument suited to this particular context rather than a validated measure.

Survey #3

A third survey was distributed after the end of the training program. This survey is composed of two separate sections, that were combined into a single form to limit survey attrition. The first section is a self-evaluation of the development of adaptive strategies during the program; the second is a summative evaluation of the quality and perceived success of the training.

The first section is an adaptation of an instrument developed by a research group at Northeastern University for the measurement of adaptive expertise in post-secondary students (Ferguson, et al., 2018). The instrument builds on Fisher and Peterson's (2001) survey and adds a dimension focused on domain-specific skills. We selected it because it is explicitly designed to be administered after a course, inviting participants to reflect on their experience in a specific learning context. Since the original instrument targeted university students reflecting on a course they just attended, many of the items were reworded to reference the Atelier. The only structural modification was the splitting of one item into two, in order to address both problem solving and problem posing separately, reflecting the two complementary moments at the centre of the Atelier's creative activity. The 21 items are all graded on a 1-6 Likert scale, in line with survey #2.

It should be noted that surveys #2 and #3 do not constitute a conventional pre-post design. Treating them as such would imply that a twelve-hour professional development program is sufficient to produce measurable change in teachers' problem solving approach. This assumption is not in line with the theoretical framework adopted in this thesis, given that habitus is understood as a deeply sedimented set of dispositions that resist transformation. The surveys therefore serve different purposes: the first and second probe teacher's existing orientations and habits prior to the Atelier, while the third does not attempt to re-measure the same constructs but instead invites participants to reflect on their experience during the program, asking in particular whether they perceived themselves as engaging with problems in a more adaptive way. The design is thus better understood as exploratory and reflective rather than evaluative in a strict before-and-after sense.

The second section of the final survey functioned as an evaluation tool for the program organizers. It was structured in three parts: a general section collecting background data on participants (including place of residence, institutional role, and degree qualifications); a five-point rating scale ranging from 1 (Not at all / Poor) to 5 (Very / Excellent) assessing participants' perceptions of the course content, delivery, and structure; and a set of questions probing the perceived transferability of the course content to participants' professional contexts and their interest in future ISLE-related initiatives.

4.2. Methods

4.2.1. Collection of responses to the surveys

The first two surveys were administered prior to the opening session of the Atelier. The lecturer provided a brief introduction to the themes of the program and informed the teachers of the purpose of the two surveys. Completion of the surveys took approximately 20 minutes. At the end of that session, 11 responses had been collected for the first survey and 10 for the second. Since not all teachers completed the questionnaires on that occasion, a link to both surveys was included in a follow-up email sent to all enrolled participants. This yielded 4 additional responds for the first survey and 3 for the second; however, in both cases, 2 of these came from teachers who had enrolled in the program but were unable to attend it. Since neither survey is tied to the specific content of the Atelier sessions, as they probe existing habits, responses from these teachers were nonetheless retained in the analysis. A final invitation to submit answers to the surveys yielded additional answers, taking the total number of respondents to 16 for both surveys.

The third survey was administered at the close of the final session. Fourteen responses were collected; however, one was submitted by a teacher who had attended only the parallel content-focused course rather than the Atelier itself, and was therefore excluded from the analysis.

For the purposes of this thesis, the survey data are analysed at the collective level: responses are treated as evidence of shared orientations, tendencies, and patterns within the group, rather than as the basis for constructing individual profiles. No attempt is made to characterise specific teachers or to cluster participants into typological categories. This choice is partly a consequence of the relative unanimity of the responses, which offered little variation on which to ground meaningful individual differentiation. The construction of individual or typological profiles, drawing on both survey responses and transcript excerpts from the Atelier sessions, could be a productive direction for future research.

4.2.2. Coding transcripts

All the Atelier sessions were recorded via Microsoft Teams. The recordings cover the whole sessions, including moments of lecturing during which teachers were not active participants. When separate breakout calls were created for group work, those too were recorded, yielding in total more than twelve hours of video material.

The first step in working with this corpus was the selection of segments for transcription. We retained those portions in which teachers worked in groups to pose and solve problems as part of the transformation activity at the centre of the Atelier, as well as subsequent moments of collective discussion. Segments of direct instruction were excluded. Because the Atelier was conducted in Italian, all transcripts are in Italian. Transcription was carried out with the aid of Microsoft Word's "Dictate" function: the audio of each video was transcribed in real time while the recording played, allowing simultaneous monitoring of the output and annotation of relevant observations. This process produced approximately eighty pages of raw transcript.

These pages were then subjected to thematic analysis, a widely used qualitative method in educational research. The analysis is inductive: themes are derived from the data rather than mapped onto a predetermined coding scheme. This choice is consistent with the case-oriented nature of the study, which does not aim to produce a generalisable taxonomy of teacher interaction but rather to uncover the social, cultural, and contextual factors shaping this particular group's engagement with problem posing and solving (Robertson, Scherr, & McKagan, 2013). It should be noted, however, that inductive thematic analysis is never fully theory-neutral: the identification and interpretation of emerging themes is always shaped by the researcher's theoretical and epistemological orientations (Braun & Clarke, 2006). This limitation is heightened by the impossibility of evaluating inter-coder analysis, as this is a single-researcher study.

The analytic procedure proceeded as follows. The transcripts were read multiple times to establish familiarity with the materials, and initial observations were noted. Segments of text were then labelled with short codes. The resulting codes were revised by unifying similar instances and grouping them in categories. During the first phases of analysis, there was not a set size for labelled segments. As the coding proceeded, segments were cut and reduced in size. The coding scheme was subsequently reviewed against the data and refined where necessary, before final categories were named and defined. An example of the final look of an episode is given in Table 4.3.

[…] very simple dynamics exercise	Assessment of problem complexity
[…] I later found it in textbooks too; I had invented it, but then I found it in the books as well.	Problem selection
[…] From that acceleration, with the mass, you calculate the total force. […]	Selection of solving strategy
and then the question, which is a terrifying trick question: is there friction? And the students fall off their chairs!	Calibration of task Knowledge of student responses Knowledge of students difficulties
[…] «I don't remember the coefficient, the formula, I don't know how to do it, there's no data...'» In reality this exercise is designed precisely to highlight that in dynamics there is a total force. And in fact, when I give it in a test, I always say: 'Be careful, because you have kinematic data'. Typically, what do they do? They calculate the acceleration and then apply F = m·a, find the force... and tell you that that is the friction. They make a mess of it.	Knowledge of reasoning patterns Role as educator

Table 4.4 English (translated) transcript of a teacher describing a past episode with her students. The coloured segments of text were coded as described by the right column.

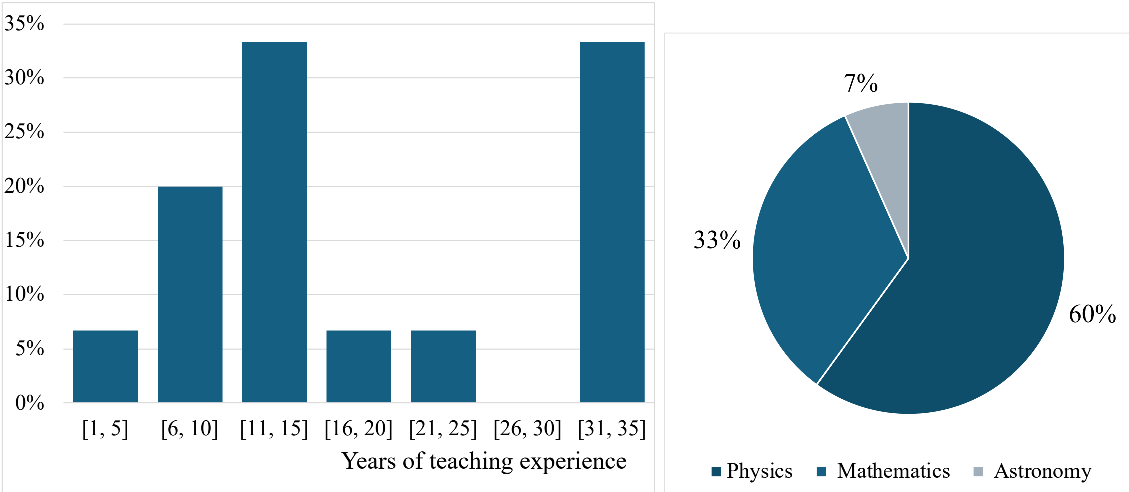
4.3. Results

4.3.1. Surveys

This section presents the data collected from the three surveys. As discussed above, the data are analysed at the collective level: convergent responses are treated as signals of shared orientations, tendencies, and patterns within the group, while individual responses are highlighted only where marked variation suggests a meaningful departure from the collective trend.

Survey #1

The opening items of Survey #1 reveal a varied population in terms of professional background. Of the sixteen teachers who submitted responses, four have fewer than ten years of teaching experience, six between ten and twenty years, and six more than twenty years. With regard to disciplinary training, nine teachers held a degree in Physics, six in Mathematics, and one in Astronomy (Figures 4.1a and 4.1b).



Figures 4.1a and 4.1b a) Number of teachers as a function of years of teaching experience; **b)** distribution of degree qualifications among teachers.

The survey then asked teachers to report the frequency with which they engage in problem solving across different phases of the didactic process. Fourteen out of sixteen teachers indicated that they assign problems as homework after every lesson; similarly, twelve reported solving problems at the board every lesson, while three do it once a week. More than half of the sample (9/15) reported conducting problem solving activities with students working individually or in groups more than once a week, while four do so around once a week. Written tests were reported to occur once a month or less across the entire sample.

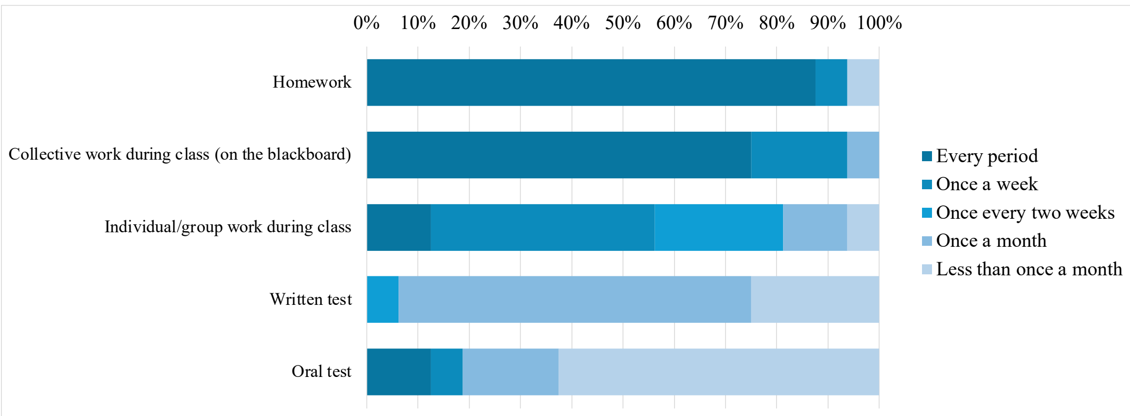


Figure 4.2 Reported frequency of use of problems during different phases of the didactic process.

Responses regarding the frequency of oral tests were notably split: some teachers indicated conducting them less than once a month, while others reported doing so every lesson. This discrepancy is likely due to an ambiguity in the phrasing of the question, which did not specify whether it referred to how often an individual student is examined orally or how often oral testing of any student takes place in class. The two interpretations would naturally yield very different answers.
All sixteen teachers indicated that they personally select the problems assigned to their students. Thirteen out of sixteen responded positively to the statement "*When I get to class I have already prepared the necessary materials*" on the Likert scale, while the remaining three gave a mid-range rating of 3 out of 6.

Regarding problem sources, eleven teachers reported drawing primarily on problems from the textbook adopted by their department at the beginning of the year, three of whom also supplement these with problems from additional textbooks. A further three teachers indicated that they habitually use problems from textbooks other than those prescribed by their school. When asked whether they use the same sources for both standard practice and written tests, responses were split: three teachers reported that they typically devise the test problems themselves.

One teacher stands out within this first section of the survey. With twenty-three years of teaching experience, she adopted the ISLE approach in her practice in recent years. Her responses depart markedly from those of the rest of the group. She reported assigning homework less than once a month and conducting written tests more frequently than her peers. She also indicated that she always prepares her materials before class, and that the problems she uses are drawn from or inspired by real-world scenarios.

The next items asked teachers to rate their agreement with a set of statements concerning their problem-selection and assignment practices on a six-point Likert scale. Reading a problem before assigning it to students emerged as near-universal practice, while solving it beforehand proved considerably less consistent, with responses distributed across the full range of the scale. Problem solving was reported as a significant component of assessment by most teachers, though not unanimously so. The strongest consensus of the section concerned continuity between practice problems and test problems, with the large majority of teachers expressing strong agreement.

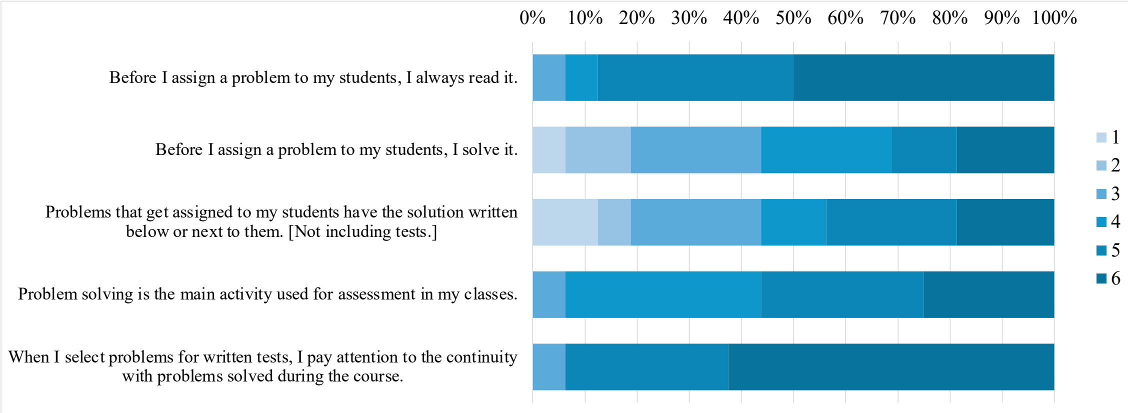


Figure 4.3 Answers to items 10-14 of the first survey. Ratings are given to a 1-6 Likert scale, with 6 representing strong agreement to the given statement.

The next two items investigated how teachers weight different components of a problem solving task when evaluating student work, distinguishing between two dimensions: the importance attributed to the *correctness* of each component and the importance attributed to its mere *presence*. The items were designed on a 1-4 scale. The five components under consideration were the quantitative result, diagrams and other representations, calculations and mathematical procedures, discussion, and unit analysis. The distributions for each component are shown in Figure 4.4.

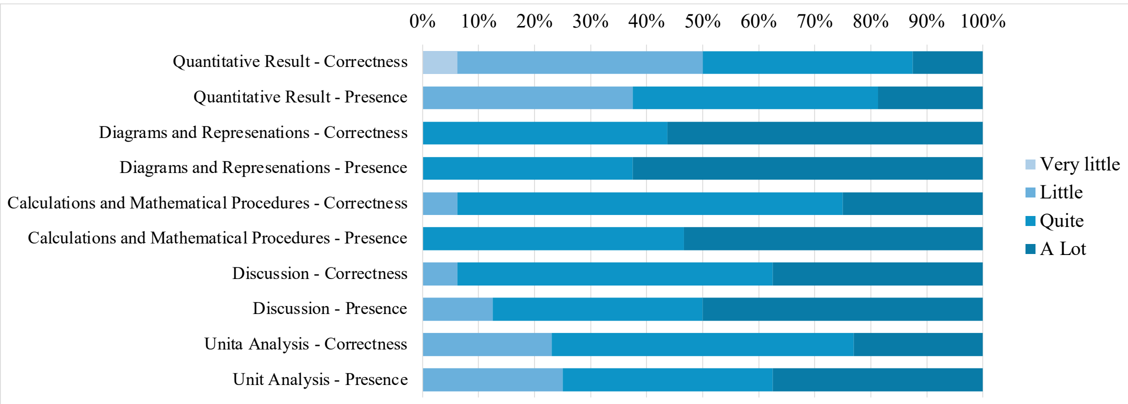


Figure 4.4 Distribution of value given to the correctness and presence of each component of a problem solution.

The graph reveals consistent patterns across the two dimensions for all components. Notably, no teacher assigned to the same component ratings to presence and correctness that differed by more than one point.

The last item asked teachers to rate the frequency with which each of twenty token verbs appears in the problems and exercises they habitually use, on a four-point scale from 1 (Never) to 4 (Often). The token verbs represent different areas of the Disciplinary Taxonomy Table designed in Section 2.2. Tasks involving calculation and determination of a numerical result stand out as the most frequent, with the large majority of teachers rating them at 4, consistent with the analysis of Italian textbooks presented in Chapter 2. Identifying, selecting, and explaining also received relatively high frequency ratings, suggesting these are common features of assigned problems. Tasks such as inventing, assembling and communicating were rated 1 or 2 by the majority of teachers. The same happens for metacognitive tasks such as finding and correcting errors. Metacognitive and evaluative requests such as "Explain" and "Discuss" are reportedly frequent.

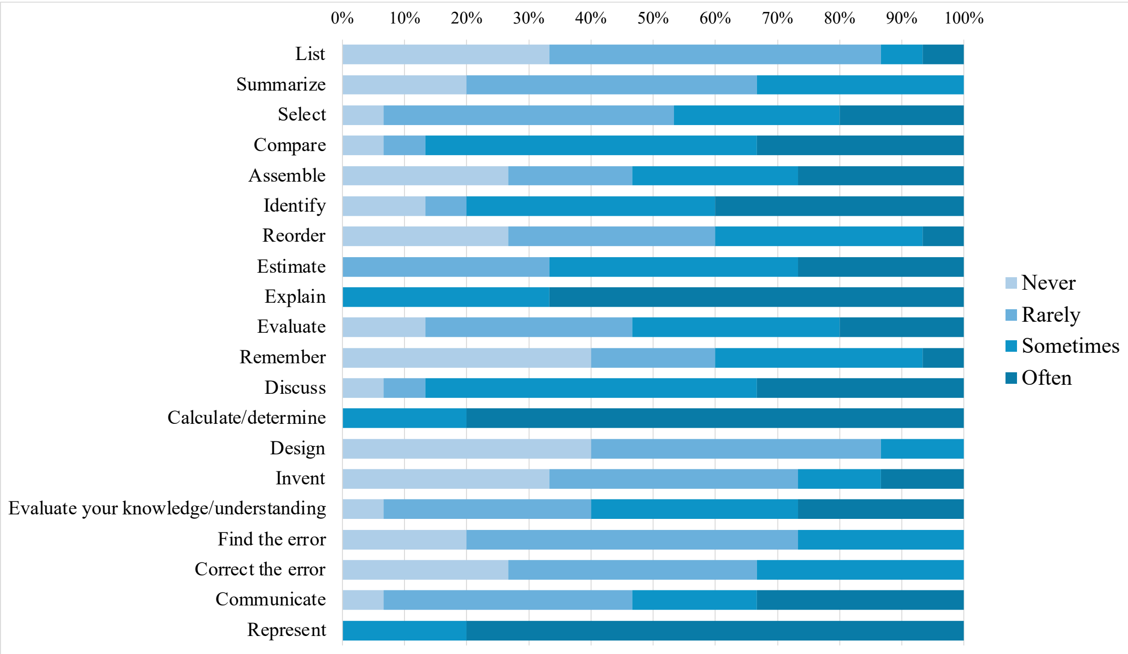


Figure 4.5 Distribution of reported frequency of requests in habitually used physics problems.

Survey #2

The first section of Survey #2 investigated teachers' orientation towards multiple perspectives in problem solving across nine items. Some of the statements were negatively worded: responses to these items were reversed prior to analysis, so that agreement with a negative statement consistently corresponds to a low score, and disagreement to a high score. The general direction of responses across the section is in the mid-to-upper range of the scale. The average scores of the teachers range across 3.3

to 4.9, with a group mean of 4.3. It is the lowest group mean recorded across the different sections of the survey.

The second section investigated teachers' metacognitive disposition. Again, the teachers reported high metacognitive abilities and in particular indicated that they are aware of content-related deficiencies. Items 14 and 15 reveal that most teachers habitually self-evaluate but rarely get feedback from colleagues and students.

The next two sections address the goals and beliefs dimension of adaptive expertise toward Physics and Teaching Physics, investigated separately. Individual mean scores across the two domains differ by no more than 0.75 points for most teachers. Three teachers, however, show more marked discrepancies. Two of them scored notably higher on the Teaching Physics section, with differences of 1.4 and 1.25 points respectively in favour of that domain. The only teacher whose scores favoured the Physics section over Teaching Physics is the teacher who has been using the ISLE approach in her practice, whose means differ by 1.2 point in that direction. Notably, for all three teachers, the responses to the paired items listed in Table 4.5 do not show corresponding inconsistencies at the item level, suggesting that the discrepancies operate at the level of overall orientation rather than on specific constructs. Figures 4.6 show the responses to each related pair of items.

	Goals and beliefs - Physics		Goals and beliefs – Teaching Physics
16	Challenge stimulates me.	24	When I'm teaching, challenge stimulates me.
17 (*)	I feel uncomfortable when I cannot solve difficult problems.	25 (*)	When I'm teaching, I feel uncomfortable when I cannot solve difficult problems.
19	Expertise can be developed through hard work.	28	One can become a better teacher through hard work.
21 (*)	To become an expert in Physics, you must have an innate talent for Physics.	29 (*)	To become an expert teacher, you must have an innate talent for teaching.
22 (*)	Experts in Physics are born with a natural talent for their field.	30 (*)	Expert teachers are born with a natural talent for teaching.
23	Even if frustrated when working on a difficult problem, I can push on.	31	When I'm teaching, even if frustrated when working on a difficult situation, I can push on.

Table 4.5. The six pairs of parallel items in Survey #2.

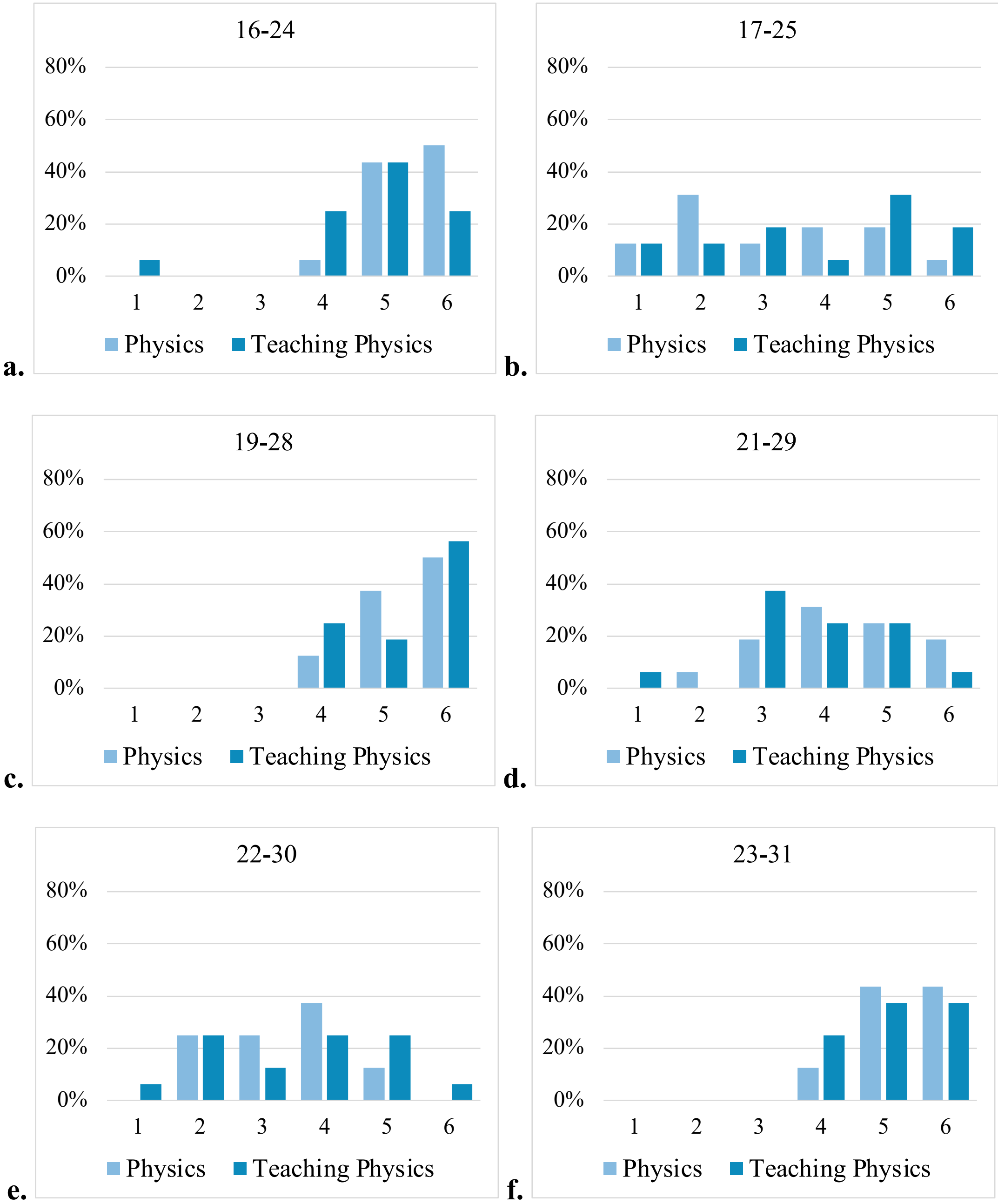


Figure 4.6 a, b, c, d, e, f Distrubutions of responses to the paired items of the "Goals and Beliefs" sections of Survey #2. The scale is that of adaptive expertise, which for some items (denoted with an asterisk in the previous table) is flipped, so that a high score does not necessarily mirror agreement with the statement but rather a demostration of adaptive dispositions..

The histograms show relative consistency between the responses to parallel items across the two domains. The most notable divergence concerns teachers' reported discomfort when faced with a difficult problem (Figure 4.6b, items 17 and 25): teachers indicated greater unease when working on a Physics problem independently than when addressing a difficult problem in the context of teaching. This is somewhat counterintuitive, as one might expect the added pressure of a teaching situation to amplify the discomfort.

The final section of Survey #2 investigated teachers' epistemological orientations. Most teachers scored well on this section, with individual means above 4 out of 6. The sole exception is one teacher whose mean of 3.1 and whose response pattern suggest a positivist view of Physics as a stable and rarely revisited body of knowledge. The otherwise high scores in this section are, however, sharply complicated by the responses to item 37, "Facts that I teach in class must be true", with which most teachers expressed strong agreement (which translated to a low score). This stands in direct tension with the epistemological stance demonstrated elsewhere in the section, where teachers broadly endorsed a view of scientific knowledge as dynamic, constructed, and subject to revision.

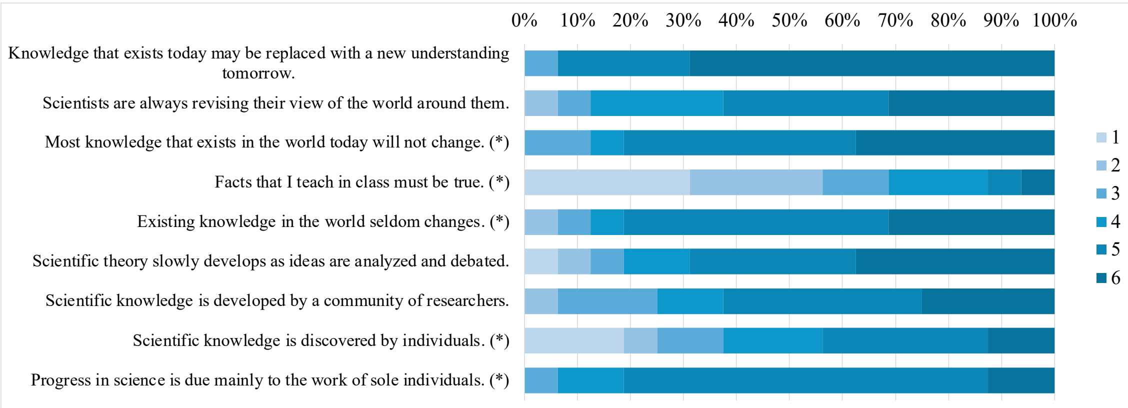


Figure 4.7 Scores to the items probing epistemological positioning. Items marked with an asterisk are negatively worded so the answers are flipped. Here, 6 does not represent agreement with the statement but a display of adaptive expertise.

Survey #3

The third survey was administered at the end of the final session and yielded 12 valid responses. The instrument was designed to prompt participants to reflect on whether they had enacted expert-like behaviours during the Atelier. The first 21 items asked teachers to rate, on a six-point scale, the extent to which they had exhibited specific behaviours associated with adaptive expertise. As shown in Figure 4.4, the distribution of responses across all items is strongly skewed toward the upper end of the scale, with the mode being 6 out of 6 after reversal of negatively worded items.

The two ratings of 1 were both assigned by the same teacher, whose responses suggest a limited self-reported disposition toward novel and unfamiliar situations. The lowest mean across all items was recorded for item 12, "during the program, I applied knowledge I learned in previous teachers' training courses". This result is likely due to the non-traditional nature of the contents presented during the Atelier.

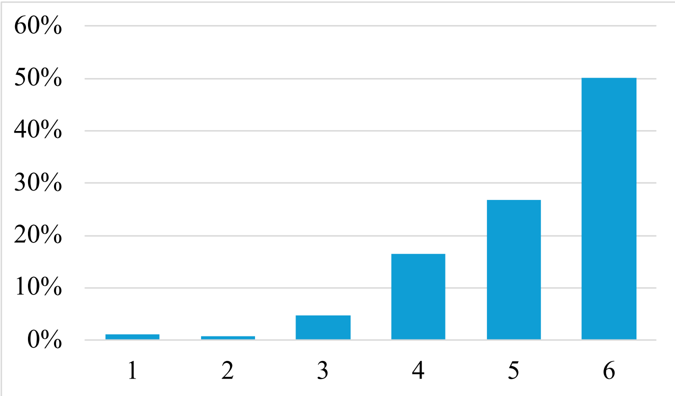


Figure 4.8 Distribution of all answers to the first 21 items of the third survey. These items probed the perceived use of typically adaptive behaviours during the Atelier.

The second section of the final survey functioned as an evaluation tool for the program organizers. The Atelier received positive reviews overall: responses indicate satisfaction with the tutors, their teaching style, and the management of instruments and materials, with all items recording a mean above 4 out of 5. Teachers also expressed interest in participating in future initiatives of a similar kind, both those who had previously received ISLE-based training (4 out of 12) and those who had encountered the ISLE approach for the first time during this academic year.

4.3.2. Thematic analysis of transcripts

The thematic scheme that emerged from the analysis comprises two main themes: "Teaching" and "Problem Posing and Solving". The first relates to the pedagogical dispositions that characterise the participants as teachers: their knowledge of students, their classroom practices, and their understanding of their professional role. The second captures the participants approach to problems. Together, these themes document the habitus that teachers carried into the Atelier and the ways in which it surfaced in the course of the activity. The following table presents the final thematic scheme derived from inductive analysis of the Atelier transcripts.

Theme	Code	Description
Teaching		
Knowledge of students	Knowledge of reasoning patterns	Teachers anticipate how students would cognitively approach a task.
	Knowledge of student difficulties	Teachers recognize probable errors and conceptual difficulties.
	Knowledge of student responses	Teachers anticipate how students would react to a task.
Instructional practices	Problem selection	Teachers select an appropriate problem or exercise for the situation. Teachers discuss how they source problems.
	Calibration of task	Teachers modify a problem to fit students' abilities or to address a specific difficulty.
Role of the teacher	Institutional constraints	Teachers reference institutional demands that shape their teaching practices.
	Role as educator	Teachers reference their relationship with students and their perceived responsibilities.
Problem Posing and Problem Solving		
Knowledge of problems	Typological knowledge of problems	Teachers refer to different types of problems or recognize the differences between two problems.
	Assessment of problem complexity	Teachers evaluate the perceived complexity of a problem.
Problem posing practices	Calibration of cognitive demand	Teachers modify the problem to elicit the desired cognitive process in the solver.
	Use of multiple representations	Teachers discuss the use and the role of multiple representations.
	Writing the problem statement	Teachers write down the problem.
Problem solving practices	Use of multiple representations	Teachers employ different representations while problem solving.
	Selection of solving strategy	Teachers select or discuss a strategy to solve a problem.

Table 4.6 Final thematic scheme derived from inductive analysis of the transcripts.

We now discuss each code and present some instances where it was flagged.

Teaching

During the Atelier, the teachers demonstrated a shared knowledge base of their students. We identified three main domains:

Knowledge of reasoning patterns refers to those instances where teachers anticipate or discuss how a typical student would approach a task. When discussing problems, teachers often stated "*here a typical student would...*" or "*we expect them (students) to…*" and then describe a specific cognitive process. These episodes are often related to the frustration of teachers toward hard-to-break habits of mind of students, who are reportedly used to resorting to mathematical procedures without discussing the physical meaning of the variables.

Knowledge of student difficulties refers to the collective knowledge base that teachers have of those conceptual nodes that demonstrate to be particularly complex for students. This knowledge is shared among the teachers and is built with experience in the classroom. Teachers usually use this knowledge to target students' difficulties when posing a problem.

Knowledge of student responses is the third component of this category and relates to those instances where teachers anticipate emotional reactions to a proposed task. These episodes are often related to the description of non-traditional problems that require more authentic scientific reasoning ("make a judgment based on data", "design an experiment",…), where teachers are worried that their students would shut down even before attempting a solution because of the unfamiliar nature of the task.

The thematic analysis highlighted some common instructional practices that teachers adopt based on their shared knowledge of students.

Problem selection is the code that refers to those moments where teachers discuss where they source problems and how they choose the right task for a specific situation. The analysis revealed that most teachers resort to traditional textbooks to source problems. Another aspect that emerged is teachers' ability to design a traditional problem that exactly simulates what one would find on a textbook. Discussing the "Evaluate" non-traditional problem type, some teachers shared that they found similar problems in their textbooks. The ISLE-based problem type asks the student to evaluate the reasoning of some (imaginary) people or evaluate the suggested solution to a problem; while the problems found in Italian textbooks ask the student to choose one of two options presented as opinions of imaginary characters and use the expression "who is right?". Of the three teachers that recognised the format of the request, two admitted that they avoided those problems because they seemed “pointless” and “weird”.

Calibration of task refers to the ability of modifying a problem or activity to match the students’ skills. Teachers report a tension between wanting to challenge students and the need of making sure that the majority of students will be able to succeed in solving a problem. Strategies like scaffolding, adjusting the wording, and providing multiple representations are the most common to guide students in problem solving.

Lastly, teachers often shared observations on their role as educators, both in relation to their position within the school institution and addressing their perceived responsibilities toward students.

Institutional constraints refers to those concerns and observations teachers share about the limits and requests that come from institutions. In particular, teachers worry about time constraints and not being able to cover all mandated materials before the end of the academic year. Many teachers also shared frustrations related to the absence of experimental materials and a lack of support from colleagues.

Role as an educator, in contrast, relates to the relationship teachers have with students. In many occasions, teachers express a feeling of responsibility toward their students and their role in their cognitive development. Statements like “*we have to take them where they don’t want to go*” expose the wish to challenge students and guide them.

Problem Posing and Problem Solving

The second main theme that emerged from the thematic analysis of the transcripts is associated with teachers’ approaches to problem posing and problem solving.

Typological knowledge of problems refers to teachers’ ability to categorize problems. Teachers mention “typical” or “classic” exercises in relation to specific area of Physics, such as “*a typical exercise about an incline*” or “*the usual problem about released and absorbed heat*” without feeling the need to characterise these problems further and treating them as part of a common knowledge base.

Assessment of problem complexity is used to refer to a subsequent step of problem identification: teachers often provide a quick evaluation of a problem's complexity before solving it.

Calibration of cognitive demand refers to those strategies that teachers employ to modify a problem so that it will capture the desired cognitive process and knowledge base. Teachers often build problems that purposely challenge students' difficulties. In a few cases, teachers expressed dissatisfaction with a problem because it "*does not force them (students) to calculate…*", suggesting that a physics problem that does not involve mathematical processes is less cognitively valid than one that does. In other cases teachers built a problem specifically to avoid quick calculation. For example, during problem posing a teacher proposed: «let's not include numerical data. I wouldn't include them, precisely to avoid the *calculator-result effect*». Instances where teachers modified problems in order to better point to a higher-order cognitive process happened mostly during the collective discussion that followed group work, prompted by observations coming from tutors and colleagues.

Use of multiple representations during problem posing is another emerging aspect. Usually, teachers include graphical or pictorial representations in their problems either as an aid to students, i.e. to simplify it, or to increase the perceived complexity of the problem. Tables, diagrams, and graphs were often added to problems in an attempt to make them "less standard" or as distractors, without a reflection on the added meaning of the representation and its structural role in the problem solving process. These representations almost never hold information that is not already given in verbal or mathematical form.

Writing the problem statement is the last step of problem posing. After having discussed the contents and scope of a problem, such as the situation to be presented and the conceptual node that it focuses on, the teachers move on to writing the problem statement. In many cases, the problem ends with the request to calculate a quantitative value even if it does not align with the cognitive objectives teachers expressed earlier in the problem posing process. For example, during the second meeting, a group of two teachers developed a non-traditional problem of the "ranking task" type that focused on the correspondence between work and the area under a curve in a pressure-volume graph.

They decided to ask students to rank three different paths between fixed points A and B by the amount of work done. The teachers decided to supply the problem with a graphical representation of the paths so that the connection between work done and area under a curve would be mediated by the representation (this is an example of Calibration of Task and a successful use of multiple representations during problem posing). The need to quantify the work done did not emerge until one of the teachers started writing the problem statement. At that point, the teachers realised that their students would not be able to rank the three paths because one of them was a isothermal process, and they would have had to calculate a definite integral. Of course, the problem could have been solved without any calculation, as the size of the area under a curve is a simple quantity to estimate (or at least to rank), but once the teachers had to write the problem statement, they added a request of calculation that made their initial problem not suitable for their students. The defaulting to a numerical request when writing problem statements even when it is not needed or when it does not fit the initial scope of the problem is observed in many cases throughout the whole Atelier.

Use of multiple representations during problem solving showcased a stronger expertise than that demonstrated during problem posing. When asked to solve a problem, teachers often chose to use graphical representations or diagrams while verbally describing their reasoning.

Selection of solving strategy refers to the choices that lead teachers to a specific solving strategy. As mentioned above, teachers often used multiple representations to describe a problem solution. When teachers had to approach a traditional problem, they often stated the mathematical steps to get the quantitative result but stopped before obtaining it. This behaviour often reversed when teachers faced a non-traditional problem. In one specific case, two teachers were asked to give feedback onto a "ranking task" problem that was formulated by another group. The problem statement gave five different frequencies and asked to rank the relative velocity of an ambulance and an observer who measured those frequencies. The statement also gave the "true" frequency of the siren. In order to solve the problem, one does not need to calculate, as the observed frequency is directly proportional to the relative velocity. The two teachers, however, spent a few minutes looking for the right equation and manipulating it so that it fit the situation at hand. They were interrupted by a tutor asking them to share observations about the non-traditional problem, and they admitted that they intended to calculate the relative velocity for each of the five given frequencies and only then ranking them from highest to lowest. This is one example of how when faced with a non-traditional problem, teachers often defaulted to a calculation-based strategy, even when the problem was specifically designed to not require one.

4.4. Discussion of Chapter 4 results

4.4.1 Detection of teachers' habitus

The responses to Survey #1 reveal a high degree of convergence across the group in terms of professional practices and evaluative priorities. The teachers, who had markedly different professional trajectories in terms of years of experience and disciplinary background exhibit substantially similar orientations towards problem solving. This convergence is interpretable as evidence of a collective habitus, a system of durable dispositions and tacit knowledge concerning problem solving that is widely shared across the group and that appears to operate largely independently of individual professional background.

With regard to organization of teaching practice, teachers in this group engage with problem solving in a consistent and structured manner: problems are assigned as homework after every lesson, solved at the board on a regular basis, and represent the primary instrument of written assessment. Problem selection is reported a personal act, yet teachers draw from a restricted set of sources, predominantly the textbook adopted by the school at the departmental level. This pattern suggests a habitus in which individual agency is parallel to structural conformity: teachers exercise judgement within a field of practice whose boundaries are determined by institutional and social constraints. The relationship that teachers have with the school as an institution also emerged as a theme from the analysis of transcripts. Teachers express preoccupations related to pressures to cover all the material before the end of the academic year and report scarce availability of equipment for experimental activities.

The data concerning assessment priorities show near-unanimous agreement on the value given to different components of a problem solution, pointing to a shared evaluative framework with largely unquestioned criteria of quality. These similarities in the orientations towards problem solving suggest that physics teaching practices in Italy are persistent across professional generations and sufficiently resilient to absorb individual variation.

Evidence from both the first survey and the transcript analysis converges on a common finding: most of the problems that teachers habitually use close with a quantitative request. The habit of using predominantly traditional problems interferes with the problem-posing process. While the early stages of problem posing were largely guided by teachers' knowledge of their students' difficulties and typical reasoning patterns, this orientation was repeatedly overridden at the point of formulation of the problem statement. Teachers often defaulted to adding numerical data and a quantitative request even when the problem did not require one. The assumption that a Physics problem must yield a quantitative result also shaped how teachers evaluated the problems they produced: tasks without a numerical answer were perceived as incomplete or of lesser value.

This practical aspect of approaching problems seems to be in contrast with other dimensions of the teachers' professional identities. Teachers consistently articulated the need for tasks that engage students in more complex cognitive processes, and expressed a sense of responsibility for providing them.

Taken together, these findings offer a partial picture of the habitus of the teachers in this group. The data illuminates specific dimensions of their professional dispositions: relationships with students and institutions, orientations toward problem solving, and a shared base of knowledge of students and problems. The Atelier created conditions under which some of these otherwise tacit dispositions became visible: the problem-posing tasks placed demands that their habitual orientations were not fully equipped to meet. The moments of interference documented in the transcript analysis are moments in which habitus encountered a context that did not fully confirm it, creating a cognitive dissonance.

4.4.2. Evaluation of adaptive expertise

The results of Survey #2 allow for an evaluation of the group's adaptive expertise. Across the five sections, teachers consistently positioned themselves above the midpoint of the scale. The lowest mean was recorded for the multiple perspectives section, which is the one that most explicitly referred to problem solving. This indicates that pluralistic and expert-like approaches to problem solving represent the least consolidated dimension of adaptive expertise within this group. The transcript analysis, however, suggests that this self-assessment may overestimate the flexibility teachers actually deployed in practice. The habits documented in the transcript analysis point to a more rigid orientation toward problem solving than the survey responses alone would indicate.

The comparison between dispositions towards Physics and Teaching Physics revealed that for most teachers orientation towards expertise is largely transferable across contexts. The counterintuitive finding that teachers report greater discomfort when working independently on a difficult problem than when addressing it in the classroom could be explained by the fact that teachers are not used to encounter difficulties or obstacles when teaching: the problems are familiar and they know how to approach them, while this is not always true for more complex Physics problems, which in turn they never encounter in class. This interpretation is supported by extracts from transcripts where teachers show discomfort when facing problems that require authentic scientific reasoning and acknowledge that such problems are absent from their teaching practice.

The metacognitive and epistemological sections yielded the strongest scores, pointing to a reflective group that endorses a dynamic view of scientific knowledge. Item 37 highlighted a tension between the epistemological orientation of teachers regarding Physics and their positioning as teachers. The prevalence of positivist epistemologies among educators is a common result in PER (Sin, 2014).

The results of the last survey suggest that teachers practiced expert-like behaviour when problem solving and posing during the Atelier. Teachers did not perceive the Atelier as continuous with prior professional development experiences: this result suggests that the program was experienced as a genuinely novel context rather than as an extension of familiar training formats. This is consistent with the design intentions of the Atelier, which sought to expose teachers to problem solving and problem posing situations that depart from their habitual repertoire. The positive evaluation of the program recorded in the second section further contextualises these findings. Satisfaction with the tutors, the materials, and the overall structure of the Atelier, combined with expressed interest in future ISLE-based initiatives across the full sample, suggest that the program was received not merely as a formal obligation but as a meaningful professional experience.

4.4.3. Closing remarks

This chapter set out to investigate to what extent the professional habits of in-service teachers can be detected through their engagement with non-habitual problem-posing tasks, and how those habits shape their practice. The evidence gathered through surveys and transcript analysis converges on a coherent, if partial, picture.

The thematic analysis of transcripts and the survey data jointly document collective habitus characterised by shared knowledge of students and problems, consistent instructional practices, and entrenched habits in problem posing and solving. Most notably, we detected the tendency to default to quantitative requests regardless of whether the task requires them. This habitus proved sufficiently stable to interfere with teachers' engagement with non-traditional problem formats, surfacing when habitual orientations were no longer adequate to the demand of the task.

The evaluation of adaptive expertise complicates this picture without contradicting it. Teachers' self-assessments were broadly positive, though the transcript evidence suggests these assessments overstate the flexibility actually demonstrated in practice. The tension between teachers' epistemological orientation toward Physics as a discipline and their orientation toward Physics as something to be taught points to a distance between scientific and professional identities that warrants further investigation.

Teachers perceived the Atelier as discontinuous with prior professional development experiences, suggesting that the program succeeded in creating a genuinely novel context. During the Atelier existing habits became visible because they proved to be ineffective. The positive reception of the program supports the case for teacher training programs that deliberately challenge teachers' habitual practices and demonstrates the effectiveness of the DHAC framework as a design tool for such programs.

Two limitations of this study indicate possible directions for future research. First, an analysis of the interactional dimension of the Atelier was not carried out. The way teachers negotiated, proposed, and deflected during group work was not systematically investigated, though the data suggests it represents a productive site for probing the social dynamics present in a context where current habitus is challenged. Second, the analysis treated the group as a collective and did not attempt to reconstruct individual professional profiles. A more fine-grained account of individual orientations and practices could allow for a sharper investigation of the suggested gap between scientific and professional identities.

Chapter 5. Discussion

This chapter aims to combine the results of the analysis of the cognitive profile of Italian high school textbooks, presented in Chapter 2, and the detection of Italian teachers' system of habits and beliefs, presented in Chapter 4, to answer the research question: *to what extent do textbooks influence the habits and routines of in-service physics teachers, and what role do those habits play in their professional practice and development?*

The first section offers an overview of the main results of the two investigations and highlights common ground and discrepancies between them, weaving them in a unified narrative. The section sections discusses the implications of this study for instruction and for Physics Education Research. Finally, future developments are proposed.

5.1. Summary of results

The study presented in this thesis is composed of two empirical analyses that yielded unrelated findings. The scope of this section is to describe the relationship between these results and present a continuous narrative.

The first empirical study was that of the cognitive demand of Italian high school textbooks and its comparison with that of a collection non-traditional ISLE-based problems. A total of 212 problems were mapped on the two-dimensional space defined by the Revised Bloom's Taxonomy. The distribution of traditional problems is piqued on the area of the taxonomy that characterises tasks that involve the implementation of already-known mathematical procedures to obtain an exact quantitative result. The analysis revealed that 75% of textbook problems foster lower order thinking skills. More complex cognitive processes such as analysing, evaluating, and creating are covered by non-traditional, research-informed problems. In summary, this investigation revealed and quantified a gap in traditional educational materials and demonstrated that non-traditional ISLE-based problems represent a good resource to expand the cognitive demand of common Italian educational materials.

The alarming level of standardisation of physics problems raised a new question on its effects on Italian teachers' practice and orientations toward problem solving. The chosen instrument to investigate this influence is that of habits. Habits are developed through repetition over time, in response to a previous goal. In our case, the assumption is that being able to solve the majority of physics problems by inserting given numbers in a known equation fosters the habit of resorting to blind calculation when faced with any problem. To probe this phenomenon, the study employs an ecological analytical lens to explore the way teachers are influenced by textbooks, assuming that effects of this relationships extend to students' perception of Physics problems. In particular, the bourdieusian concepts of field and habitus are introduced as a systemic frame to describe the dynamics that govern a scholastic environment and its elements.

To detect Italian teachers' habitus, a training program designed to engage teachers in non-habitual creative problem posing activities was selected, the Creative Atelier of Physics Problems and Exercises. The program was structured in four three-hours-long sessions, that were attended by a varying number of participants, between 6 and 16. During the Atelier teachers solved and posed non-traditional problems staring from traditional ones. Data was collected with surveys administered before and after the Atelier and with transcripts of the group work and moments of collective discussion. Evidence gathered in this phase of the study provided a picture of teachers' habitus. Teachers demonstrated a shared base of knowledge of students and problems and reported similar teaching practices regarding the use of problems. In particular, the group of teachers reported a strong reliance on textbooks to source materials and problems. Results from the second survey and evidence from the transcripts highlighted a gap between the perceived and enacted flexibility of teachers during problem posing and problem solving. Thematic analysis of the transcripts revealed that teachers defaulted to calculation-based strategies to solve problems that were specifically designed to not require one. Moreover, teachers perceived as incomplete or of lesser value problems that did not include a mathematical request. The Atelier confirmed to be a fitting context to detect tacit assumptions and beliefs of a group of Italian physics teachers, by positioning them in an environment where previously developed habits proved to be ineffective.

Comparing the results of the first and second phase of this study suggests that the educational practices of Italian high school teachers are highly influenced by textbooks' catalogue of problems. This influence does not relate only to the sourcing of the problems but also on the habits of mind of teachers. With the vast majority of proposed exercises being procedural tasks, teachers appear to assimilate an idea of what a physics problem looks like and of how to solve it successfully. With this in mind, the textbook acts not merely as a resource but as a normative framework: it implicitly defines what a physics problem is, what a valid solution looks like, and which cognitive moves are expected. Teachers who have been trained and who have worked within this framework appear to have internalised these definitions, so that the procedural template becomes the default schema for problem selection and problem solving.

This finding is aligned with the bourdieusian framework discussed in Chapter 3: the textbook contributes to the construction of a professional habitus in which certain dispositions toward problem solving such as the favouring of procedural tasks are reproduced and difficultly questioned. In this perspective, the textbook acts as a conveyor of reasoning patterns that do not reflect those of adaptive experts. Where adaptive expertise involves flexible, context-sensitive reasoning and the capacity to reframe problems when standard procedures fail, the habitus shaped by conventional textbook use tends toward the efficient execution of familiar routines.

5.2. Implications for instruction and PER

The findings of this study open a set of questions that appear productive for both research and instructional practice.

From a research perspective, the most notable implication concerns the relative absence of socio-anthropological frameworks in mainstream PER. The field has investigated the cognitive dimension and developed frameworks that describe knowledge organization and utilisation during problem solving in depth. Comparatively little attention has been paid to the social and cultural structures that shape those processes and that influence how an individual comes to have certain dispositions and preferences. The present study suggests that Bourdieu’s concepts of field and habitus, already extensively used in educational sciences, offer a productive frame for this kind of investigation. Habitus, in particular, directs attention toward the dispositions teachers and students carry into the classroom as a result of prolonged participation in the school field. This study focused specifically on detecting teacher's habitus in the specific sub-field of school Physics in relation to problem solving practices. The disposition that compose habitus are largely pre-reflective, which makes them difficult to observe without the employment of specifically designed instruments. The Atelier provided an appropriate context in which habits and beliefs became visible and disputable.

More broadly, the analysis points toward the value of ecological and systemic frames in PER. Research tends to prefer more circumscribed frames: cognitive and interactional analyses are methodologically better defined but often avoid to consider contextual factors. This study suggests embracing complexity and pointing more attention to the dynamics that emerge from the analysis of the whole system before focusing on a single phenomenon.

Regarding instructional practice, the findings suggest that the role of the textbook in shaping teaching style deserves closer attention. The analysis conducted here documents a predominance of procedural tasks and limited variation. If habits are partly constituted through repeated exposure to certain types of tasks, the textbook may function not only as a resource but as a structuring influence on the very dispositions teachers and students develop toward physics problems. This study supports the hypothesis that instructional reform cannot treat materials as neutral, and that a systematic review of textbook content is needed.

Finally, the Atelier represents an example of what a professional development program attentive to the development of habits could look like in the Italian context. The DHAC framework offers a principled basis for extending this work, with an emphasis on cultivating productive habits from the earliest stages of teacher training.

5.3. Future developments

The limitations of this study mirror possible future developments.

The systematic examination of cognitive demand described in Chapter 2 focused on a selection of Italian secondary physics textbooks. A next step is to extend this analysis to educational materials such as assessments, authority-mandated curricula, and others. The extension of the analytical lens could also be toward university-level instruction. A broader and more complete characterization of the cognitive demand of Italian physics instruction would allow the development of an analytical lens to map the gaps between formal curricula and enacted practice at all levels.

The transcripts collected during the Atelier sessions represent a resource that offers space for analysis of different dimensions. A systematic discourse or conversation analysis of these materials would allow for a finer-grained reconstruction of the social dynamics undergoing during the sessions. Moreover, several participants in the Atelier displayed what appeared to be a tension between their identity as physicists and their identities as school teachers. A dedicated investigation drawing from interview data and excerpts from the transcripts would allow for a more rigorous examination of this epistemological dissonance.

One of the broader theoretical commitments of this work is the embracing of a systemic view. Expanding this commitment to other research work could help capture the mutual influences among the principal nodes of the relational network of the school. This rearrangement of the way we look at physics instruction could help the converging of more cognition-focused and social accounts of physics-specific learning processes, mapping them in a broader ecological understanding of physics education.

Appendix

Survey #1

Items marked (*) denotes “negative” items.

#	Survey item
	Personal data
1	Name and Surname
2	Indicate the type of high school you’re employed at. [5]
3	Indicate your teaching experience (in years).
4	Indicate your major: ☐ Mathematics ☐ Physics ☐ Engineering ☐ Other:
	Habits
5	For each of these situations, indicate how often written exercises or problems are involved: [1 – Every period, 2 – Once a week, 3 – Once every two weeks, 4 – Once a month, 5 – Less than once a month] 1. Homework 2. Collective work during class (on the blackboard) 3. Individual/group work during class 4. Written test 5. Oral test
6	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *I personally select which problems get assigned to my students.*
7	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *When I get to class I already prepared the necessary materials.*
8	Indicate where you get exercises and problems. ☐ School mandated textbooks ☐ Other textbooks

[5] Italian high schools are characterized by the predominant study area. For example scientific, classical (ancient Greek and Latin), linguistic, technical, social sciences, etc.

	☐ Online archives ☐ Other
9	Do you use the same sources to find problems for regular activities and tests? ☐ Yes ☐ No ☐ Other
10	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *Before I assign a problem to my students, I always read it.*
11	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *Before I assign a problem to my students, I solve it.*
12	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *Problems that get assigned to my students have the solution written below or next to them. [Not including tests.]*
13	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *Problem solving is the main activity used for assessment in my classes.*
14	Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree] *When I select problems for written tests, I pay attention to the continuity with problems solved during the course.*
15	Indicate how influent the correctness of each component is to your evaluation of a problem solving task. [1 – Very little, 2 – Little, 3 – Quite, 4 - A lot] 1. Quantitative result 2. Diagrams and other representations 3. Calculations and mathematical procedures 4. Discussion 5. Unit analysis
16	Indicate how influent the presence of each component is to your evaluation of a problem solving task. [1 – Very little, 2 – Little, 3 – Quite, 4 - A lot] 1. Quantitative result 2. Diagrams and other representations 3. Calculations and mathematical procedures 4. Discussion 5. Unit analysis
17	For each of these tasks, indicate how frequent it is in the exercises and problems you habitually use. [1 – Never; 4 - Often] List Remember Summarize Discuss Select Calculate/determine

	Compare Assemble Identify Reorder Estimate Explain Evaluate	Design Invent Evaluate your knowledge/understanding Find the error Correct the error Communicate Represent

Survey #2

Items marked (*) denotes "negative" items.

#	Survey item
Multiple perspectives in Problem Solving (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
1 (*)	When I assign my students a problem, I expect that most of them will use the same approach to solve it.
2 (*)	When I assign my students a problem, I have in mind an approach to solve it that I expect my students to use.
3 (*)	When I approach a problem with my students, I try to have them solve it the same way I would.
4	When I approach a problem with my students, before starting, I ask them to describe possible strategies for solving it.
5	I make an effort to encourage my students to propose new ways to look at a problem.
6 (*)	After finding a solution with my students, we rarely discuss other possible ideas.
7 (*)	When I introduce a new problem, I expect my students to use an approach they already know.
8 (*)	When I introduce a new problem, I suggest that my students use an approach they already know.
9	For every problem, it is important to consider all possible approaches.
Metacognitive dispositions (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
10 (*)	While learning, one cannot evaluate their own understanding of new material.
11	I can recognize areas of Physics where my understanding is incomplete.
12 (*)	I have difficulty in determining how well I understand a topic without an external feedback.
13	I often feel the need of receiving feedback, from students or colleagues.

14 (*)	I rarely get evaluated.
15	I often self-evaluate.
Goals and beliefs – Physics (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
16	Challenge stimulates me.
17 (*)	I feel uncomfortable when I cannot solve difficult problems.
18	One can increase their level of expertise in any area if they are willing to try.
19	Expertise can be developed through hard work.
20 (*)	When I think of my students, I know that some of them will never be successful in Physics.
21 (*)	To become an expert in Physics, you must have an innate talent for Physics.
22 (*)	Experts in Physics are born with a natural talent for their field.
23	Even if frustrated when working on a difficult problem, I can push on.
Goals and beliefs – Teaching Physics (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
24	When I'm teaching, challenge stimulates me.
25 (*)	When I'm teaching, I feel uncomfortable when I cannot solve difficult problems.
26 (*)	When I'm teaching, I am afraid to try tasks that I do not think I will do well.
27 (*)	Although I hate to admit it, I would rather have my students solve a problem successfully than fully understand it.
28	One can become a better teacher through hard work.
29 (*)	To become an expert teacher, you must have an innate talent for teaching.
30 (*)	Expert teachers are born with a natural talent for teaching.
31	When I'm teaching, even if frustrated when working on a difficult situation, I can push on.
32 (*)	When I'm teaching, I feel uncomfortable when unsure if I am approaching a situation the right way.
33 (*)	When I struggle, I wonder if I'm fit for teaching.
Epistemology (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
34	Knowledge that exists today may be replaced with a new understanding tomorrow.
35	Scientists are always revising their view of the world around them.
36 (*)	Most knowledge that exists in the world today will not change.
37 (*)	Facts that I teach in class must be true.
38 (*)	Existing knowledge in the world seldom changes.

39	Scientific theory slowly develops as ideas are analysed and debated.
40	Scientific knowledge is developed by a community of researchers.
41 (*)	Scientific knowledge is discovered by individuals.
42 (*)	Progress in science is due mainly to the work of sole individuals.

Survey #3

Items marked (*) denotes “negative” items.

#	Survey item
Personal data	
1	Name Surname
Development of Adaptive Expertise (Indicate your agreement with the statement: [1 – completely disagree; 6 – completely agree])	
2	I gained a better understanding of concepts in the field of the training program.
3	When I was provided with suggestions, I was able to incorporate other people’s ideas into my work.
4 (*)	My understanding of concepts in my field did not change.
5 (*)	I realized that once you become an expert teacher, you do not need to continue learning in order to stay an expert.
6 (*)	I realized that knowledge in Physics education is set and does not change.
7	I focused on new challenges.
8	I focused on developing new approaches to solving problems.
9	I focused on developing new approaches to posing problems.
10	I looked for unfamiliar tasks.
11	I was able to draw on prior knowledge to perform the proposed tasks.
12	During the program, I applied knowledge I learned in previous teachers’ training courses.
13	I showed that I am willing to keep learning new information and skills related to my field.
14	I was able to see how knowledge I learned in the Atelier related to what I had learned in the past.
15	I took expertise from one context and applied it to another.
16 (*)	My prior knowledge was not helpful when performing unfamiliar tasks.
17	I was able to recognize what can help me add to my knowledge of Physics teaching.

18 (*)	When I received feedback, I did not find other people's suggestions or ideas to be helpful to my work.
19 (*)	I did not often monitor my own performance on tasks.
20	I kept trying to learn new things, even if I didn't succeed right away.
21	I enjoyed the challenge of learning difficult new things.
22(*)	When trying to learn something new, I gave up if I was not initially successful.
Final evaluation	
23	State the district of school where you teach.
24	Indicate the type of school: ☐ Liceo scientifico (science-oriented upper secondary school) ☐ Altro Liceo (non-science-oriented upper secondary school) ☐ Istituto tecnico (technical institute) ☐ Istituto professionale (vocational school) ☐ None of the above
25	Indicate your role in the school: ☐ Teacher ☐ Substitute teacher ☐ Other (not a teacher)
26	Indicate your degree: ☐ Physics ☐ Mathematics ☐ Engineering ☐ Not yet obtained
Evaluate: [1 – Scarce; 5 – Good]	
26	Coherence between contents and stated goals of the program.
27	Coherence between contents of the program and professional interests.
28	Transferability of contents to classroom activities.
29	Your appreciation for the activities.
30	Teaching style of tutors.
31	Time management in relation to the goals of the course.
32	Space allocated for questions, comments, observations.
33	Mastery of the content covered and clarity of presentation.
34	Classroom management: communicative and relational skills with working groups
35	Availability of the trainers outside of class.
36	Quantity of materials.
37	Quality of materials.
38	Quality of communication and media (Google Drive, slides, recordings, …)
Applicability/Application of the content to teaching practice	
39	Have you ever used the non-traditional problem types presented in the Atelier? ☐ Yes

	☐ No
40	Is yes, how? ☐ During class ☐ Homework ☐ Written tests ☐ Other
41	If not, are you interested in starting to use non-traditional problems? ☐ Yes ☐ No
42	Which of the ten non-traditional problem types have you used/are you most interested in using? ☐ Jeopardy ☐ Ranking tasks ☐ Choose an answer and explanation ☐ Choose a measuring procedure ☐ Evaluate ☐ Make Judgement based on data ☐ Linearization ☐ Multiple choice and tell all ☐ Design an experiment ☐ Problem based on real data
43	Do you currently tools to assess scientific abilities? ☐ Yes ☐ No
44	Do you currently tools for auto-evaluation? ☐ Yes ☐ No
45	Have you ever used problem solving tasks to assess scientific abilities? ☐ Yes ☐ No
46	If not, are you interested in doing so? ☐ Yes ☐ No
47	How would you evaluate the importance given to scientific abilities *before* participating in the Atelier? [1 – Little; 5 – A lot]
48	How would you evaluate the importance given to scientific abilities *after* participating in the Atelier? [1 – Little; 5 – A lot]
Future planning	
49	Is it the first time you participated in a ISLE-based training program? ☐ Yes ☐ No
50	Are you interested in participating to future ISLE-based activities similar to the Atelier? ☐ Yes ☐ No
51	Which of the following areas of the ISLE approach are you more interested in learning? ☐ Specific disciplinary content ☐ Methodology ☐ Learning process ☐ Laboratories ☐ Other

52	What were the main difficulties you encountered in following the training course? (timing, overlap with school commitments, forgetting, …)
53	Have you already used the ISLE materials provided during the sessions? If yes, what were the main difficulties you encountered? If no, what are the reasons that make it difficult to use them?
54	In your opinion, what would be the best formats for running this type of training course? (sessions spread over time, full working days, a multi-day summer school, …)
55	This space is open. We welcome advice, suggestions, comments, and observations about the materials presented to you, the topics discussed during the sessions, and the structure of the training course.

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