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Abstract

The importance of reducing the incidence of low achievement is clearly recognized by the European Union, which – within its strategic framework for European cooperation in education and training – has set the objective of reducing the share of low-achieving 15-year-olds in mathematics, reading and science below 15% by 2020. This report uses data from the 2015 OECD Programme for International Student Assessment (PISA) to analyse the relationship between teaching practices – teacher-directed instruction, enquiry-based teaching, and adaptive instruction – and the likelihood that students are low achievers in science. Results show that teaching practices are strongly related with the probability of being a low-achieving student. Moreover, some complementarity exists between teaching practices. Properly combining different instruction methods leads to lower levels of underachievement in science. In particular, better outcomes are found in situations with high levels of adaptive instruction and teacher-directed methods, and medium intensity of enquiry-based practices.

1 Introduction

Key competences and basic skills are needed by all for personal fulfilment and development, employability, social inclusion and active citizenship. With a view to ensuring that all learners attain an adequate level of basic skills, the 2009 strategic framework for European cooperation in education and training (ET 2020) set a European benchmark establishing that by 2020, the share of low-achieving 15-year-olds in reading, mathematics and science should be less than 15%. Low achievement is measured by the OECD Programme for International Student Assessment (PISA), which defines low achievers as those students who score below the baseline level of proficiency (Level 2) on the PISA mathematics, reading and/or science scales. The latest PISA 2015 science scores show that in the European Union (EU) as a whole, an average of 20.6% of 15-year-olds were low achievers in science, that is 5.6 percentage points above the benchmark (European Commission, 2016a). Moreover, large differences exist among EU Member States (MS). In fact, only Estonia and Finland have shares of low achievers that are below 15%, while Bulgaria, Romania and Cyprus have values above 35% ([1]). What is even more alarming is that, compared to 2012, in most MS the share of low achievers in science has gone up, with only three countries (Denmark, Portugal and Sweden) showing some signs of improvement.

Overall, this indicates that the EU is facing a double challenge, with large within- and between-country inequality in student performance. These inequalities do not work in favour of a cohesive Europe, and vast across-country differences in human capital measured at the beginning of secondary education are likely to be reflected or expanded by tertiary education. Hence, reducing the share of low achievers is clearly an important objective for the EU as well as for individual MS, if they intend to guarantee fair opportunities in life to all, starting from education.

Factors such as socio-economic status and immigrant background are widely acknowledged to be among the key determinants of students' performance. However, the role of education policies, schools, and teachers in promoting high student performance is also increasingly recognized (IEA, 2016; Hanushek and Woessmann, 2014). In fact, education policy is one of the most important factors in breaking the cycle of the low socio-economic status of one generation leading to a low educational attainment, which then leads to low socio-economic status of the next generation (i.e. to low social mobility; see Stuhler, 2018). Among educational policies, teaching quality is universally recognized as a decisive factor in determining students' achievement. This is even more true for students that are low achievers and for those that come from disadvantaged socio-economic background, since typically they cannot find a supportive environment for learning at home; for them, teaching quality can really be a determinant factor in shaping their future lives. However, teaching quality is a multidimensional object that includes many aspects, such as skills and qualifications, experience and attitudes, and teaching instructional methods and practices used in class. The latter refer to the activities performed in class by teachers, which include organization of instructional time and educational resources as well as specific activities and strategies proposed and adapted to students' characteristics.

Previous studies that use data from international large-scale assessments (see Isac et al., 2015) show the positive relationship between teachers' use of cognitive activation teaching strategies and students' achievement in mathematics. Costa and Araujo (2018) found a positive relationship between students' science achievement and teacher-directed instruction, as well as with a more basic level of scientific enquiry. Using PISA 2015 data for participating EU Member States, this report builds on the knowledge base from these previous studies, by considering teaching practices that are specific to science teaching and their relationship with the likelihood of being a low achiever; it focuses on

([1]) Results are a bit more reassuring if we look at the shares of students that are low achievers in all domains at the same time. In this case the EU average is 12.3%, with Estonia and Finland remaining the best performing countries, while the highest values are found for Romania, Bulgaria and Cyprus.

investigating possible complementarities and non-linearities in the relationship between learning outcomes and teaching practices. PISA captures the learning environment in science classrooms by asking students and school principals questions about the frequency of school-specific science activities and related conditions for learning. Given the focus on science test scores, the most relevant teaching practices are teacher-directed instruction, enquiry-based instruction, and adaptive instruction.

Teacher-directed and enquiry-based instruction ([2]) methods refer to instructional practices that are specific to the way teachers teach science (OECD, 2016c). The first encompasses well-structured and informative lessons that include teachers' explanations of concepts, classroom debates and students' questions. The students have a predominantly passive role in the acquisition of this knowledge. In contrast, enquiry-based teaching refers to science activities that lead students to study the natural world and to explain scientific ideas by engaging in experimentation and hands-on activities. Although the students have a predominantly active role during these activities, they are often guided by their teachers, who ask leading questions and model the thought processes involved in science enquiry (Hanauer et al., 2009; OECD, 2016c). Thus, as defined in PISA, during enquiry-based teaching students are actively doing laboratory work and carrying out experiments. Nonetheless, enquiry-based teaching can also include teacher-directed aspects, such as asking students to make specific observations and reach predefined conclusions and/or requesting predictions and explanations of phenomena (OECD, 2016c; Wenning, 2007). Adaptive instruction refers to the teachers' flexibility in adapting the lessons to students with different knowledge and abilities. While this is not specific to science teaching, it is very important when focusing on the learning outcomes of different groups or sub-groups, such as low achievers: ideally, low achievers would gain when teachers adapt the learning environment and the teaching style to the fact that they start from a lower level of knowledge or that they exert a lower level of effort, when compared to average or even high achievers.

To understand how teaching practices relate to students' achievement (the status of low achiever in our case), in our analysis we include other teaching effectiveness dimensions, such as learning hours ([3]). Moreover, we take into account student and classroom input factors (i.e. gender, socio-economic status, immigrant status, class size, motivation level and perceived feedback) to control for student background and structural system-level educational factors that may be related to science learning outcomes.

The analysis provided in this report aims to provide evidence to support policy initiatives focussing on high-quality teaching, which can improve the effectiveness of education and training systems thereby raising the skills levels in the population (European Commission, 2015).

This report proceeds as follows. Section 2 summarizes the literature on teaching practices and learning outcomes, with a special focus on students with low abilities and/or low socio-economic status. Section 3 presents the data and the models used in the empirical analysis. Section 4 provides summary statistics on the relevant variables. Section 5 presents the results of our different models, and Section 6 concludes.

([2]) "Enquiry" and "inquiry" have the same meaning. While the latter is more commonly used in the literature, the OECD uses the term "enquiry" for the index built in PISA; as a consequence, as a rule we use the same terminology as in PISA, although the two terms can be used interchangeably.

([3]) Other more general conditions for learning that are not specific to a given subject or discipline can also affect the effectiveness of teaching (Kyriakides et al., 2014), such as teacher support and disciplinary climate, but these are not the focus of this study (on these aspects see Costa and Araujo, 2018).

2 Literature review

Education policies, schools and teachers are fundamental drivers of students' performance. While the literature on the relationship between educational policies, schools, teachers and students' outcomes is extensive, this literature review focuses mostly on teaching practices and the differential role they might have for students with different learning abilities.

In this report, we focus on three main teaching practices, namely teacher-directed instruction, enquiry-based instruction, and adaptive instruction.

As previously indicated, one of the most debated issues in the area of science teaching/learning is that of the role of enquiry-based (EB) methods. The National Science Education Standards (National Research Council, 1996) describes enquiry as a set of science practices: "*Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations*". (p. 23)

It is not easy to map these indications about *science practices* into a set of *teaching methods*. However, there seems to be some consensus that EB teaching involves less the teacher and more the students, who are expected (to a certain extent) to analyse existing evidence, frame a proper research question deriving some form of testable hypothesis/hypotheses, gather relevant data and information/samples etc., and use such data and info to test the hypothesis/hypotheses consistent with the research framework. This is seen by science education communities (e.g., American Association for the Advancement of Science, 1994; European Commission, 2007) as a natural way of stimulating and improving students' critical thinking in science.

Enquiry-based science teaching is characterised by activities that are student-initiated, for example: (1) authentic and problem-based learning activities where there may not be a correct answer; (2) a certain amount of experimental procedures, experiments and hands-on activities, including searching for information; (3) self-regulated learning sequences in which student autonomy is emphasised; (4) discursive argumentation and communication with peers ("talking science") (Jorde et al., 2012). The role of the teacher in this is often left undefined: students have a predominant role but teachers can (more or less intensively) support and guide them. We expect teachers to have a different role than the one they have in more traditional practices, where they transfer knowledge through face-to-face relationships and ask students to memorize the content of what is discussed in class. The main point of the EB method is that students have an active role, through their participation to the various phases of scientific experiments, and that it may involve some teacher-led activities. In fact, the PISA measurement of enquiry-based teaching also includes teacher-directed aspects ([4]).

When evaluating the impacts of EB instruction on students' achievement, the evidence is mixed and a negative relationship between measures of EB instruction and learning outcomes is not uncommonly found. Direct instruction models that are teacher-centred encompass well-structured lessons and have been shown to have a positive impact on students' achievement (Mayer, 2004). On the other hand, the meta-analysis by Minner et al. (2010) documents that students' active thinking and responsibility for learning within the investigation cycle (i.e., generating questions, designing experiments, collecting data, drawing conclusion, and communicating findings), is associated with improved student content learning, especially learning scientific concepts (see also Schroede et al.,

([4]) The PISA definition of enquiry in science teaching is about the students initiating science activities, such as designing their own experiments and raising their own questions for investigation. This reflects the notion that "*students should engage in science using the same methods and approaches similar to those that scientists use to carry out scientific investigations*" (Gee and Wong, 2012, p. 303).

2007). However, Minner et al. (2010) find no significant association between instruction practices and learning outcomes, and meta-analyses that have measured the impact of both teacher-initiated and student-initiated science activities find larger mean effect sizes for teacher-initiated activities than for those with student-led conditions (Furtak et al., 2012; Cairns and Areepattamannil, 2017).

In fact, some researchers have argued that student-led investigations may lack the kind of teacher-led instructional guidance that promotes learning (Flick and Lederman, 2004; Jiang and McComas, 2015; Kang and Keinonen, 2017). In particular, Jiang and McComas (2015) use data from PISA 2006 to identify a (potentially) causal relationship between a measure of EB instruction and students outcomes, as measured by PISA tests scores in science. They do not use the index for EB instruction proposed by PISA but they develop their own measure (following the contribution by Shulman and Tamir, 1973), which defines five levels of openness in enquiry instruction, based on teachers' and students' involvement in four enquiry components: (1) conducting activities, (2) drawing conclusions, (3) designing investigations, and (4) asking questions ([5]). The authors then map PISA students' background information regarding science learning and teaching into the five possible levels of prevalence of enquiry teaching, where the mapping should reflect the levels of intensity of EB instruction and not so much their frequency. Particularly interesting is the finding that the highest learning outcomes in PISA are found for EB teaching level number 2, which corresponds to students conducting activities and drawing conclusions, but not designing investigations or asking questions. This level reflects a balance between teacher-directed instruction and enquiry-based instruction in which students conduct activities and draw conclusions from data, but teachers design investigations and ask.

Similarly, Valente et al. (2011), with data for eight countries that participated in PISA 2006, report that a higher frequency of investigations in science teaching and learning tend, on average, to be associated with lower achievement. However, in the same countries, students who report high levels of participation in application models in science have higher science scores. As the authors conclude, hands-on activities related to the latter can be positively related to science achievement, but student-initiated investigations whereby students design their own experiments, choose an experimental design and test their own hypotheses are negatively associated with achievement in science.

As for the most recent OECD study using PISA 2015, the results indicate that, on average, across OECD countries, "*greater exposure to inquiry-based teaching is negatively associated with science performance in 56 countries and economies*" (OECD, 2016c, p. 71). On the contrary, using teacher-direct instruction more frequently is associated with higher science achievement, after controlling for the socio-economic status of students and schools (OECD, 2016c, p. 65).

Teig et al. (2018) test the hypothesis that the relationship between EB instruction and learning outcomes might be non-linear. Using data from Norwegian TIMSS (Trends in International Mathematics and Science Study) 2015 the authors indeed find evidence of a concave relationship, indicating that higher values for enquiry-based instruction are correlated with higher achievement in science only up to a threshold value (i.e. there exists an optimal value for EB instruction). Above this optimum value, higher intensity in EB instruction is associated to lower learning outcomes. This nonlinear pattern is interpreted as an indication that excessive use of enquiry strategy in science classrooms may have diminishing returns in terms of students' performance.

These results are consistent with the intuition that if students are left on their own to solve problems and to independently select and carry out investigations, their efforts may be counterproductive (see Kirshner et al., 2006). That is, their learning of scientific

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([5]) These elements capture the following four basic questions: (1) Do students conduct the activities by themselves? (2) Do students make conclusions from data by themselves? (3) Do students design the investigation by themselves? (4) Do students raise the question for investigation by themselves?

facts and ideas may be inhibited rather than enhanced by "high level" EB instruction, because such processes place cognitive demands on students that they cannot handle. In fact, "high levels" of EB instruction might have different effects for student with different levels of knowledge, skills and motivation, e.g. for high vs. low achievers ([6]).

We read these results as an indication that a sharp dichotomy in instructional modes that are either teacher-led or student-initiated offers too narrow a view of what really happens in the science classroom and its relation with students' achievement.

Indeed, research offers empirical evidence that different levels of enquiry need to be considered to understand the relationship between quality of science teaching and learning (Furtak et al., 2012; Minner et al., 2010). In particular, Furtak et al. (2012) propose to distinguish between a cognitive and a guidance dimension of enquiry-based teaching. The cognitive dimension refers to the cognitive demand placed on the students and they identify four main cognitive dimensions of enquiry-based teaching: the conceptual domain (facts, theories and principles of science), the epistemic domain (how science is generated), the social domain (how students participate to scientific practices), and the procedural domain (the methods used in scientific domain). For the guidance dimension, they argue that there is a continuum of enquiry-based teaching methods, with teacher-led traditional instruction at one extreme, student-led enquiry on the other, and various forms of teacher-guided instruction in the middle.

Following their conceptual approach, Furtak et al. (2012) conduct a meta-analysis and find that: (1) on the cognitive dimensions, engaging students in generating, developing and justifying explanations are important elements of science learning; (2) on the guidance dimension, teacher-led enquiry tends to affect more positively students' performance than student-led enquiry. These two findings, put together, allow us to conclude that teachers do have a very important role in shaping the way in which the cognitive dimensions of enquiry-based learning are activated. However, in their contribution, Furtak et al. (2012) do not frame the analysis in terms of complementarity between teaching practices.

As for the role of adaptive instruction, there exists a vast literature debating the importance of tailoring teaching methods to the preferences and abilities of students. In particular, this literature has stressed that optimal instruction should be tailored to the "learning styles" of students, under the hypothesis that learning would improve if the teaching style (including level and intensity) is close to the preferred learning style and to students' level of ability. This has given rise to various attempts to define learning styles, in terms of preferred information type (abstract vs. concrete), presentation style (pictures vs. speech vs. words), learning action (active vs. reflective) or mental activity (analysis vs. listening). However, an undisputed definition of what constitutes a learning style has not been reached ([7]). While there exists a consistent literature that provides evidence on perceived differences in preferred learning styles among students (Pashler et al., 2009), or on improved satisfaction by students when learning is adapted to learning preferences (Akbulut and Cardak, 2012), there is no generalized consensus that adapting teaching to the preferred learning style also improves learning outcomes (see Pashler et al., 2009 and Murray and Perez, 2015; exceptions are Houtveen et al., 1999 and Gomendio, 2017, who find that the use of adaptive instruction is positively associated with students' test scores).

To sum up, we think that there exists sufficient evidence indicating that the relationship between learning outcomes, teacher-directed and enquiry-based instruction is complex and likely to be non-linear. On the one hand, enquiry activities in science classrooms are beneficial for student learning, by emphasising the development of critical scientific thinking. On the other one, enquiry-based instruction is a process that emphasises

([6]) Interestingly, Zohar and Dori (2003) find that efforts by science teachers to stimulate high order thinking have positive and relevant impacts on the improvement of learning outcomes of low achievers.

([7]) Keefe (1979), p.1, defines learning styles as "a set of cognitive, emotional, characteristic and physiological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment".

students' cognitive capacity (see Stull and Mayer, 2007), with effects that might be different for students with different abilities and skills.

The literature points out (1) that there could be an "excessive" level of EB instruction intensity, but this level might also depend upon other teaching practices (*in primis* teacher-directed instruction); (2) that this level might be different for different students and (3) that teacher-directed instruction could well complement ([8]) EB instruction by providing a common ground of shared knowledge over which experiments can be successfully performed; (4) that teaching methods that adapt to the differences among students might be especially important in fostering (science) learning by students experiencing difficulties (i.e. low achievers). In particular, the complementarity between teacher-directed and EB instruction, by lowering the cognitive pressure on students, is likely to be especially beneficial for low achievers. The rest of this report is therefore devoted to investigating the extent to which the different teaching practices are complementary in fostering the learning outcomes of students, and low achievers in particular, and what levels of intensity in each of them is associated to better outcomes in science scores.

([8]) In this context, complementarity means that the effect of one teaching practice depends on the extent to which it is combined with other practices. The implication of this is that the "impact" of a given practice cannot be estimated in isolation and it will depend upon the other complementary practices as well.

3 Methodology

3.1 Data source and variables

The analysis presented in this report is based on the PISA 2015 dataset. PISA is an international large-scale assessment conducted by the Organization for Economic Co-operation and Development (OECD) and is designed to measure students' ability to use or apply the knowledge acquired in school to solve problems they might encounter in everyday life. In short, the main aim of PISA is to assess the cognitive skills that are necessary for adult life. Accordingly, its target population consists of 15 years-old students. PISA was launched for the first time in 2000 and since then the OECD has been running the international large assessment of students' skills in mathematics, science and reading every three years. PISA offers comparative indicators of students' achievement and has been used to monitor educational systems worldwide. One of the central purposes of PISA is to collect and report trend information about students' performance enabling countries to monitor their progress in meeting key learning objectives. Each PISA assessment cycle has a main domain, which in 2015 (the latest available) was science. PISA students' test scores in mathematics, science and reading are calculated according to Item Response Theory with scores scaled as an OECD mean of 500, set in the first cycle of the survey, and a standard deviation of 100. Starting from the score points, seven proficiency levels are identified on the scientific literacy scale, with the purpose of characterising typical student performance at each level and simplifying comparisons across groups of students; each proficiency level requires a certain set of competencies, knowledge and understanding to be completed successfully ([9]).

PISA also gathers contextual information through the application of questionnaires to the students and to school principals ([10]). The PISA design includes information on teaching and learning and allows for establishing relationships among cognitive and non-cognitive domains. Information about teachers' beliefs, attitudes and pedagogical practices are collected both in the students' and in the schools' questionnaires. These data collection instruments capture the perceptions students have of their teachers and their teaching practices and, in the case of the school questionnaire, they capture the perceptions of principals about the teaching practices of their staff in the sampled schools.

Science literacy in PISA is defined as "*the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourse about science and technology, which requires the competencies to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically*" (OECD, 2016a, p. 13).

The PISA 2015 assessment framework is conceptualised to capture how science teachers teach science and how they use both teacher-directed instruction and enquiry-based practices (OECD, 2016a). The first relates to activities that are teacher centred or teacher-initiated. For example, the teacher takes the lead and is the one who conducts experiments and asks questions. Accordingly, teacher-directed science instruction refers to the delivery of "*clear and informative lessons on a topic, which usually includes teacher's explanations, classroom debates and students' questions*" (OECD, 2016c, p. 63). Enquiry-based instruction is defined in the PISA assessment framework as the type of instruction that calls for real-life applications. OECD defines it as follows: "*In science education, enquiry-based instruction is about engaging students in experimentation and hands-on activities, and also about challenging students and encouraging them to develop a conceptual understanding of scientific ideas*" (OECD, 2016c, p. 69). Nonetheless, the PISA definition of enquiry also refers to having students develop a conceptual understanding of scientific ideas. Accordingly, those activities that relate to real-life applications are also considered enquiry-based instruction, even if they are

([9]) http://www.oecd.org/pisa/summary-description-seven-levels-of-proficiency-science-pisa-2015.htm
([10]) Four additional were offered in PISA as optional: a computer familiarity questionnaire, an educational career questionnaire, a parent questionnaire, and a teacher questionnaire.

teacher-directed or teacher-initiated. Specifically, whereas in PISA "the teacher explains scientific ideas" is considered teacher-directed science instruction (OECD, 2016c, p. 63), "the teacher explains how a science idea can be applied to a number of different phenomena" is an enquiry-based practice (OECD, 2016c, p. 71).

On a parallel ground, adaptive instruction refers to the teachers' flexibility in adapting the lessons to students with different knowledge and abilities. While this is not specific to science teaching, and it is hence compatible both with teacher-directed and enquiry-based methods, we think that adapting the level of instruction to the knowledge, skills and ambitions of students might have relevant impacts on the learning outcomes of low achievers.

Table 1 presents an overview of the three teaching practices considered.

Table 1. Teaching practices/strategies for science

Teacher-directed science instruction	Well-structured and informative lessons that include teachers' explanations of concepts, classroom debates, and students' questions
Enquiry-based science instruction	Science activities that lead students to study the natural world and to explain scientific ideas by engaging in experimentation and hands-on activities
Adaptive instruction in science lessons	Teachers' flexibility in adapting the lessons to students with different knowledge and abilities

In practice, three PISA indices were used, constructed by OECD using students' responses to multiple questions, which are then aggregated into a continuous scale with approximately mean of 0 and standard deviation of 1. These three indices measure, respectively, the intensity of teacher-directed science instruction (TDTEACH), enquiry-based instruction (IBTEACH), and adaptive instruction (ADINST) ([11]).

Table 2 describes the variables that are used to construct the three indices, taking into account that the latter also reflect the frequency with which the various activities are carried out, as reported by the students ("never or almost never", "some lessons", "many lessons" or "every lesson or almost every lesson"). Higher values for these indices indicate that the activities/practices happened more frequently in science lessons.

It is worth noticing that TDTEACH and IBTEACH are not measuring alternative practices. What this means is that a high value of TDTEACH can coexist with a high value of IBTEACH, as the two measure different and potentially complementary practices. In fact, one of the purposes of this report is to test the extent to which the two practices are complementary in fostering the learning outcomes of students, and low achievers in particular. This reflects our belief that the science teacher has an important role in shaping the knowledge base and guide students through their learning experience. On the other hand, learning is likely to be more effective when students are more directly involved in science discovery.

([11]) Detailed information can be found in OECD (2016c) and here.

Table 2. PISA variables measuring teaching practices

Name of the variable	Questions/Items/Variables
Teacher-directed Science instruction (**TDTEACH**)	**How often do these things happen in your lessons for this <school science> course?** - The teacher explains scientific ideas - A whole class discussion takes place with the teacher - The teacher discusses our questions - The teacher demonstrates an idea
Enquiry-based instruction (**IBTEACH**)	**The teacher explains how a Science idea can be applied to a number of different phenomena** - Students are given opportunities to explain their ideas - Students spend time in the laboratory doing practical experiments - Students are required to argue about science questions - Students are asked to draw conclusions from an experiment they have conducted - The teacher explains how a science idea can be applied to a number of different phenomena - Students are allowed to design their own experiments - There is a class debate about investigations - The teacher clearly explains the relevance of science concepts to our lives - Students are asked to do an investigation to test ideas.
Adaptive instruction (**ADINST**)	**How often do these things happen in your lessons for this <school science> course?** - The teacher adapts the lesson to my class' needs and knowledge; - The teacher provides individual help when a student has difficulties understanding a topic or task; - The teacher changes the structure of the lesson on a topic that most students find difficult to understand.

Given that the amount of time devoted to science learning is often found to have an important impact on learning outcomes (Lavy, 2015), we also investigate this factor in our analysis; in particular, we use the number of learning hours per week in science, constructed using the variable SMINS (Learning time – minutes per week – in science, computed by multiplying the number of minutes on average in the test language class by the number of test language class periods per week).

Besides these main variables of interest, we control for a number of student and classroom input factors, namely gender, socio-economic status, immigrant status, class size, motivation level and perceived feedback. Annex 1 provides the list of the reference variables in the PISA dataset that are used to capture this information, as well as the questionnaire where they are provided.

The student's socio-economic status is controlled for through the PISA Index of Educational, Social and Cultural Status (variable *ESCS*), which is derived from several variables related to students' family background: parents' education, parents' occupations, a number of home possessions that can be taken as proxies for material wealth, and the number of books and other educational resources available in the home. It is a composite score derived from these indicators via Principal Component Analysis, and it is constructed to be internationally comparable (OECD, 2016b).

Immigrant status is based on the index of immigrant background (variable *IMMIG*), and identifies immigrants as individuals who are either first- or second-generation immigrant students, i.e. those born outside the country of assessment and whose parents were also born in another country or those born in the country of assessment but whose parent(s) were born in another country.

As a measure of the context of instruction we include class size (variable *CLSIZE*). This variable refers to the average class size and is derived from one of nine possible categories in question SC003, of the principals' questionnaire, ranging from "15 students or fewer" to "More than 50 students".

The motivation level is proxied by the index of achievement motivation (variable *MOTIVAT*), which was constructed using students' responses to a new question developed for PISA 2015. Students reported, on a four-point Likert scale with the answering categories "strongly disagree", "disagree", "agree", and "strongly agree", their agreement with the following statements: "I want top grades in most or all of my courses"; "I want to be able to select from among the best opportunities available when I graduate"; "I want to be the best, whatever I do"; "I see myself as an ambitious person"; "I want to be one of the best students in my class". Higher values indicate that students have greater achievement motivation (OECD, 2016c).

The index of perceived feedback (variable *PERFEED*) was constructed from students' reports on how often ("never or almost never"; "some lessons"; "many lessons"; "every lesson or almost every lesson") the following happened in their science lessons: "The teacher tells me how I am performing in this course"; "The teacher gives me feedback on my strengths in this <school science> subject"; "The teacher tells me in which areas I can still improve"; "The teacher tells me how I can improve my performance"; "The teacher advises me on how to reach my learning goals" (OECD, 2016c).

The analysis is presented for 24 EU Member States ([12]), namely Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), the Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), the Netherlands (NL), Poland (PL), Portugal (PT), the Slovak Republic (SK), Spain (ES), and the United Kingdom (UK).

3.2 Models

The purpose of our analysis is to show how different levels of intensity and different combinations of the three teaching practices are associated with the estimated probability that a student is classified as a low achiever. To this end, we estimate a logistic regression model on the pooled sample of the 24 EU MS listed above, with country fixed effects, using probability weights. The dependent variable in the logistic regression is a binary variable equal to 1 if the student is a low achiever in science, and 0 otherwise (based on 10 plausible values). A low achiever (or low performer) is defined as a student performing below Level 2 on the assessment proficiency scale, which is considered the baseline level of proficiency ([13]).

The main variables of interest are the three teaching practices indices described in Table 2. Table 3 presents the two models that we estimate, with the purpose of modelling increasing levels of non-linearity and complementarity between the variables of interest. Non-linear relationships are taken into account through the use of squared terms, following Teig et al. (2018).

In the base model (Model 1) we include the three teaching practices indices and their squared terms. In the extended model (Model 2), we fully explore both the complementarity and non-linearity hypotheses, by adding two- and three-way interactions between teaching practices and their quadratic terms. This is intended to capture all the complementarities among the practices consistent with the hypothesis that their relationship with low achievement might be non-linear. In particular, we are

([12]) All 28 EU MS participated in PISA 2015; however, Malta, Romania, Slovenia and Sweden were excluded from the analysis due to non-availability of at least one of the variables used in the model.

([13]) According to OECD, in science, students scoring at Level 2 can draw on their knowledge of basic science content and procedures to identify an appropriate explanation, interpret data, and identify the question being addressed in a simple experiment. Low performers, on the other hand, may be able to use basic or everyday scientific knowledge to recognise or identify aspects of familiar or simple scientific phenomena; however, they also often confuse key features of a scientific investigation, apply incorrect scientific information and mix personal beliefs with scientific facts in support of a decision.

interested in testing whether enquiry-based teaching practices are complementary to teacher-directed and adaptive instruction. This would be the case if the possibility given to students to design and implement their own experiments is preceded (or followed) by the teacher explaining the contextual and cognitive elements that are relevant for the experiment, in a way that is tailored to the cognitive levels of the students. In other words, the efficacy of the students' experimental activity is enhanced by teachers' guidance. In such a case we would expect that increasing the intensity of students' experimentation without simultaneously increasing teachers' guidance and/or the level of adaptive learning would not lead to higher educational outcomes for low achievers.

In all models, we include also learning time, as well as the set of control variables described above (gender, socio-economic status, immigrant status, class size, motivation level and perceived feedback). As previously mentioned, all regressions include country fixed effects.

Table 3. Main explanatory variables in the two models

Variables of interest	**Model 1**	**Model 2**
Main effects		
Teacher-directed instruction	X	X
Enquiry-based instruction	X	X
Adaptive instruction	X	X
Squared terms		
(Teacher-directed instruction) ^{2}	X	X
(Enquiry-based instruction) ^{2}	X	X
(Adaptive instruction) ^{2}	X	X
Two-way interactions		
(Teacher-directed instruction) * (Enquiry-based instruction)		X
(Teacher-directed instruction) * (Adaptive instruction)		X
(Enquiry-based instruction) * (Adaptive instruction)		X
Two-way interactions with squared terms		
(Teacher-directed instruction) * (Enquiry-based instruction) ^{2}		X
(Teacher-directed instruction) * (Adaptive instruction) ^{2}		X
(Teacher-directed instruction) ^{2} * (Enquiry-based instruction)		X
(Teacher-directed instruction) ^{2} * (Enquiry-based instruction) ^{2}		X
(Teacher-directed instruction) ^{2} * (Adaptive instruction)		X
(Teacher-directed instruction) ^{2} * (Adaptive instruction) ^{2}		X
(Enquiry-based instruction) * (Adaptive instruction) ^{2}		X
(Enquiry-based instruction) ^{2} * (Adaptive instruction)		X
(Enquiry-based instruction) ^{2} * (Adaptive instruction) ^{2}		X
Three-way interactions		
(Teacher-directed instruction) * (Enquiry-based instruction) * (Adaptive instruction)		X
(Teacher-directed instruction) * (Enquiry-based instruction) * (Adaptive instruction)^2		X
(Teacher-directed instruction) * (Enquiry-based instruction)^2 * (Adaptive instruction)		X
(Teacher-directed instruction) * (Enquiry-based instruction)^2 * (Adaptive instruction)^2		X
(Teacher-directed instruction)^2 * (Enquiry-based instruction) * (Adaptive instruction)		X
(Teacher-directed instruction)^2 * (Enquiry-based instruction) * (Adaptive instruction)^2		X
(Teacher-directed instruction)^2 * (Enquiry-based instruction)^2 * (Adaptive instruction)		X
(Teacher-directed instruction)^2 * (Enquiry-based instruction)^2 * (Adaptive instruction)^2		X
Control variables	X	X
Country fixed effects	X	X

Because of the plausible values used in PISA (Mislevy et al., 1992), all estimates are obtained using multiple imputation methodology. This involved first fitting ten sets of models, each with one plausible value, and then aggregating the estimates using the Rubin's rule (Little and Rubin, 1987), as per OECD recommendations (OECD, 2007, p. 156).

4 Summary statistics

Table 4 presents the mean and standard error (S.E.) of the share of low achievers in science, of the three types of teaching practices, and of learning hours per week in science in the 24 EU MS considered in our analysis as a whole (EU24) and in each country ([14]). The table reveals that the share of low achievers in the 24 EU MS varies between 7.2% in Estonia and 34.5% in Cyprus. Considering the EU goal of reducing the share of 15-years-old that are low achievers in reading, maths and science below 15% by 2020 ([15]), we notice that in 2015 there were still 11 EU MS (out of 24) not yet fulfilling the EU benchmark.

Table 4. Average share of low achievers in science; average values for the three types of teaching practices and for learning hours in science, by EU MS

	Science									
	Share of low achievers		**Teacher-directed instruction**		**Enquiry instruction**		**Adaptive instruction**		**Learning hours**	
	Average	S.E.	Average	S.E.	Average	S.E.	Average	S.E.	Average	S.E.
AT	0.122	0.009	-0.003	0.021	-0.305	0.033	-0.295	-0.295	4.828	0.081
BE	0.097	0.006	-0.219	0.013	-0.220	0.017	-0.393	0.018	3.187	0.041
BG	0.261	0.016	-0.076	0.017	0.147	0.027	0.244	0.018	4.123	0.042
CY	0.345	0.010	0.212	0.017	0.411	0.014	0.111	0.014	3.098	0.027
CZ	0.151	0.008	-0.357	0.015	-0.054	0.018	-0.151	0.017	4.153	0.056
DE	0.094	0.009	-0.217	0.017	0.058	0.020	-0.223	0.019	3.958	0.083
DN	0.110	0.008	-0.141	0.016	0.356	0.018	0.289	0.022	3.446	0.047
EE	0.072	0.006	-0.053	0.015	-0.081	0.017	-0.184	0.017	3.665	0.043
EL	0.269	0.016	0.251	0.020	-0.105	0.029	0.056	0.027	3.777	0.039
ES	0.152	0.007	0.074	0.019	-0.253	0.022	0.150	0.024	3.792	0.046
FI	0.084	0.006	0.242	0.016	-0.308	0.018	-0.010	0.018	2.844	0.048
FR	0.136	0.008	-0.051	0.018	0.155	0.017	-0.297	0.019	3.201	0.044
HR	0.187	0.011	0.007	0.020	-0.203	0.020	-0.162	0.022	3.512	0.073
HU	0.207	0.012	0.008	0.021	-0.232	0.020	-0.118	0.022	3.399	0.049
IE	0.116	0.009	-0.010	0.022	0.012	0.018	-0.018	0.018	2.547	0.029
IT	0.186	0.012	-0.139	0.016	-0.221	0.022	-0.059	0.018	2.557	0.054
LT	0.206	0.010	0.017	0.018	0.169	0.013	-0.115	0.019	4.328	0.016
LU	0.193	0.007	-0.044	0.016	0.117	0.015	-0.313	0.015	3.323	0.025
LV	0.148	0.008	-0.025	0.014	0.127	0.015	0.192	0.018	4.314	0.042
NL	0.135	0.013	-0.265	0.021	-0.271	0.020	-0.074	0.024	5.166	0.096
PL	0.145	0.008	0.244	0.018	-0.077	0.024	-0.078	0.024	2.992	0.048
PT	0.145	0.011	0.368	0.022	0.311	0.021	0.546	0.020	5.060	0.109
SK	0.235	0.011	-0.376	0.016	-0.270	0.025	-0.240	0.018	3.196	0.061
UK	0.124	0.008	0.089	0.018	-0.029	0.017	0.164	0.018	4.842	0.046
EU 24	0.145	0.002	-0.016	0.005	-0.052	0.006	-0.066	0.007	3.658	0.020

Source: JRC computations on PISA 2015 data.

In what concerns to teaching instructional practices, Portugal is the EU MS where students reported the highest values for the index on teacher-directed instruction (i.e. where teacher-directed instruction happened more frequently). On the other hand, the Slovak Republic is the EU MS where the values for this index are lower. As for enquiry-based instruction, the highest values are found in Cyprus and the lowest in Finland. The index for adaptive instruction is, on average, higher in Portugal, with the lowest values reported in Belgium. Regarding the number of hours of science learning, Ireland is the EU MS where the students reported the lowest value (2.5 hours of learning of science per week), with the highest values found in the Netherlands (more than 5 hours of science lessons).

([14]) The means of the control variables per EU MS are presented in the Annex 2.
([15]) See May 2009 Council Conclusions on a strategic framework for European co-operation in education and training: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2009:119:0002:0010:en:PDF

5 Results

In this section we present the results on the relationship between the estimated share of low achievers, the three teaching practices and hours of learning in science in 24 EU countries ([16]). In particular, we first present (Section 5.1) the results from Model 1, where the three teaching practices and their square are considered, without allowing for any interaction between them. Then (Section 5.2) we present the results of Model 2, in which we allow for two- and three-way interactions between the three indices and their squared terms, showing how different levels of intensity of the three teaching practices are associated with the estimated probability that a student is classified as a low achiever.

5.1 A non-linear relationship between teaching practices and student performance

As a first step, we show the results of the logistic regression of Model 1, which, as mentioned above, includes the three teaching practices and learning hours, their squared terms, the set of control variables and country fixed effects. The regression (provided in Annex 3) shows that indeed there appears to be a non-linear relationship between the probability that a given student is a low achiever and the teaching practices investigated.

In order to better show these non-linear relationships, Figure 1 presents the marginal effects of each variable of interest as in Model 1 (see Annex 3), with the other control factors held fixed at mean values ([17]). The figure shows that, for the EU24 as a whole, the higher the intensity of both teacher-directed instruction and adaptive instruction, the lower the probability that a given student is a low achiever. The same is true for hours of learning, with more hours of science learning being related to a lower probability of being a low achiever. The strongest associations can be seen for teacher-directed instruction and hours of learning. In classrooms where teachers are using directed instruction very rarely the estimated share of low achievers is approximately 23%. However, in classrooms with a very high intensity for this practice, the estimated share of low achievers goes down to around 9%. A similar order of magnitude is found for hours of learning.

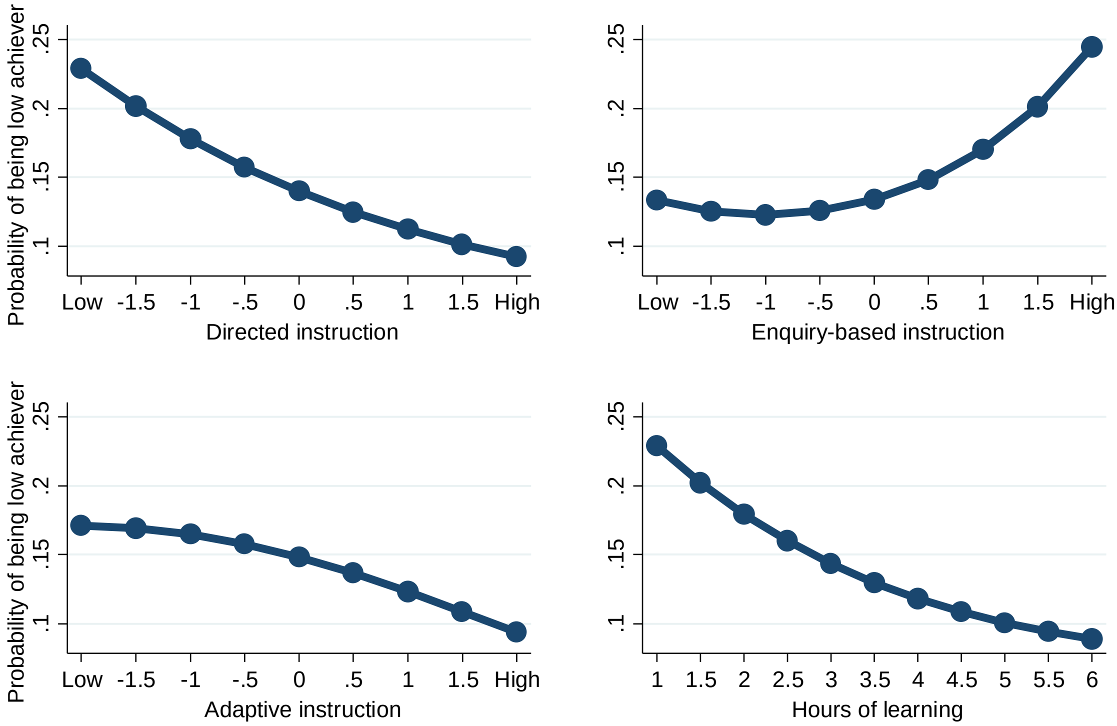
On the other hand, changing the intensity of adaptive instruction from very low to very high is associated with 8 percentage points lower chances of being low achiever (17 vs. 9%).

Interestingly, *ceteris paribus*, a higher frequency of use of enquiry-based instruction in the classroom appears to be associated with a higher probability of a student being classified as a low achiever, increasing from below 15% to 25%. It is also worth to notice that the estimated increase in the rate of low achievers refers only to the change from medium to high intensity of enquiry-based instruction, meaning that this teaching practice is associated with worse students' outcomes only when it reaches high intensity.

([16]) It should be highlighted that this report does not claim that there is any causality between the teaching practices and the probability of being a low achiever, as the study investigates associations between these factors rather than causal relationships.

([17]) For more details on the procedure used, see Williams (2012).

Figure 1. Relations between the expected share of low achievers in science, three types of teaching practices and hours of learning



Source: JRC computations on PISA 2015 data. The graphs show expected probabilities of being a low achiever at different levels of the four variables of interest, holding all other variables at the EU average. Estimates based on the logistic regression model described above (Model 1).

The relationships between low achievement on the one hand and teaching practices on the other one are largely confirmed when we look at individual EU MS (see Annex 4). In particular: (1) in 21 EU MS a higher intensity of teacher-directed instruction is associated with a lower probability of a student being a low achiever; (2) in 18 EU MS higher values for adaptive instruction negatively correlate with the probability that a given student is a low achiever; (3) the positive association between the probability of being a low achiever and the intensity of enquiry-based instruction is confirmed in 16 EU MS.

The fact that student-led investigations may lack the kind of teacher-led instructional guidance that promotes learning could explain the positive relationship between the intensity of enquiry-based instruction and the probability of being classified as low achiever. This might be especially relevant for low achievers, who would suffer the most if left on their own to solve problems and to independently select and carry out investigations (Flick and Lederman, 2004; Jiang and McComas, 2015): their learning of scientific facts and ideas may be inhibited rather than enhanced because such enquiry-based processes place on them cognitive demands that they cannot handle.

In the next section we consider the complementarity between different instructional practices for low achievers in the science classroom in EU MS.

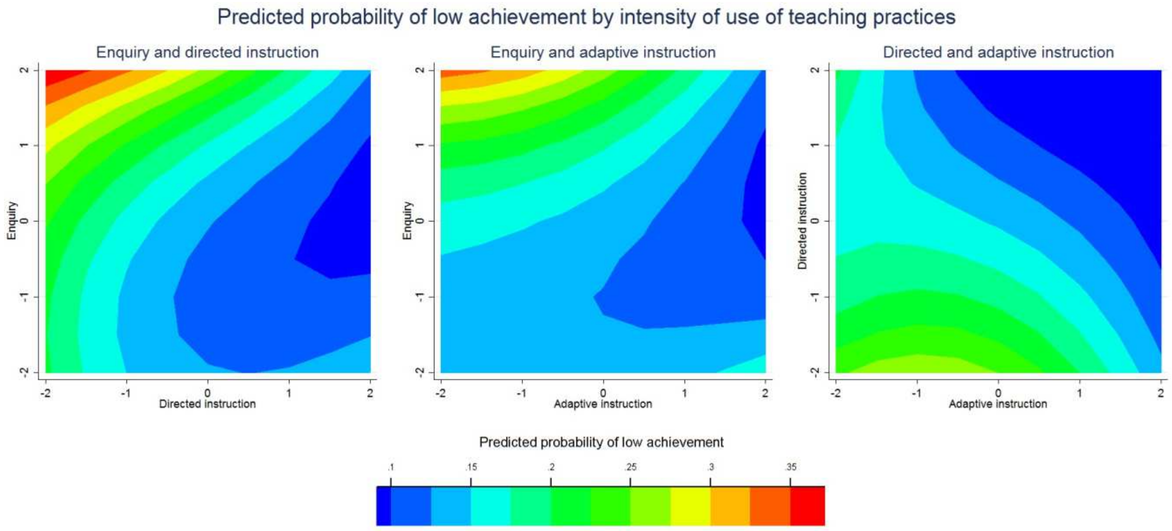
5.2 Complementarities between teaching practices

In this section we extend Model 1 to cover different levels of complementarity between the teaching practices under investigation, with the purpose of understanding the relevance of modelling this additional layer in our analysis. In particular, we explore the full complementarity hypothesis in a non-linear context by adopting Model 2, in which the two- and three-way interactions between teaching practices and their squared terms are added. The regression results for Models 2 are provided in Annex 3 ([18]).

The main results of Model 2 are the negative and significant interactions between teacher-directed instruction and enquiry-based instruction on the one hand and between enquiry-based instruction and adaptive instruction on the other one. Due to the many interaction terms included in the model, the regression results are quite complex and very hard to interpret; we therefore provide a graphical interpretation of the main results to facilitate their understanding. In Figure 2 we report the values for the likelihood of being a low achiever as a function of two teaching practices at a time ([19]). Each coloured area identifies a set of values for various combinations of two teaching practices that give the same probability of observing a student that is a low achiever (iso-probability areas). For instance, in the left-hand panel, the darker blue area identifies values for the teacher-directed (horizontal axis) and the enquiry-based (vertical axis) indices for which the probability of being a low achiever is the lowest (10%). On the other hand, the red area identifies combinations of values for the same two teaching practices that are associated with the highest probability (35%) of being a low achiever. Similar considerations apply to the other two graphs, where we look, respectively, at: (1) central panel: adaptive instruction (horizontal axis) and enquiry-based (vertical axis); (2) right-hand panel: adaptive instruction (horizontal axis) and teacher-directed (vertical axis).

We are especially interested in the light blue and dark blue areas, which correspond closely to the policy target of reducing the share of low achievers.

Figure 2. Combined relations between the expected share of low achievers in science and the three types of teaching practices



Source: JRC computations on PISA 2015 data. The graphs show expected probabilities of being a low achiever at different levels of the variables of interest, holding all other variables at the EU average. Estimates based on the logistic regression model described above (Model 2), using the 10 plausible values for the science score.

([18]) In order to evaluate the relevance of investigating complementarities between teaching practices, we estimate a number of models and use the Bayesian information criterion (BIC) to compare them. As a first step, we add to Model 1 each of the two-way interaction terms among our main variables capturing teaching practices separately. To explore the full complementarity hypothesis in a non-linear context we then move to Model 2, in which the two and three-way interactions between teaching practices and their squared terms are added. Annex 5 reports the measures of goodness of fit for all these models, showing a decrease in the BIC, and therefore a better fit of the model, with the inclusion of more interaction terms between the teaching practices considered. The best model identified is Model 2, which we therefore adopt as a basis for the subsequent analysis.

([19]) More in particular, predicted probabilities are projected into a two-dimensional space characterising regions with high and low probability of being low achiever depending on the level of two variables at a time. For doing this, we cut the values of each teaching practice index into 10 equal discrete values bands, and evaluate the predicted probability of low achievement in each of the 100 (10x10) resulting prediction regions.

Our graphical interpretation supports the hypothesis of complementarity between teacher-directed and enquiry-based teaching. While increasing the value of enquiry-based teaching alone has a positive association with the likelihood of being a low achieving student (and particularly so for low levels of the teacher-directed index), there is also a vast area in which teacher-directed and enquiry-based instructional methods can be combined to generate low (the light blue area) and very low (the dark blue area) probabilities of being a low achiever. These two teaching practices seem to work well together when they have values that are not at the extremes (especially for the enquiry-based measure). This would correspond to a situation in which teachers combine the presentation of concepts, theories, and measurement with students' experimentation.

Similarly, we find clear evidence of a vast area of complementarity between enquiry-based and adaptive instruction (central panel): the latter can be a powerful tool to complement students' experimentation (keeping in mind that teacher-directed instruction is held constant).

When we look at the combination of teacher-directed instruction and adaptive instruction (keeping fixed the enquiry-based index), we find that the two practices both complement and substitute each other. They are complementary because higher values for both tend to be associated with lower probabilities of being a low achiever. On the other hand, a given probability of being a low achiever can be obtained by very different combinations of the two practices. For instance, a low achievement value of 15% (light blue) can be obtained by a combination of low adaptive instruction and high teacher-directed instruction or, vice versa, by high adaptive instruction and low teacher-directed instruction.

6 Conclusions

Our results appear to support the hypothesis of some form of complementarity between teacher-directed and enquiry-based teaching. While increasing the value of enquiry-based teaching alone has a positive association with the likelihood of being a low achieving student (and particularly so for low levels of the teacher-directed index), there is also clear evidence that teacher-directed and enquiry-based instructional methods can be combined to generate low and very low probabilities of being a low achiever, which is the ultimate policy target. These two teaching practices seem to work well together when they have values that are not at the extremes (especially for the enquiry-based measure). This would correspond to a situation in which teachers combine the presentation of concepts, theories, and measurement with students' experimentation.

A very similar analysis applies to the relationship between enquiry-based and adaptive instruction: the latter can be a powerful tool to complement students' experimentation. When we look at the combination of teacher-directed instruction and adaptive instruction, we find that the two practices both complement and substitute each other. They are complementary because higher values for both tend to be associated with lower probabilities of being a low achiever. On the other hand, a given level of low achievement probability can be obtained by very different combinations of the two practices.

Our analysis shows that the way science is taught can be significantly associated with students' performance; properly combining different teaching practices might therefore improve the performance of low achievers. This is in line with research showing that high-quality teaching involves the use of diversified instructional strategies (Creemers and Kyriakides, 2008; McKinsey and Company, 2017).

However, it should also be kept in mind that, besides teaching instructional practices, general teaching effectiveness-enhancing factors must be improved, especially if the goal is to improve the performance of low achievers. For example, providing good quality of initial teacher education, promoting effective collaboration among teachers and offering teachers professional development programmes that help them address the needs of different groups of students, are all policies that can increase the effectiveness of teaching activities and especially benefit low achievers. Finally, we should remember that factors such as students' socio-economic background, school environment, and school resources are also associated with students' learning outcomes. School and class segregation should be avoided and additional resources – especially infrastructures and teachers – should be directed to those schools in which the shares of low achievers are higher (European Commission, 2016b).

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List of abbreviations and definitions

BIC – Bayesian information criterion
EB (method/instruction) – Enquiry-based (method/instruction)
EC – European Commission
ESCS – (Index of) educational, social and cultural status
EU – European Union
MS – Member State
OECD – Organization for Economic Co-operation and Development
PISA – Programme for International Student Assessment
TIMSS – Trends in International Mathematics and Science Study

EU country abbreviations

Code	Country name
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

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Annexes

Annex 1. Control variables included in the model

Variables	Code	Questionnaire
Gender	ST004D01T	Student
SES	ESCS	Student
Immigration background	IMMIG	Student
Motivation for achievement	MOTIVAT	Student
Class size	CLSIZE	School
Perceived feedback	PERFEED	Student

Annex 2. Average of the control variables included in the model

	Gender (Female)	ESCS	Immigration status	Motivation for achievement	Class size	Perceived feedback
AT	0.536	0.206	0.194	-0.279	25.035	-0.232
BE	0.512	0.296	0.149	-0.469	20.281	-0.186
BG	0.506	0.058	0.007	-0.017	25.314	0.394
CY	0.539	0.232	0.103	0.231	23.583	0.194
CZ	0.503	-0.154	0.029	-0.262	24.451	-0.088
DE	0.526	0.238	0.131	-0.353	25.842	-0.282
DN	0.504	0.641	0.085	-0.115	21.609	-0.268
EE	0.503	0.058	0.096	-0.030	25.092	-0.099
EL	0.507	-0.037	0.097	-0.072	23.528	0.055
ES	0.489	-0.453	0.109	-0.119	26.836	0.116
FI	0.497	0.275	0.035	-0.617	19.191	-0.287
FR	0.513	-0.053	0.111	-0.245	29.998	-0.146
HR	0.539	-0.184	0.102	-0.222	25.040	0.037
HU	0.512	-0.194	0.026	-0.304	28.363	0.001
IE	0.498	0.198	0.138	0.437	24.635	-0.008
IT	0.512	-0.035	0.078	-0.155	23.316	0.058
LT	0.506	-0.045	0.016	0.036	24.329	0.187
LU	0.518	0.172	0.501	-0.147	21.569	-0.200
LV	0.517	-0.416	0.050	-0.015	21.418	0.248
NL	0.503	0.209	0.103	-0.449	26.318	-0.077
PL	0.496	-0.392	0.003	-0.414	24.435	0.211
PT	0.463	-0.318	0.068	0.220	25.696	0.094
SK	0.498	-0.028	0.009	-0.257	22.388	-0.051
UK	0.516	0.268	0.152	0.532	24.426	0.345
EU 24	0.509	-0.020	0.096	-0.136	25.56	0.018

Source: JRC computations on PISA 2015 data.

Annex 3. Relations between the expected share of low achievers in science, teaching practices and hours of learning (EU24)

	Model 1		Model 2	
	Coeff.	**S.E.**	**Coeff.**	**S.E.**
Teacher-directed instruction	-0.317***	(0.027)	-0.410***	(0.035)
(Teacher-directed instruction)^2	0.0182	(0.014)	0.0327	(0.023)
Enquiry-based instruction	0.222***	(0.020)	0.280***	(0.034)
(Enquiry-based instruction)^2	0.101***	(0.010)	0.122***	(0.017)
Adaptive instruction	-0.191***	(0.025)	-0.192***	(0.033)
(Adaptive instruction)^2	-0.0437**	(0.015)	-0.0535*	(0.024)
Hours of learning	-0.448***	(0.026)	-0.445***	(0.026)
(Hours of learning)^2	0.0274***	(0.002)	0.0271***	(0.002)
Teacher-directed instruction * Enquiry-based instruction			-0.0611*	(0.029)
(Teacher-directed instruction)^2 * Enquiry-based instruction			-0.0235	(0.019)
Teacher-directed instruction * (Enquiry-based instruction)^2			0.0100	(0.013)
(Teacher-directed instruction)^2 * (Enquiry-based instruction)^2			-0.0105	(0.007)
Teacher-directed instruction * Adaptive instruction			-0.0281	(0.023)
(Teacher-directed instruction)^2 * Adaptive instruction			-0.0163	(0.015)
Enquiry-based instruction * Adaptive instruction			-0.0996**	(0.030)
Teacher-directed instruction * Enquiry-based instruction * Adaptive instruction			0.0136	(0.014)
(Teacher-directed instruction)^2 * Enquiry-based instruction * Adaptive instruction			0.00658	(0.008)
(Enquiry-based instruction)^2 * Adaptive instruction			-0.00810	(0.014)
Teacher-directed instruction * (Enquiry-based instruction)^2 * Adaptive instruction			0.00413	(0.006)
(Teacher-directed instruction)^2 * (Enquiry-based instruction)^2 * Adaptive instruction			0.00260	(0.004)
Teacher-directed instruction * (Adaptive instruction)^2			0.0816***	(0.019)
(Teacher-directed instruction)^2 * (Adaptive instruction)^2			0.0192	(0.010)
Enquiry-based instruction * (Adaptive instruction)^2			-0.0210	(0.021)
Teacher-directed instruction * Enquiry-based instruction * (Adaptive instruction)^2			0.00589	(0.009)
(Teacher-directed instruction)^2 * Enquiry-based instruction * (Adaptive instruction)^2			-0.00378	(0.006)
(Enquiry-based instruction)^2 * (Adaptive instruction)^2			0.0127	(0.009)
Teacher-directed instruction * (Enquiry-based instruction)^2 * (Adaptive instruction)^2			-0.00634	(0.005)
(Teacher-directed instruction)^2 * (Enquiry-based instruction)^2 * (Adaptive instruction)^2			-0.00200	(0.003)
Female	0.245***	(0.042)	0.252***	(0.042)
Perceived feedback	0.441***	(0.024)	0.433***	(0.024)
Index of educational, social and cultural status (ESCS)	-0.685***	(0.023)	-0.680***	(0.023)
Immigrant	0.472***	(0.069)	0.472***	(0.069)
Achievement motivation	-0.120***	(0.025)	-0.117***	(0.025)
Class Size	-0.0413***	(0.008)	-0.0419***	(0.008)

	Model 1		Model 2	
	Coeff.	S.E.	Coeff.	S.E.
Austria	.	.	.	.
Belgium	-0.833***	(0.129)	-0.841***	(0.130)
Bulgaria	0.937***	(0.132)	0.912***	(0.133)
Croatia	0.0541	(0.129)	0.0417	(0.130)
Cyprus	1.209***	(0.125)	1.198***	(0.125)
Czech Republic	-0.0583	(0.124)	-0.0940	(0.124)
Denmark	0.0702	(0.131)	0.0506	(0.133)
Estonia	-0.808***	(0.146)	-0.818***	(0.147)
Finland	-0.641***	(0.127)	-0.650***	(0.128)
France	-0.153	(0.143)	-0.174	(0.144)
Germany	-0.462**	(0.147)	-0.474**	(0.147)
Greece	0.894***	(0.130)	0.887***	(0.130)
Hungary	0.462***	(0.138)	0.462***	(0.138)
Ireland	-0.251	(0.132)	-0.242	(0.133)
Italy	-0.0548	(0.137)	-0.0520	(0.137)
Latvia	-0.328*	(0.128)	-0.342**	(0.128)
Lithuania	0.607***	(0.125)	0.581***	(0.126)
Luxembourg	-0.0876	(0.167)	-0.106	(0.166)
Netherlands	0.221	(0.162)	0.219	(0.162)
Poland	-0.367**	(0.125)	-0.361**	(0.126)
Portugal	-0.193	(0.135)	-0.169	(0.135)
Slovak Republic	0.228	(0.121)	0.203	(0.122)
Spain	-0.239	(0.124)	-0.233	(0.125)
United Kingdom	0.291*	(0.130)	0.299*	(0.131)
Constant	-0.138	(0.217)	-0.132	(0.217)
Observations	116421		116421	
BIC	712148.2		700865.8	

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Source: JRC computations on PISA 2015 data. Results from logistic regressions as explained in Section 3.2. BIC is the average from 10 models each using one plausible value.

Annex 4. Relations between the expected share of low achievers in science, teaching practices and hours of learning, by EU MS

	Teacher-directed instruction		(Teacher-directed instruction)^2		Enquiry-based instruction		(Enquiry-based instruction)^2		Adaptive instruction		(Adaptive instruction)^2		Learning hours		(Learning hours)^2	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
AT	-0.029***	(0.007)	0.004	(0.004)	0.020*	(0.008)	0.015***	(0.004)	-0.001	(0.007)	-0.006	(0.004)	-0.011	(0.007)	0.001	(0.001)
BE	-0.019**	(0.007)	0.009*	(0.004)	0.030***	(0.008)	0.020***	(0.003)	-0.002	(0.008)	-0.003	(0.004)	-0.049***	(0.007)	0.003***	(0.001)
BG	-0.025***	(0.007)	0.006	(0.005)	0.058***	(0.008)	0.01**0	(0.004)	-0.055***	(0.010)	-0.009	(0.006)	0.044	(0.026)	0.000	(0.002)
CY	-0.052***	(0.009)	-0.003	(0.005)	0.035***	(0.010)	0.010**	(0.004)	-0.041***	(0.011)	-0.004	(0.006)	-0.127***	(0.016)	0.009***	(0.001)
CZ	-0.019*	(0.009)	0.004	(0.005)	0.039***	(0.010)	0.019***	(0.004)	-0.021**	(0.008)	-0.008	(0.005)	-0.055***	(0.010)	0.004***	(0.001)
DE	-0.017	(0.009)	0.005	(0.006)	0.015	(0.009)	0.003	(0.006)	-0.028***	(0.007)	-0.006	(0.005)	-0.058***	(0.009)	0.004***	(0.001)
DK	-0.006	(0.009)	0.000	(0.007)	-0.023	(0.013)	0.023***	(0.007)	-0.043***	(0.009)	0.002	(0.006)	-0.064***	(0.016)	0.006***	(0.001)
EE	-0.020***	(0.006)	0.000	(0.004)	0.045***	(0.009)	0.015***	(0.004)	-0.015*	(0.006)	-0.007*	(0.003)	-0.029**	(0.010)	0.002	(0.001)
EL	-0.061***	(0.008)	0.004	(0.006)	0.060***	(0.010)	0.010*	(0.004)	-0.022*	(0.011)	-0.007	(0.007)	-0.118***	(0.014)	0.008***	(0.001)
ES	-0.044***	(0.009)	-0.004	(0.006)	0.032***	(0.009)	0.020***	(0.005)	-0.008	(0.009)	-0.009	(0.005)	-0.048**	(0.013)	0.003*	(0.001)
FI	-0.023***	(0.006)	0.002	(0.004)	0.038***	(0.008)	0.021***	(0.004)	-0.020**	(0.006)	0.002	(0.004)	-0.023	(0.010)	0.002	(0.001)
FR	-0.032***	(0.008)	0.007	(0.004)	0.008	(0.011)	0.019***	(0.006)	-0.001	(0.008)	-0.003	(0.005)	-0.062***	(0.012)	0.005***	(0.001)
HR	-0.035***	(0.008)	-0.004	(0.005)	0.041***	(0.009)	0.011***	(0.003)	-0.024**	(0.008)	-0.001	(0.005)	-0.091***	(0.015)	0.006***	(0.002)
HU	-0.031***	(0.010)	-0.002	(0.006)	0.039***	(0.011)	0.021***	(0.005)	-0.031**	(0.010)	-0.009	(0.006)	-0.039	(0.017)	0.004*	(0.002)
IE	-0.030***	(0.009)	0.002	(0.005)	0.020	(0.013)	0.024***	(0.007)	-0.017**	(0.007)	-0.005	(0.005)	-0.056***	(0.015)	0.006***	(0.002)
IT	-0.082***	(0.011)	-0.001	(0.006)	0.058***	(0.009)	0.009	(0.005)	-0.016	(0.009)	-0.008	(0.007)	-0.041***	(0.012)	0.002*	(0.001)
LT	-0.015	(0.008)	0.001	(0.004)	0.015	(0.009)	0.021***	(0.004)	-0.030**	(0.009)	-0.004	(0.005)	-0.419**	(0.136)	0.048**	(0.016)
LU	-0.042***	(0.009)	0.007	(0.005)	0.001	(0.009)	0.018***	(0.004)	-0.020*	(0.008)	-0.006	(0.005)	-0.003	(0.010)	-0.001	(0.001)
LV	-0.027**	(0.008)	-0.009	(0.005)	0.028*	(0.012)	0.016**	(0.006)	-0.034**	(0.010)	-0.004	(0.006)	-0.095***	(0.012)	0.007***	(0.001)
NL	-0.040**	(0.014)	-0.007	(0.008)	0.049***	(0.014)	0.022**	(0.007)	-0.049***	(0.010)	0.002	(0.007)	-0.047***	(0.013)	0.003***	(0.001)
PL	-0.039***	(0.008)	0.000	(0.005)	0.050***	(0.009)	0.012*	(0.005)	-0.019*	(0.008)	-0.004	(0.005)	-0.157***	(0.030)	0.019***	(0.004)
PT	-0.031**	(0.010)	0.005	(0.006)	0.018	(0.011)	0.006	(0.004)	-0.013	(0.010)	-0.008	(0.006)	-0.029***	(0.007)	0.001	(0.000)
SK	-0.025**	(0.008)	-0.005	(0.005)	0.055***	(0.007)	0.018***	(0.003)	-0.030***	(0.009)	-0.007	(0.006)	-0.055***	(0.008)	0.003***	(0.001)
UK	-0.022*	(0.010)	0.005	(0.006)	0.021	(0.012)	0.026***	(0.006)	-0.026*	(0.011)	0.006	(0.005)	-0.041***	(0.011)	0.002*	(0.001)

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Source: JRC computations on PISA 2015 data. The table reports coefficients from the linear probability model regressing the probability of being a low achiever on the variables of interest (based on 10 plausible values, probability weighting and accounting for cluster sampling by replication weights), controlling for gender, socio-economic status, class size, motivation level and subjectively perceived feedback.

Annex 5. A comparison of the goodness of fit of different models

Model	Average BIC
Model 1	712148.2
Model 1 + Teacher-directed instruction* Enquiry-based instruction	710567.2
Model 1 + Teacher-directed instruction* Adaptive instruction	712119
Model 1 + Enquiry-based instruction* Adaptive instruction	708408.6
Model 1 + the three linear interactions above	708085.9
Model 2	700865.8

Source: JRC computations on PISA 2015 data. BIC is the average from 10 models each using one plausible value.

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