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Country, School and Students Factors Associated with Extreme Levels of Science Literacy Across 25 Countries

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A huge gap in science literacy is between students who do not show the competencies that are necessary to participate effectively in life situations related to science and technology and students who have the skills which would give them the potential to create new technology. The objective of this paper is to identify, for 25 countries, distinct subgroups of students with characteristics that appear to be associated with this proficiency gap. Data were based on the answers of 46,131 PISA 2006 students with scores classified below level 2 or above level 4, as well as the answers of their principals to school questionnaire and the OECD indicators of the financial and human resources invested in education at the national level for secondary school. The dependent variable of the analysis was a dichotomous variable the values of which represent the two different groups of students. The independent variables were the OECD indicators, and the items and indices derived from the student and school questionnaires. The analysis was based on classification trees and the findings were replicated and extended by the means of a multilevel logistic regression model. The results show that very specific levels of teachers' salaries, parental pressure on schools, school size, awareness of environmental issues, science self-efficacy and socio-economic status have a very important role in predicting whether 15 year olds in OECD countries will belong to the lower or the highest proficiency groups as regards their aptitude in the context of life situations involving problems of a scientific nature.

Keywords: *Scientific literacy; Classification and regression trees; Multilevel logistic models*

Introduction

The Programme for International Student Assessment (PISA), promoted by the Organisation for Economic Co-operation and Development (OECD), identifies 6

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different skill levels for scientific literacy, determined on the basis of the different tasks that students with similar scores have shown that they are able to resolve (Organization for Economic Co-operation and Development [OECD], 2007a). This procedure represents an operationalization of scientific literacy, which is quite a broadly applied concept in the literature (Bybee, 1997) with meanings that sometime change from one author to another (Bybee, 1997; Fensham, 2000; Garthwaite, France, & Ward, 2014; Koballa, Kemp, & Evans, 1997; Lam & Lau, 2014; Mayer, Nagengast, Fletcher, & Steyer, 2014; Osborne, Simon, & Collins, 2003; Roberts, 2007). According to the OECD definition (OECD, 2007a), from skill level 5 onwards students show that they are able to identify the scientific aspects of many complex situations of daily life and are able to develop explanations based on evidence and arguments that are the result of their critical analysis. At the highest level, level 6, they possess a degree of expertise that enables them to identify and explain scientific concepts, applying their scientific knowledge in a coherent way to a variety of complex situations in daily life and using it to make decisions related to personal, social or global situations and issues that are not necessarily familiar to the students and that therefore require a certain degree of innovation. As regards situations requiring a lower level of proficiency, students at level 1 have very limited scientific knowledge that can only be applied to a few familiar situations and they are only able to provide rather simple and obvious scientific explanations. On the whole, students at or below level 1 do not show that they possess the skills and knowledge that are considered basic for science subjects (OECD, 2007a). The ability to participate in life situations in future that may involve problems of a scientific and/or technological nature therefore differs widely between these different groups of students.

What are the variables, at the various different levels, that are associated with this huge gap in skills between students in science subjects and that thus affect their future opportunities? The present study, based on the data from PISA 2006 for the OECD countries, will try to answer this question taking into account a very large number of factors at the country, school and student levels. The results of PISA 2006 are still relevant to the present and are particularly important due to the fact that this was the latest PISA survey focused on science literacy, involving the collection of context information on variables that were potentially related to this construct at the level of the school and the student. As similar context data are not available for PISA 2009 (focused on reading) or PISA 2012 (focused on mathematics) these two researches will not be considered in this paper.

Theoretical Framework

The theoretical framework of the present study is based on the PISA 2006 assessment framework (OECD, 2006a), which examines a large number of contextual factors that potentially influence students' performance in scientific literacy. These factors are related to the following contexts: the context of the education system at the national level, the school context and the individual student context.

Consistently with the theoretical framework of PISA, the OECD collected a wide range of data on the contexts of the education system, school and the individual student. Despite this, to date there is a lack of studies that consider these variables simultaneously as regards their possible relationships to the attainment of different levels of competence in science studies. This fact is particularly curious when one considers that the theoretical framework of the project (OECD, 2006a) did not identify a limited number of variables that were considered to be the most important, or a specific pattern of effects that these factors were presumed to have on the performance of students in science subjects. This situation is perhaps less surprising when one bears in mind that the PISA data have generally been analysed with traditional methods such as regression, which make it very difficult to explore and interpret the relationships between a large number of variables of different types (Allore, Tinetti, Araujo, Hardy, & Peduzzi, 2005).

Objective of the Present Study

The objective of the present study is to simultaneously analyse the vast range of factors related to the various contexts of the education system, schools and individual students, which are considered relevant within the PISA theoretical framework and about which the OECD collects data, in order to identify those that are most closely associated with large differences in scientific proficiency between students.

Review of the Literature

The literature on PISA gives various explanations for differences in science literacy results. In the present review we will take into consideration the variance in PISA outcomes that can be studied on at least three different levels: students, schools and countries.

Student-Level Factors

At the student level the PISA theoretical framework (OECD, 2006a) takes into account background factors such as students' social, economic and cultural status (SES), and many studies agree that these are important variables (e.g. Chiu, 2007; Woods McConney, Oliver, McConney, Maor, & Schibeci, 2013). More malleable factors such as the students' self-efficacy, motivation, interest in natural sciences and awareness of environmental issues are also considered at the student level. Various studies have, in fact, already indicated that these factors are associated with science proficiency (e.g. Basl, 2011; Britner & Pajares, 2006; Bybee & McCrae, 2011; Coertjens, Boeve-De Pauw, De Maeyer, & Van Petegem, 2010; Krapp & Prenzel, 2011; McConney, Oliver, Woods McConney, & Schibeci, 2011; Osborne et al., 2003).

Concerning the literature on PISA there is a broad consensus regarding the fact that students' socio-economic status has an important effect on the performance of students. Apart from the analysis by the OECD (2007a) this fact has been emphasized in various in depth studies based on samples in individual countries. For example, a positive impact of students' SES on science literacy was detected by Sun, Bradley, & Akers (2012) and by Lam and Lau (2014) on the PISA Hong Kong sample, by Gilleece, Cosgrove, & Sofroniou (2010) in Ireland, by Alivernini, Losito, & Palmerio (2010) on the Italian sample, as well as by Tomul and Celik (2009) in Turkey. Concerning student background variables, several studies have shown a significant influence of the gender of the students on their performance in science subjects, with males showing better results than females (Lam and Lau, 2014; OCSE, 2007a; Sun et al., 2012).

If instead we take students affective factors into account, various studies show that they are related to science literacy, as measured in PISA 2006. For example, motivation and interest in science were identified as variables related to positive results in PISA (Bybee & McCrae, 2011; Lam & Lau, 2014; Ozel, Caglak, & Erdogan, 2013; Sun et al., 2012). Science self-efficacy has been quite consistently pointed out as a factor associated with better performance in science subjects (Alivernini et al., 2010; Lam & Lau, 2014; OECD, 2007a; Sun et al., 2012). The results with reference to the self-concept are instead more controversial (OECD, 2007a). For example in Turkey Ozel et al. (2013) found that it had a negative relationship with science literacy, while in Italy it was found to have a positive relationship (Alivernini et al., 2010).

Finally, taking into account the parental factors apart from the SES, Ho (2010) showed that students' science literacy performance is associated with certain types of parental investment and involvement. A subsequent study by Lam and Lau (2014), which took into account the effect of students' attitudes, as well as parental factors, pointed out that only the 'parents' value of science' had a significant role compared to the other variables identified by Ho.

School-Level Factors

As regards the school context, Sun et al. (2012) have suggested that the factors associated with science literacy could be divided into two sets. The first set includes variables such as school financial resources, school location, enrolment size, student body socioeconomic status and the quality of human resources (e.g. the proportion of fully certified teachers). The second set of factors includes variables concerning what is referred to as the school climate. Examples of this are the autonomy of the school in decision-making, specific school activities to promote students' learning of science subjects and parental pressure on academic standards.

As for the explanation of the differences of the PISA results at the school level, Sun et al. (2012) showed that the differences in science achievement can be explained by school enrolment size, school SES composition and instruction time per week. Lam and Lau (2014) have questioned these results, particularly those affecting the enrolment size and instruction time per week. In general there is no agreement in the literature as to which school-level variables taken into account by PISA are most closely associated with science performance and various studies have given different results.

The factor that appears to be more stably associated with the difference between the average results of schools is the average school socio-economic status (Alivernini et al., 2010; Gilleece et al., 2010; Ho, 2010; Sun et al., 2012).

Country-Level Factors

According to OECD (2006b, 2007b, 2008) at the national level the main factors influencing science literacy are related to financial and human resources invested in education (e.g. proportion of national wealth spent on education; services and resources in which funds for education are spent) as well as the learning environment and the general organization of schools (e.g. time that students spend in the classroom and the ratio of students to teaching staff). However, there is a lack of studies that attempt to explain differences in science literacy between countries. More general studies that focus on differences in educational achievement suggest that the quality of teaching, as measured by teacher salaries and the education levels of teachers might be relevant factors (Hanushek & Woessmann, 2010)

Method

Data Sources

Data for this study are based on the answers PISA 2006 OECD students with scores classified below level 2 and above level 4, as well as the answers at the school questionnaire of their principals. In order to provide more information about country-level variables, the PISA data-set was matched with OECD indicators of financial and human resources invested in education at the national level for secondary school (year of reference: 2005; OECD, 2008) and with OECD indicators related to the learning environment and organization of schools (year of reference: 2005; OECD, 2008). Data from Canada, Poland, Slovakia and Turkey, which showed a large number of missing values as regards OECD educational indicators, were not taken into consideration for the present paper. The data analysed refer to 25 different countries (Australia, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the USA) and it involved a total number of 46,131 students.

Variables

The dependent variable of the analysis was a dichotomous variable the values of which represent the two different groups of students (students with scores classified below level 2 and students with scores classified above level 4). The independent variables were the OECD indicators mentioned above and all the indices at the school as well as at the student level in the PISA 2006 database that will be described in Tables 1–3. Information about schools in the PISA database

Table 1. The country-level variables taken into consideration for the present study

Source	Variables
OECD educational indicators related to financial and human resources invested in education (year of reference 2005)[a]	• expenditure on educational institutions per student; • proportion of national wealth spent on education; • relative proportions of public and private investment in education; • total public expenditure in education; • tuition fees charged by institutions and public subsidies to students; • services and resources in which education funding are spent; • how efficiently the resources are used in education.
OECD educational indicators related to the learning environment and organization of schools (year of reference 2005)[a]	• time that students spend in the classroom; • ratio of students to teacher staff and average class size; • teacher salaries; • time that teachers spend teaching; • impact of evaluation and assessments within education systems; • level of decision-making in education systems.
Variables from PISA 2006 Student Questionnaire aggregated (mean) at the country level[b]	Index of Economic, Social and Cultural Status (ESCS) created on the basis of the following variables: • home possession index: a summary index of family wealth possessions (e.g. cellular phones), cultural possessions (e.g. classic literature, paintings), educational resources (e.g. educational software), and number of books at home (but recoded into three categories: 0–25 books, 26–100 books and 101 or more books); • the highest occupational status of parents: obtained by coding students' answers to open-ended questions about their parents' job to the four-digit ISCO codes (International Labour Organisation [ILO], 1990) and then mapping them to the international socio-economic index of occupational status (ISEI; Ganzeboom, de Graaf, & Treiman, 1992). The index corresponds to the higher ISEI score of either parent or to the only available parent's ISEI;

(*Continued*)

Table 1. Continued

Source	Variables
	• the highest educational level of parents expressed as years of schooling: obtained by recoding students' reports on the educational level of their parents into the International Standard Classification of Education (ISCED) categories (UNESCO, 2006). The index corresponds to the higher ISCED level of either parent recoded into estimated years of schooling.

[a]For a detailed description and statistics about the variables please refer to OECD (2008)

[b]For a detailed description and statistics about the variables please refer to OECD (2009).

(e.g. school size, availability of computers, student–teacher ratio, and proportion of teachers with qualifications) was also analysed. Students' gender was included in the analysis since previous studies (e.g. Good, Woodzicka, & Wingfield, 2010; Sanchez & Wiley, 2010) showed that it could be a relevant factor in explaining science literacy.

For a detailed description of how the indices and the other variables used in this study were constructed see the PISA 2006 Technical Report (OECD, 2009). Table 1 presents the country-level variables taken into consideration for the present study.

Table 2 presents the school-level variables and indices from PISA 2006 School Questionnaire and Student Questionnaire taken into consideration in this study.

Table 3 presents the student-level variables and indices from PISA 2006 Student Questionnaire taken into consideration in this study.

Statistical Models and Analysis

In the first phase of the analysis, given the large number of possible predictors of different types taken into consideration, we decided to adopt a method that was suited to detecting and interpreting complex relations within large data-sets that most traditional means of regression and classification analysis might ignore (Allore et al., 2005). This is the method of classification and regression trees (CART; Breiman, Friedman, Olshen, & Stone, 1984; Strobl, Malley, & Tutz, 2009; Williams, Lee, Fisher, & Dickerman, 1999).

CART is not affected by problems of multi-collinearity between predictors and it makes no assumptions regarding the underlying distribution from which the subjects are sampled. The algorithm proceeds by performing successive binary divisions of the subjects on the basis of a statistical criterion. Starting from the full sample (called root node or parent node) each independent variable is evaluated on the basis of the extent

Table 2. The school-level variables taken into consideration for the present study

Variable or Index	Description[a]
Variables and indices from PISA 2006 School Questionnaire aggregated (mean) at the school level	
School size	The total enrolment at school based on the enrolment data provided by the school principal.
Availability of computers	The number of computers available at school.
Student–teacher ratio	It is computed by dividing the school size by the total number of teachers.
Index of school selectivity	It refers to how much consideration was given to the students' academic record and the recommendation of feeder schools (computed by assigning schools to four different categories from 'schools where none of these factors is considered for student admittance' to 'schools where at least one of these factors is a pre-requisite for student admittance')
Index of school responsibility for resource allocation	It is derived from six items measuring the school principal's report on who has considerable responsibility for tasks regarding school management of resource allocation (e.g. 'Selecting teachers for hire'; 'Formulating the school budget').
Proportion of fully certified teachers	It is calculated by dividing the number of fully certified teachers by the total number of teachers.
Proportion of teachers with an ISCED 5A qualification	It is obtained by dividing the number of teachers with an ISCED 5A qualification by the total number of teachers.
Index of school responsibility for curriculum and assessment	It is obtained from four items measuring the school principal's report concerning who had responsibility for curriculum and assessment (e.g. 'Establishing student assessment policies', 'Choosing which textbooks are used')
Index of teacher shortage	It is computed on the basis of four items measuring the school principal's perceptions about how much the school's capacity to provide instruction was hindered by the shortage of teachers.
Index of quality of educational resources	It is derived from seven items measuring the school principal's perceptions of potential factors hindering instruction at school (e.g. 'Shortage or inadequacy of science laboratory equipment').
Index of school activities to promote students' learning of science	It is computed on the basis of principal's reports about school's involvement in science activities (e.g. 'Science clubs', 'Excursions and field trips').

(*Continued*)

Table 2. Continued

Variable or Index	Description[a]
School activities for learning environmental topics	It is derived from principal's reports on the occurrence at school of activities to promote students' learning of environmental topics (e.g. trips to museums, extracurricular environmental projects).
Parental pressure on academic standards	It is derived from principal's report about parental expectations towards the school in terms to set very high academic standards and to have the students achieve them.
Variables and indices from PISA 2006 Student Questionnaire aggregated (mean) at the school level	
ESCS	See the index description in Table 1.

[a]For a detailed description and statistics about the variables please refer to OECD (2009).

to which it is able to reduce the impurity of the parent node by dividing the subjects into two groups (called child nodes). Independent variables can be nominal, ordinal or continuous. The impurity consists in the degree to which the students at a node vary compared with the dependent variable: a minor impurity indicates a greater homogeneity of the subjects for the values of the dependent variable. In the case under examination a completely pure node would be one which includes students who only belong to the highest levels of skills or only belong to the lowest levels of skills. The Gini index was adopted as measure of purity in the present study. The CART analysis was conducted using a hierarchical approach in three stages (Fabbris, 1997; Hox, 2010). We developed a model:

(1) with only country-level variables;
(2) with school-level variables nested under the country model identified at stage 1;
(3) with student variables nested under the country and school model identified at stage 2.

This model was developed on a random subset of the data (training sample) and then the results were validated on a separate random sample (test sample). The accuracy model was estimated using cross validation techniques (Breiman et al., 1984)

In the second phase of analysis a multilevel logistic regression model based on the results of the CART model was computed in order to replicate and extend the findings by means of a more traditional statistical technique. The details of the logistical model developed are described in Results section.

Results

Figure 1 shows the final tree produced by CART in order to identify the segments of students with the greatest disparities in their science proficiency levels.

The classification tree shows that the most important factor at the country level is related to teachers' salaries in lower secondary education: if they are more than 16%

Table 3. The student-level variables taken into consideration for the present study (source: PISA 2006 Student Questionnaire[a])

Variable or Index	Description[a]
Gender	Coded as 0 = male, 1 = female.
ESCS	See the index description in Table 1.
Index of interest in science learning	It is derived from eight items measuring student's interest about broad science topics (e.g. 'topics in physics', 'the biology of plants').
Index of enjoyment of science	It is computed on the basis of four items measuring student's enjoyment of science learning (e.g. 'I enjoy acquiring new knowledge in broad science', 'I like reading about broad science').
Index of instrumental motivation to learn science	It is derived from five item measuring student's motivation to learn science (e.g. 'I study school science because I know it is useful for me', 'I will learn many things in my school science subject(s) that will help me get a job').
Index of future-oriented science motivation	It is computed on the basis of four items measuring expectations about science-related studies and careers (e.g. 'I would like to work in a career involving broad science', 'I would like to study broad science after secondary school').
Index of science self-efficacy	It is derived from eight items measuring student's confidence in performing science-related tasks (e.g. 'Describe the role of antibiotics in the treatment of disease', 'Interpret the scientific information provided on the labelling of food items').
Index of science self-concept	It is computed on the basis of six items about student's opinion about himself/herself (e.g. 'I learn school science topics quickly', 'I can easily understand new ideas in school science').
Index of general value of science	It is derived from five items measuring student's perceptions on the general value of science (e.g. 'Broad science is valuable to society', 'Broad science is important for helping us to understand the natural world').
Index of personal value of science	It is derived from five items measuring student's perceptions of the personal value of science (e.g. 'Broad science is very relevant to me'; 'I find that broad science helps me to understand the things around me').
Index of science-related activities	It is computed on the basis of six items measuring the frequency of student's participation activities related to science (e.g. 'Watch TV programs about broad science', 'Borrow or buy books on broad science topics').
Index of awareness of environmental issues	It is derived from five items about student's report about how much he/she is informed about several environmental issues (e.g. 'nuclear waste', 'acid rain').

(*Continued*)

Table 3. Continued

Variable or Index	Description[a]
Index of perception of environmental issues	It is derived from six items measuring the concern of the student about several environmental issues (e.g. 'air pollution', 'energy shortage').
Index of environmental optimism	It is derived from six items measuring student's perceptions about the improvement of problems related to environmental issues (e.g. 'air pollution', 'water shortage').
Index of responsibility for sustainable development	It is derived from seven items measuring student's support for sustainable development (e.g. 'I am in favor of having laws that regulate factory emissions even if this would increase the price of products', 'To reduce waste, the use of plastic packaging should be kept to a minimum').
Index of school preparation for science career	It is derived from four items measuring students' perceptions of the usefulness of schooling as preparation for science-related careers (e.g. 'The subjects I study provide me with the basic skills and knowledge for a science-related career', 'My teachers equip me with the basic skills and knowledge I need for a science-related career').
Index of student information on science careers	It is derived from four items measuring how much students' are informed about aspects of science-related careers (e.g. 'Science-related careers that are available in the job market', 'Where to find information about science-related careers').
Index of science teaching—interaction	It is computed on the basis of four items measuring students' reports on the frequency of interactive teaching in science (e.g. 'Students are given opportunities to explain their ideas', 'The students have discussions about the topics').
Index of science teaching—hands-on activities	It is computed on the basis of four items measuring students' reports on the frequency of hands-on activities (e. g. 'Students spend time in the laboratory doing practical experiments', 'Students are required to design how a school science question could be investigated in the laboratory').
Index of science teaching—student investigations	It is derived from three items measuring students' reports on the frequency of student investigations in science (e.g. 'Students are allowed to design their own experiments', 'Students are asked to do an investigation to test out their own ideas').
Index of science teaching—focus on models or applications	It is derived from five items measuring students' reports on the frequency of teaching in science lessons with a focus on applications (e.g. 'The teacher uses science to help students understand the world outside school', 'The teacher clearly explains the relevance of broad science concepts to our lives').

[a]For a detailed description and statistics about the variables please refer to OECD (2009).

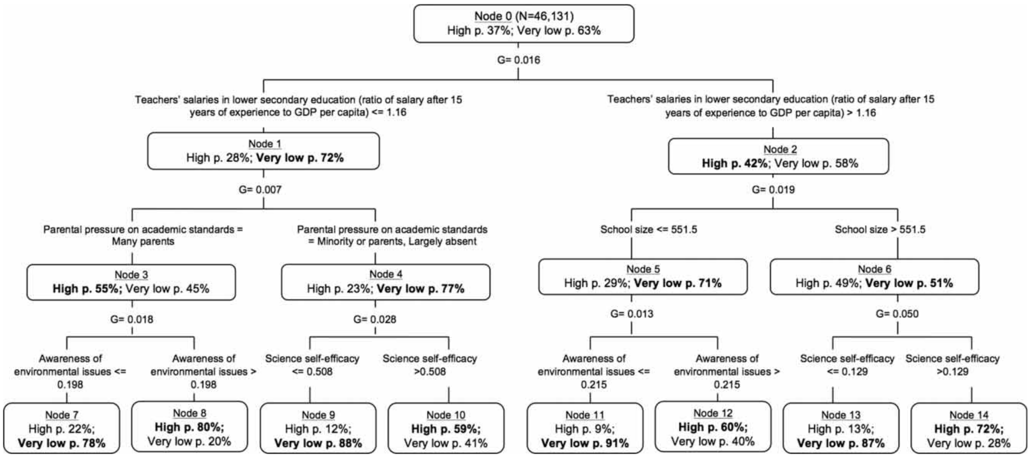

Figure 1. The final tree produced by CART. High P. = High Performers; Very low P. = Very low Performers. Bold character is used for category which increases compared to the proportions in the precedent node.

above the country's GDP per capita (node 2), the percentage of students classified as top performers as regards science literacy goes up from 37% to 42%. If teachers' wages are less than or equal to this amount (node 1), the percentage of top performers goes down from 37% to 28%. At the school level, for countries where the income of teachers is at a lower level (on the left-hand side of the tree), parental pressure on academic standards is very important: if this pressure is exerted by many parents (node 3), the percentage of top performers rises from 28% to 55%. When there is less parental pressure (node 4), this percentage drops to 23%. As regards schools in countries where the income level of teachers is higher (on the right-hand side of the tree), the size of the schools proves to be relevant: in larger schools (school size > 551), the percentage of top performers rises from 42% to 49% (node 6). In smaller schools (school size ≤ 551) it falls from 42% to 29% (node 5). If we take student variables into account, we find that the difference between top performers and low achievers is always due to different levels of student awareness of environmental issues and science self-efficacy. For example, in the purest node of the tree, a percentage of very low performers of as high as 91% has been identified (node 11).

The results showed that country, school and student factors interact in a complex way and that their interrelationships lead to the identification of student groups with particular ratios between top performers and low achievers. The most problematic group (node 11), where the percentage of very low achievers is equal to 91%, is made up of students who live in countries where teachers' salaries are higher, who attend smaller schools and who have lower levels of awareness of environmental issues. On the other hand, the group of more privileged students (node 8), in which the percentage of top performers is 80%, live in countries where teacher salaries are lower. They also attend schools where many parents exert pressure on academic standards and they tend to have higher levels of awareness of environmental issues.

Table 4. Indicator variables in the logistic model

Indicator	Coding
Teacher salaries	0 = Teacher salaries ≤ 1.16
School size	0 = School size ≤ 551
Parent pressure	0 = Minority of parents or parents largely absent
Awareness of environmental issues	0 = Awareness ≤ 0.198
Science self-efficacy	0 = Science self-efficacy ≤ 0.508

In order to replicate and extend the findings from the classification tree, a three-level logistic regression model was tested. This model is an extension of the preceding tree model because the relationships found within subsets of the data, for example, the associations between school size and science performance group detected for the sub-sample of students who live in countries with higher teachers' salaries (nodes 5 and 6) are tested on the whole sample.

Table 4 presents the indicator variables (coded 0/1) that represented the classification tree splits (Lemon, Roy, Clark, Friedmann, & Rakowski, 2003) with the highest impurity reduction in the logistic model (i.e. divisions which led to a group with a high percentage of students who perform below the baseline level or at the top level).

In the three-level logistic model the Index of Economic, Social and Cultural Status (ESCS) was included at each level as a control variable.

The logistic model of this study for P_{ijk}, that is, the probability of being a science top level performer for a student i attending a school j and living in a country k, ($P_{ijk} = 1$), was estimated on the basis of the following equation.

Level 1: student

$$\text{Logit}\ (P_{ijk} = 1) = \beta_{0jk} + \beta_1(\text{student SES})_{ijk} + \beta_2(\text{awareness of env. issues})_{ijk} \\ + \beta_3(\text{science self} - \text{efficacy})_{ijk} + \mathrm{e}_{ijk}. \tag{1}$$

Level 2: school

$$\beta_{0jk} = \gamma_{00\mathrm{k}} + \gamma_{01}(\text{school size})_{jk} + \gamma_{02}(\text{ parent pressure})_{jk} + \gamma_{03}(\text{school SES})_{jk} + u_{jk}.$$

Level 3: country

$$\gamma_{00k} = \pi_{000} + \pi_{001}(\text{teacher salaries})_{\mathrm{k}} + \pi_{002}(\text{country SES})_{\mathrm{k}} + v_k.$$

Results show that the findings from the classification tree have been replicated and extended in the multilevel logistic model. In Table 5 coefficients, P-values and odd ratios from the results of the multilevel logistic model are reported.

Table 5. Results of the multilevel logistic model

Indicator	Coefficient	Odds ratio
Country level		
Teacher salaries	0.90*	2.45
ESCS country mean	0.27	1.31
School level		
School size	0.27*	1.31
Parent pressure	0.33*	1.40
ESCS school mean	1.6*	4.94
Student level		
Science self-efficacy	1.44*	4.24
Awareness of environmental issues	1.61*	5.04
ESCS	0.5*	1.65

*$p < .001$

Discussion

The analysis carried out in this study used an exploratory and hierarchical approach. In other words pre-formulated hypotheses were not tested, but a data-driven model based on the theoretical framework of PISA 2006 (OECD, 2006a) was developed. The multilevel structure of PISA 2006 data was taken into consideration by means of a hierarchical analysis of the country variables, school/teacher variables and parent/student variables. In order to ensure the reproducibility of the findings, the classification model was developed on a training sample and tested on a control sample. Additionally, the findings from the classification tree were replicated and extended by means of a multilevel logistic regression model.

Results showed that the country-level variable that makes the greatest difference between student performance groups is the salaries of teachers in lower secondary education. This finding is consistent with various studies that show a positive correlation between teachers' wages and the performance of students. Regarding this point Loeb and Page (2000) showed that, when considering non-pecuniary aspects of the job and alternative wage opportunities, raising teachers' wages by 50% reduces high school dropout rates by more than 15% and increases college enrolment rates by 8%. In their review of the literature on the relationship between teacher salary and student performance Hanushek and Rivkin (2006) state that better salaries are more likely to be positively related to student achievement, although this is statistically significant only in a minority of studies.

Teacher salaries may influence the choice of the first job, the decision to enter into the teaching profession and change of profession. Imazeki (2005) pointed out that science and maths teachers have higher exit and transfer rates from the profession compared to teachers of other subjects and that there is much evidence to show that salary increases can motivate experienced teachers to stay in their jobs. This factor is in turn associated with student performance. Nevertheless the relationship between teacher salaries and student performance is still a controversial point (Beteille

& Loeb, 2009) and, since most of the research conducted so far has only compared states or districts within the USA, further evidence is needed before the result can be considered conclusive.

As mentioned in the literature review, there is a lack of studies focused on explaining differences between countries in science literacy. The results of the present study, conducted on the PISA OECD countries, constitute a valid addition to the literature and they suggest that teachers' salaries could be a relevant factor in explaining the large performance gaps in science literacy between students. If we look at the data from PISA 2006, in those countries where teachers with 15 years of experience have a salary more than 16% above the country's per capita domestic product, the students are 2.45 times more likely to be top science performers.

As regards the variables relating to school characteristics, a clear distinction can be made between students at the top level and students below the base level on the basis of parental expectations towards the school in terms of setting very high academic standards and of making sure that students attain them. Parental pressure on schools can be exerted in many ways, such us through parent associations, elected parents' representatives, individual parents visiting the school and talking to the teachers, etc. According to McMillan (2000) the involvement of parents has an important influence on the quality of teaching in schools and this naturally affects students' academic development. Hill and Craft (2003) also found that parental involvement in education is positively associated with academic outcomes in high school. On the other hand, the 2007 OECD analysis (OECD, 2007a) showed that parental pressure does not have a statistically significant effect on student performance when socio-economic factors are accounted for, and Lam and Lau (2014) showed that most of the parental factors do not have significant impacts on achievement. The results of the present study suggest that parental pressure is a relevant factor only when exerted by a substantial number of parents: in this case students are 1.4 times more likely to be top performers in science literacy tests.

Results show that also the total enrolment at school is a variable relevant at the school level. The effect of school size is a rather controversial issue in the literature (Ahn & Brewer, 2009) and the findings of the present study are consistent with the analysis of Schneider, Wyse, and Keesler (2006), which showed that small schools can have a negative effect on some students' outcomes. Additionally this study suggests that there could be a cut-off point in investigating this phenomenon: those students who are in schools where the total enrolment exceeds 550 are more likely to be top science performers. Lee and Smith (1997) showed that there could be an optimal school size in relation to students' achievements, with the largest learning gains taking place in schools that enrol 600–900 students. Interestingly the cut-off we identified is very near the lower limit of this ideal school size.

There are similarities and differences between the results of the present study and those of previous studies that have focused on school-level factors in PISA. As regards the role of school size, our findings basically correspond to those of the study by Sun et al. (2012), but they differ from those of the study by Lam and Lau (2014). Our research, however, differs from this latter study in many general factors (e.g. the larger number of countries considered, the high number of variables analysed, the focus on extreme levels of competence), and also because our study identified a specific threshold for the effect of school size and addressed a very specific issue. Concerning the role of the school socio-economic status our findings confirmed the results of previous studies (Alivernini et al., 2010; Gilleece et al., 2010; Ho, 2010; Sun et al., 2012). Finally, our findings have indicated the importance of parental pressure at school. While this result has not been emphasized in the literature on PISA hitherto, it appears to be consistent with the findings of Ho (2010) and Lam and Lau (2014) regarding the importance of the 'parents' value of science', as a factor at the student level.

Two student-level variables that play a significant role concerning student performance groups are student awareness of environmental issues and science self-efficacy. The interest expressed in the scientific literature (e.g. Eagles & Demare, 1999; Schultz, Oskamp, & Mainier, 1995) in students' awareness of environmental topics (e.g. acid rain) is mainly due to the fact that this variable is seen as a predictor of students' future behaviour concerning the environment and to the attempt to explain the variance of this variable between student groups. The relationship between science abilities and awareness of environmental issues has not yet been studied sufficiently (Coertjens et al., 2010), but the present study extends our knowledge of this phenomenon, highlighting the strong link between environmental awareness and scientific literacy: in fact it appears to be sufficient for students to have a slightly above average environmental awareness (1/5 of a standard deviation) for them to be five times more likely to be a top performer in science subjects. Science self-efficacy, that is students' judgements as regards their capabilities to organize and carry out a course of action in order to attain good results in science-related subjects, is widely acknowledged in the literature as an important predictor of science performance (Britner & Pajares, 2001, 2006; Lam & Lau, 2014; Lent, Brown, & Larkin, 1986; Sun et al., 2012). The present study confirms this relationship, especially in the case of extreme levels of competence, while also showing that it is sufficient for students to have a science self-efficacy score that is moderately above average (1/2 of a standard deviation) in order to be four times more likely to be top performers in the science subjects.

If, more specifically, we look at the studies presented in the literature review in this paper that have focused on the student-level factors as regards the results of scientific literacy in PISA, we can see some similarities to our findings as well as some differences. Our study confirmed the known relevance of student SES (Alivernini et al., 2010; Gilleece et al., 2010; Lam & Lau, 2014; OECD, 2007a; Sun et al., 2012; Tomul & Celik, 2009) and, more interestingly, our findings confirmed the importance of science self-efficacy (Alivernini et al., 2010; Lam & Lau, 2014; OECD, 2007a; Sun et al., 2012), also identifying levels of this variable that might be associated with large discrepancies in science proficiency. The self-concept, on the other hand, which has had controversial results in the literature (Alivernini et al., 2010; OECD, 2007a; Ozel et al., 2013), does not appear to have a particularly important role. As regards affective factors such as motivation and interest in science, variables which have been identified as correlated to positive results in PISA (Bybee & McCrae, 2011; Lam & Lau, 2014; Ozel et al., 2013; Sun et al., 2012), the present study shows that if one take into consideration a large number of countries and a large number of predictors at the student level, their role does not appear to be central to the achievement of extreme levels of competence.

Conclusions

This study, based on data from 25 countries, provides an in-depth analysis of students with serious discrepancies in their science proficiency, which extends our knowledge of the factors that, at various different levels, determine these contrasting outcomes. At the country level, the findings suggest that teacher salaries may be a relevant factor in explaining large performance gaps in science literacy between different educational systems. At the school level, parental pressure on schools and school size have been shown to be relevant factors associated with the gap in student performance between schools. At the student level, student awareness of environmental issues plays an important role in predicting science competencies. As in the case of previous studies, student socio-economic status and student self-efficacy are closely related to results in science subjects.

One characteristic of this study is that the two-step methodology we adopted allowed an accurate identification of the categories of variables and/or thresholds that are associated with the gap in science performance, and it therefore provided some very precise information for possible interventions. At the country level, as concerns the level of remuneration of teachers, it would seem that the point beyond which positive results tend to appear is when the teacher salary is slightly higher than the country's per capita domestic product. As regards the implications of the study for school policies, the results show that schools should encourage interactions with parents (Sun et al., 2012), while paying particular attention to the number of parents involved, since quantity seems the relevant factor in this case. If we consider what teachers can do in the classroom we have some confirmation of the results of preceding studies, as well as some new information. It is not surprising that promoting students' self-efficacy and awareness of environmental issues can lead to significant improvements in performance in science subjects. An important new discovery is that the amount of change required in these variables could be quite low in order to generate significant improvements in student performance. In fact, the present study suggests that a relatively small extra investment of time by teachers on these two specific issues, could lead to some very encouraging results, especially in improving levels of competence in students that are below those considered as basic. In conclusion, some specific elements of the present study should be noted as compared to the existing contributions on PISA that we have summarized in the literature review. These are elements which, as already mentioned in the discussion, should be carefully considered while making a comparison of the various results. The first specific element is that here three levels of analysis of the results are taken into account (country, school and student), while previous studies focussed on school and student levels. The addition of the country level and the matching of the PISA data-set with the OECD indicators of financial and human resources invested in education provided us with some new opportunities for analysis. The second element is that at each level (student, school and country) we considered a much higher number of potential predictors than was done in the studies previously carried out on PISA. The third specific element is that the focus of the present paper is on extreme levels of science literacy that are described in terms of associated skills and not in terms of the average performance of students.

Finally, it should be noted that one limitation of the present study, due to its explorative nature, is that it does not identify the specific mechanisms by means of which the various variables interact and it is not specifically focussed on causal explanations. A follow-up study could concentrate on testing different models, which would provide some alternative hypotheses to explain the relationships that have been identified in this particular study.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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