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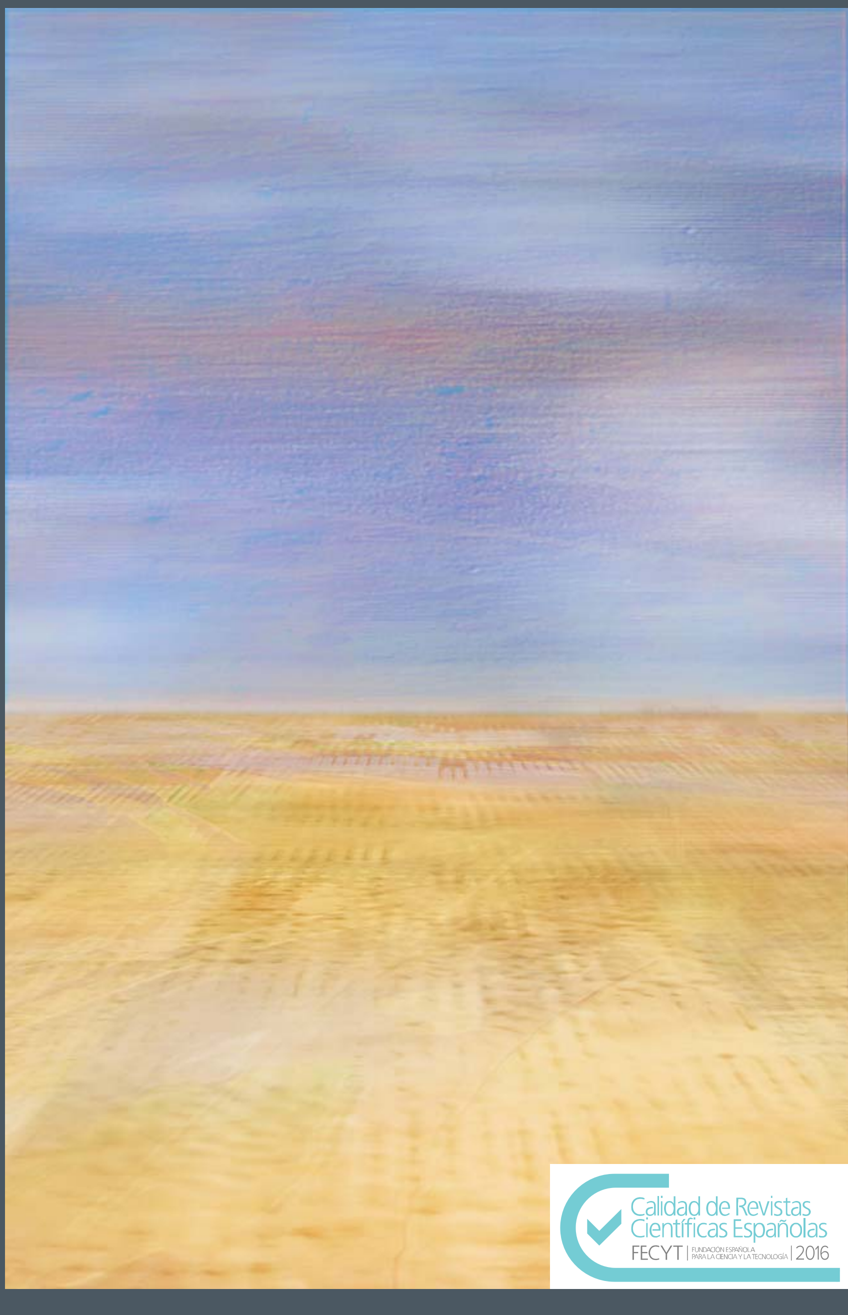

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The epistemic knowledge in the PISA 2015 evaluation of scientific competence[1]

El conocimiento epistémico en la evaluación de la competencia científica en PISA 2015

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Abstract

Science education research has developed a fruitful line on epistemology, sociology and the history of science contents (in short, nature of scientific knowledge or nature of science), because these contents are currently considered an essential component of scientific and technological literacy for average citizens. As a novelty, under the label of epistemic knowledge, PISA 2015 asks for students' opinions about the nature and validity of scientific knowledge, which constitutes the aim of this study. Three basic beliefs make up the theoretical framework of PISA 2015 for the epistemic knowledge: the recognition that scientific knowledge changes, the appreciation that empirical evidence is the basis of knowledge and the assessment of critical thinking as a tool to validate ideas and knowledge. From this framework, PISA 2015 constructs several indices to characterize epistemic knowledge and analyze students' beliefs. Results show that most students agree that scientific knowledge changes and empirical evidence is very important to validate knowledge. The most interesting result shows that, in all countries, the increase in the index of epistemic knowledge is positively and systematically associated with the increase of PISA science achievement average score. In addition, teacher-led instruction, good material equipment and per-

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sonnel in science department, research-based instruction and adaptive instruction are positively related to stronger beliefs of epistemic knowledge, whereas teacher qualification seems to have no influence. Finally, the main findings of the study, the methodological limitations of the six epistemic phrases in the student questionnaire, and the impact of research-based teaching are discussed.

Key words: Scientific and technological literacy, nature of science, epistemic knowledge, procedural knowledge, science evaluation, PISA 2015, teaching methods, inquiry-based teaching, teacher qualification, science department resources.

Resumen

La investigación didáctica en la enseñanza de la ciencia ha desarrollado una fructífera línea sobre contenidos de epistemología, sociología e historia de la ciencia (brevemente, naturaleza del conocimiento científico o naturaleza de la ciencia), porque se consideran hoy un componente esencial de la alfabetización científica y tecnológica de un ciudadano medio. Como novedad, PISA 2015 pregunta a los estudiantes sus opiniones acerca de la naturaleza y la validez del conocimiento científico bajo la etiqueta de conocimiento epistémico que constituye el objetivo de este estudio. Tres creencias básicas conforman el marco teórico de PISA 2015 para el conocimiento epistémico: el reconocimiento que el conocimiento científico cambia, la apreciación de que las evidencias empíricas son la base del conocimiento y la valoración del pensamiento crítico como medio para validar ideas y conocimientos. Desde este marco, PISA 2015 construye varios índices para caracterizar el conocimiento epistémico y desarrollar los análisis sobre las creencias de los estudiantes. Los estudiantes están muy mayoritariamente de acuerdo con las dos primeras creencias: el conocimiento científico cambia y la experimentación es muy importante para validar el conocimiento científico. El resultado más interesante es que, en todos los países, el aumento del índice de conocimiento epistémico se asocia positiva y sistemáticamente con un aumento de la puntuación media del rendimiento de ciencias. La instrucción dirigida por el profesor, el buen equipamiento en material y personal del departamento de ciencias, la instrucción basada en la investigación y la instrucción adaptativa se relacionan positivamente con creencias más fuertes de conocimiento epistémico, mientras la cualificación del profesorado parece no tener influencia. Finalmente, se discuten los principales hallazgos del estudio, las limitaciones metodológicas de las seis frases epistémicas del cuestionario de los estudiantes y el impacto de la enseñanza basada en investigación.

Palabras clave: alfabetización científica y tecnológica, naturaleza de la ciencia, conocimiento epistémico, conocimiento procedimental, evaluación en ciencias, PISA 2015, métodos de enseñanza, enseñanza basada en investigación, formación del profesorado, dotación de la educación.

Introduction: approach and foundation

Since more than twenty years ago, the contents of epistemology, sociology, and history of science (or knowledge of the nature of scientific knowledge) constitute a fruitful line of research in science education, as they are considered an essential component of scientific and technological literacy (McComas, 1998; Vázquez & Manassero, 2012). Under the heading of epistemic knowledge (EK), PISA 2015 has emphasized these contents as part of the evaluation of scientific literacy. The aim of this study is to analyze the results of this novel inclusion (OECD, 2016a).

The nature of science is the designation used to describe the interdisciplinary content about what science is and how science works in today's world to justify the knowledge it produces, which reflects the meta-cognitive level of thinking and scientific processes. The most transversal trait of different scientific disciplines is, perhaps, the provisionality of knowledge, that is, its constant openness to continuous revision and change; other general features are its empirical evidence basis and the use of a variety of methods to propose theories, laws, and explanatory models of natural phenomena, the human nature of the scientific enterprise and the pre-assumption of order and consistency in the natural systems (Vázquez & Manassero, 2012; McComas, 1998; Matthews, 2014).

The PISA 2015 theoretical framework to assess scientific literacy is the result of the evolution from the previous framework, developed for PISA 2006 assessment. Scientific literacy 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 (S&T), and to make decisions for daily life, which involves everything that 15-year-old students should know, appraise, and be capable of doing as their "preparation for life" in society. Students' ability to make use of these skills depends of their scientific knowledge, their positive attitudes towards scientific issues, and their willingness to engage in topics related to S&T. According to PISA, scientific literacy requires three competences:

- explaining phenomena scientifically (recognizing, offering and assessing explanations for a range of natural and technological phenomena),

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- assessing and designing scientific enquiry (describing and assessing scientific research and proposing ways of addressing issues scientifically), and
- interpreting data and evidence scientifically (analyzing and assessing the data, statements, and arguments and reaching the appropriate scientific conclusions).

Scientific literacy in PISA 2015 covers not only knowledge of the natural world and technological artifacts (knowledge of contents), but also the knowledge and comprehension of how (procedural knowledge and epistemic knowledge) such ideas are produced by scientists (OECD, 2016b). The scientific knowledge required for the development of the competences has three components:

- Knowledge of contents: comprehension of the main facts, concepts, and explanatory theories that form the basis of scientific knowledge and that include both the natural world and technological artifacts.
- Procedural knowledge: knowledge of the essential processes of scientific research for the production and derivation of scientific knowledge, which sustain the collecting, analysis, and interpretation of scientific data.
- Epistemic knowledge (hereafter EK): comprehension of the underlying reasons and justifications of these procedures and their use to obtain valid and reliable data, and the distinction between observations, facts, hypotheses, models and theories, but also to understand why certain procedures, such as experiments, are central to establishing knowledge in science.

Students should use these competences in specific, personal, local/national, and global contexts, both current and historical, and this requires some comprehension and certain attitudes toward S&T. Attitudes include positive dispositions and appraisal of scientific research, together with the perception and awareness of environmental issues. Students' capacity to apply their competences to specific contexts is influenced by their attitudes, their knowledge of scientific ideas and how they are produced and justified (EK).

The main novelty in the PISA 2015 framework is that the general concept of "knowledge about science" (2006) has been divided into two components: procedural and epistemic (EK). Precisely, this study seeks to present findings from PISA 2015 on this latter aspect (EK) as its central goal.

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Procedural knowledge refers to processes that involve dependent and independent variables, the distinction between different types of measures (qualitative and quantitative, categorical and continuous), ways of assessing and minimizing uncertainty (repeating measures and observations), strategies for variable control and their role in experimental designs, communication and presentation of results, and different degrees of certainty (depending on the nature and amount of empirical evidence).

EK refers to the comprehension of the nature of scientific knowledge, and it reflects students' capacity to think and to participate in a reasoned discourse, similar to that of scientists. Epistemology is the theory of the nature, organization, justifications, and sources of human knowledge; in other words, the theory of how knowledge is acquired and how people know that it is valid (BonJour, 2002; Hofer & Pintrich, 1997). EK is necessary to understand the difference between observations, facts, hypotheses, explanations, models, and theories, but also to understand why certain procedures, such as experiments, are essential to validate scientific knowledge.

EK conforms personal representations about what is considered "true" or how to establish the validity of an argument (Hofer & Pintrich, 1997). Students adopt a scientific approach to research when they question statements, seek data and their meaning, demand verification, respect logic, pay attention to the premises, and show dispositions that make up a scientific attitude. In fact, beliefs and dispositions are both traits that characterize scientific thinking, and it is has been shown that they are directly related to students' capacity to learn new knowledge and improve their grades in school science (Mason, Boscolo, Tornatora & Ronconi, 2013).

EK changes with age, as an effect of cognitive development and education (Kuhn, 2012). Older people are more prone to believe that scientific knowledge is complex, provisional, and evolutionary, that it is not the property of scientific authorities, and that it can be validated with confirmatory evidence (Mason et al., 2013). Students' beliefs about science as a body in constant change and the need for scientific experiments to justify scientific knowledge are also related to beliefs about learning, and in particular, with the belief that EK can be increased (Chen & Pajares, 2010).

The goal of this study is to analyze the EK outcomes of the PISA 2015 evaluation through beliefs about science, such as the positive disposition towards scientific reasoning, the commitment to use empirical evidence as the basis for beliefs, and the appraisal of critical thinking as a means to validate ideas.

Method

The set of guiding principles and methodological decisions for the development and application of the PISA 2015 assessment on scientific competence have been extensively detailed (OECD, 2016a). We present herein some basic elements to allow the reader to follow the outcomes about EK, the central goal of this study.

Participants

PISA 2015 establishes guidelines and standards for designing representative samples in order to achieve some measurement accuracy. Thus, it specifies a sample size through minimum number of participants (schools and students) to achieve representative samples of the population in each country, so that the collected data will accurately reflect the level of scientific literacy of the students of a country.

Approximately 535791 students, who attended 18541 schools of 70 countries, completed the PISA 2015 assessment, representing about 29 million 15-year-old youths. The sample of the 36 countries of the OECD has 248620 students belonging to 9370 schools. In Spain, the sample is 37205 students from 980 schools (MECD, 2016).

Instruments

The PISA 2015 contents of the science knowledge are grouped into three scientific areas:

- Physical systems
- Living systems
- Earth and space

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Nearly one-third of all the science items of PISA 2015 (61 out of 184) refers to physical systems, 74 to living systems, and the remaining 49 to terrestrial and space systems.

Scientific literacy requires comprehension of the main facts, concepts, and explanatory theories that form the basis of scientific knowledge of physics, chemistry, biology, and terrestrial and spatial sciences and how they are applied in contexts where the elements of knowledge are interdependent or interdisciplinary. Three response formats were used:

- simple multiple choice (select only one response, from four options, or a "hot spot", a selectable item within a chart or text)
- complex multiple-selection (a set of responses that are considered as a single element: a series of related questions, selecting various responses from a list, sentence completion by selecting options, filling in multiple blanks, matching, ordering, or categorizing), and
- constructed response (these require a written or drawn response, which varies from a sentence to a short paragraph, a drawing, a figure, or a diagram). To ensure reliable and comparable results and coding coherence, detailed technical guidelines and practical training are provided in the PISA 2015 Technical Report.

Approximately one-third of the items belong to each of the three previous response categories.

About one half of all the assessment items in PISA 2015 (98 out of 184) mainly evaluated the students' knowledge of contents. Sixty items evaluated the students' procedural knowledge and the remaining items (26 items, 10% of the total) assessed students' EK.

All the items of the PISA 2015 scientific test were assigned to one of these three categories of knowledge but, for the purpose of deriving subscales, the last two categories were combined into a single subscale called "procedural knowledge and EK", because there were very few "EK" tasks to support a separate EK subscale with appropriate psychometric properties.

By competences, approximately 50% of the items refer to scientifically explaining the phenomena, 30% to scientifically interpreting the data and tests, and 20% to assessing and designing scientific research. The combination of competences and the depth of the knowledge or item cognitive demand (low 30%, medium 62%, and high 8%) offer a variable range that allows evaluating scientific competence equitably.

PISA 2015 assessed the students' capacity to interpret scientific statements by means of test items classified in the EK category (for example, in the unit SLOPE-FACE INVESTIGATION). It also assessed personal beliefs about the nature of knowledge and research methods as sources of valid knowledge through the questionnaire of antecedents, where the students expressed their degree of agreement ("strongly agree", "agree", "disagree" or "strongly disagree") with statements about EK such as the following:

A. A good way to know if something is true is to do an experiment;
B. Ideas in science sometimes change;
C. Good answers are based on evidence from many different experiments;
D. It is good to try experiments more than once to make sure of findings;
E. Sometimes, scientists change their minds about what is true in science;
F. The ideas in science books sometimes change.

Procedure

Data should be collected in an equivalent way in all the countries, using equivalent assessment materials, so that the results of the tests are comparable between regions and countries.

PISA 2015 provides results of an overall scale of science literacy, which is based on all the scientific questions, as well as on the three scientific competences, the three areas of contents and the two categories of procedural knowledge and EK. The metric for the global scientific scale has an average of 500 points and a standard deviation of 100 points, established since PISA 2006.

To characterize EK, PISA 2015 builds a normalized index, so that the OECD average student would obtain an index value of zero and, approximately, two-thirds of the student population of the OECD would be between the values -1 and 1 (standard deviation 1). Negative (positive) values in the index imply that the students responded less (more) positively than the average response in the OECD countries. In addition, the authors built another single weighted index (range 1-4) to characterize each of the six EK phrases for each country.

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Results

The central goal of this study is to present the results of EK, due to its novelty in PISA 2015, and to relate it to other variables. Firstly, the results of the three main variables of knowledge are presented; then, the relationships of the EK index with the scores of global scientific competence, the specific analysis of the responses to the six phrases about the epistemology of science, through the authors' elaboration and, lastly, the relationships of EK with diverse variables of the context (OECD, 2016b, 2016c).

Tables of the results containing all the countries would be very extensive, so to respect the maximum extension of the journal, tables are only presented partially; the complete table can be consulted as complementary data.

Epistemic knowledge: global results

Table I shows the countries and grades in PISA 2015 in each of these three dimensions: students' general science performance, their performance in knowledge of contents, and in procedural knowledge and EK. Spain is located precisely at the average value corresponding to the OECD countries in the three dimensions of science performance.

Table I also shows the existing relation between the performance in the two scales of knowledge (knowledge of contents and procedural knowledge and EK), underlining the cells corresponding to countries where one of the two types of knowledge is significantly greater than the other. The fourth column shows 16 countries whose performance in the knowledge of contents is significantly greater than the performance in procedural knowledge and EK, whereas the last column contains 12 countries whose performance in procedural knowledge and EK is significantly higher than their performance in knowledge of contents.

For example, among the countries that are close to the OECD average, France and the United States are significantly stronger in the capacity of their students to resolve issues related to procedural knowledge and EK, whereas in Austria and the Czech Republic, the capacity of the students to resolve issues related to knowledge of contents is greater. However, in spite of these differences between the subscales of knowledge, the mean score of these four countries in the general scientific scale are not statistically different. Spain presents no significant differences between the two types of knowledge (contents vs. procedural knowledge and EK).

TABLE I. Comparison of countries in the different subscales of scientific knowledge of PISA 2015

	Average science performance (Global science scale)	Average performance Subscales of scientific knowledge		Relative strengths in science: Average performance in the subscales of scientific knowledge ...	
		Knowledge of contents (kc)	Procedural and epistemic knowledge (pe)	... knowledge of contents (kc) is greater than (pe)	... procedural and epistemic knowledge (pe) is greater than (kc)
Singapore	556	553	558		co
Japan	538	539	538		
Estonia	534	534	535		
Chinese Taipei	532	538	528	pe	
Finland	531	534	528	pe	
Macao (China)	529	527	531		co
Canada	528	528	528		
United States	496	490	501		co
Austria	495	501	490	pe	
France	495	489	499		co
Sweden	493	498	491	pe	
OECD average	493	493	493		
Czech Republic	493	499	488	pe	
Spain	493	494	492		
Latvia	490	489	492		co
Dominican Republic	332	331	330		

The blank rows correspond to a series of deleted countries; the complete table is offered in complementary files. (The original designation of countries in PISA 2015 report has been respected).

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Gender differences in the knowledge global performance (not shown due to lack of space) favor the boys, and are more marked for knowledge of contents than for procedural knowledge or EK. In the OECD countries, the mean difference between boys and girls in the science scores is low (4 points); but boys obtain 12 points more than girls in the subscale of knowledge of contents, and girls obtain 3 points more than boys in the subscale of procedural knowledge and EK. This suggests that girls are more interested in knowing how scientists investigate and build scientific theories, whereas boys are relatively more interested in the explanations of phenomena provided by science.

Epistemic Knowledge Index: relations with performance

In this section, the science performance is compared with the index of the pure EK component (devoid of the procedural component). Table II presents the list of countries, arranged from highest to lowest value of the EK index.

The results of Table II allow us to observe that some countries with low scores in average science performance (such as Iceland and Israel) are near the top (third and eleventh position, respectively) according to the average EK index. Other similar examples would be countries with a modest score of average science performance, located at the average of the OECD (United States, Sweden and Spain) which also have high average EK indices (among the first fourteen places).

A similar symmetrical situation occurs at the bottom of the EK index, where obviously there are some countries with low scores in global science performance, but the presence of some countries with significantly high scores (Netherlands and Germany), and other countries with science performance at the average of the OECD (Czech Republic and Lithuania) is noticeable.

TABLE II. Indices that represent epistemic beliefs (support for scientific research methods)

	Average science performance	EK about the nature and origin of scientific knowledge	
		EK index (support for scientific research methods)	Difference of points of performance by unit in the EK index
	Mean	Mean index	Differences
OECD average	493	0,00	**33**
Chinese Taipei	532	0,31	**38**
Canada	528	0,30	**29**
Iceland	473	0,29	**28**
Portugal	501	0,28	**33**
Australia	510	0,26	**39**
United States	496	0,25	**32**
United Kingdom	509	0,22	**37**
Singapore	556	0,22	**34**
New Zealand	513	0,22	**40**
Ireland	503	0,21	**36**
Israel	467	0,18	**38**
Denmark	502	0,17	**32**
Sweden	493	0,14	**38**
Spain	493	0,11	**30**
Slovak Republic	461	-0,35	**36**
Hungary	477	-0,36	**35**
Romania	435	-0,38	**27**

The blue cells represent scores of the variable significantly higher than the mean; grey cells represent scores significantly lower than the mean; white cells represent scores whose difference with the mean is non-significant. The empty rows correspond to a set of deleted countries.

The most interesting outcome of Table II is in the last column, which presents the increase of points in the average science performance per unit of the EK index (about the nature and origin of scientific knowledge). The increase global average is 31 points, but the most notable characteristic of these incremental differences is that all of them are positive, that is,

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an increase of the EK index is systematically associated with a positive increase of the average science performance.

Although this association is positive and significant for all countries, the scores vary a lot across countries, from the maximum (Malta, 54 points) to the minimum (Dominican Republic, 13 points). Thus, even the countries with the lowest and negative EK indices display differences of improvement in the global science performance that are not only positive but, in some cases, high and even higher than the mean. For example, Hungary and the Slovak Republic, which occupy the second to last and third to last place in the EK index (around the lowest EK indices), have associated values of 35 and 36 points of positive increase in the global science performance. Spain occupies place number 14 according to the EK index, although the increase of the global science performance is on the mean (30 points). At the other end, the association in Algeria, Costa Rica, Dominican Republic, Indonesia, Kazakhstan, Mexico and Tunisia is positive, though notably weaker.

Globally, less than 6% of the variation in the science performance can be explained by differences in the students' EK (positive difference under 20 points in the associated mean science performance per unit in the EK index). However, for girls, the differential variation in science performance attributed to their EK of science represents approximately 12%, a relatively high score, comparable to the variation of performance associated with the students' socioeconomic status.

For OECD countries, an increase of one unit in the EK index improves the scientific assessment of PISA by an average of 33 points of science performance, which is approximately the estimated increase for one year of schooling. Among the countries with greater science performance, the EK average beliefs display higher variability than the countries with lower science performance, where students tend to have lower EK indices. Further, the mean correlation index between EK index and global science performance is moderate and positive (0.5).

In sum, the fact that all the differences in the fourth column are positive scores for all countries indicates that higher levels of agreement with the questions that reflect students' EK beliefs are associated with a higher performance. This outcome indicates a sound positive relation between science performance and epistemic comprehension, such that the more firmly the students agreed that science ideas change with time and that experiments provide good ways of establishing whether something is true, the better their science performance in PISA 2015.

Epistemic knowledge: results for the six epistemological phrases

The most important part of the results about EK is based on the six phrases about the nature of scientific knowledge and research, about which students had to express their level of agreement (or disagreement).

The average levels of support to these six epistemic statements of the survey show very high averages in the OECD countries (around 80% of responses of agreement or strong agreement with each statement). Thus, 84% of the students expressed agreement with the statement that a good way of knowing if something is true is to do an experiment; 81% agreed that science ideas sometimes change; 86% reported that good answers are based on evidence from many different experiments; 85% agreed that it is good to try experiments more than once to make sure of findings; 80% agreed that sometimes scientists change their minds about what is true in science; and 79% agreed that the ideas in science books sometimes change (FIGURE I).

These high percentages of agreement vary across countries. Whereas more than 93% of the students in Ireland, Singapore, and Taipei reported that good answers are based on evidence from many different experiments, less than 77% of the students in Albania, Algeria, Austria, Montenegro, and Turkey agreed with that statement. Similarly, more than nine out of ten students in Australia, Ireland, New Zealand, Portugal, Taipei, United Kingdom, and United States agreed that ideas in science sometimes change, but barely six out of ten students of Austria, Indonesia, Lebanon, Romania, and Tunisia agreed with this.

The results referring to the students' high degree of agreement on these six epistemic issues were elaborated in depth. The percentages of students' direct response to each of the original four-category format of the Likert scale (agreement-disagreement) were collapsed into a mean weighted index by country; this index is the average of each one of the four points of the scale (1-2-3-4) weighted by the percentages of response to each point. This mean weighted index of the degree of agreement takes into account more precisely the different distribution of the percentages of the four categories of agreement-disagreement and, at the same time, it reflects simply and synthetically the position of each country on each of the sentences (Table III).

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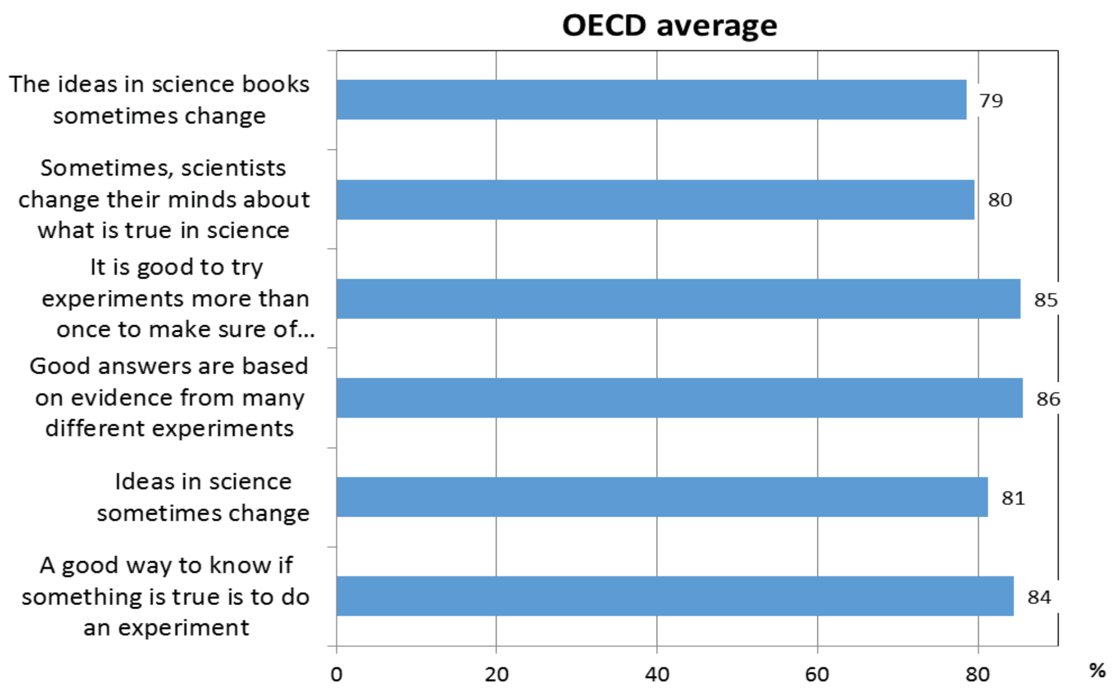
FIGURE I. Percentage of students belonging to OECD countries who agree or strongly agree with each of the 6 phrases that represent diverse epistemic beliefs about scientific and technological knowledge



The mean weighted indices of the OECD countries (overall average M = 3.02) and the mean weighted indices of the partner countries (overall average M = 2.97) are shown at the end of Table III. The comparison of the global averages of both groups of countries on the six questions allows us to observe (Figure II) that the partners have systematically lower mean indices than the OECD countries, and that the quantitative differences between the two groups are very small and similar in the six phrases examined (approximately 0.05 points of the scale employed 1-4).

The average profiles of the phrases in the two groups of countries are approximately parallel, and the relative maximum and minimum are also the same in the two groups (FIGURE II). In the group of OECD countries, phrase D reaches the highest weighted index of all (M = 3.15) and very close to that of phrase C (both about the goodness of repeating experiments); in contrast, the phrases with the minimum scores are all in the group of partners (phrases B, E, and F around change), although they all locate within the area of clear agreement (M = 2.89). Phrase A is located in an intermediate position between the two relative maximums and minimums.

TABLE III. Mean weighted indices of the degrees of agreement/disagreement with the six phrases of epistemic beliefs for each country, which are arranged from highest to lowest mean index score (elaboration of authors)

	Six phrases about epistemic beliefs						
	A (%)	B (%)	C (%)	D (%)	E (%)	F (%)	Media (1-4)
Portugal	3,15	3,17	3,17	3,28	3,15	3,17	3,18
Canada	3,13	3,17	3,25	3,27	3,12	3,12	3,18
Australia	3,10	3,17	3,24	3,33	3,09	3,06	3,16
Iceland	3,15	3,09	3,25	3,30	3,09	3,06	3,16
Ireland	3,24	3,10	3,27	3,37	2,96	2,97	3,15
United States	3,11	3,18	3,21	3,28	3,06	3,08	3,15
New Zealand	3,10	3,13	3,22	3,35	3,06	3,04	3,15
United Kingdom	3,11	3,15	3,19	3,34	3,06	3,05	3,15
Denmark	3,16	2,96	3,19	3,19	3,19	2,95	3,11
Israel	3,15	3,03	3,17	3,27	3,01	2,97	3,10
Sweden	3,05	3,03	3,15	3,23	3,05	3,03	3,09
Spain	3,12	2,95	3,18	3,25	2,96	2,99	3,08
OECD average	3,05	2,94	3,10	3,15	2,93	2,92	3,02
Finland	3,00	2,94	3,10	3,13	2,86	2,88	2,99
Slovak Republic	2,78	2,77	2,90	2,90	2,78	2,76	2,81
Partners							
Chinese Taipei	3,05	3,22	3,27	3,24	3,18	3,20	3,19
Singapore	3,16	3,06	3,27	3,36	3,05	3,03	3,16
Malta	3,08	3,03	3,21	3,34	2,88	2,90	3,07
Romania	2,82	2,67	3,03	3,00	2,69	2,63	2,81
Partners Media	2,99	2,89	3,06	3,11	2,89	2,89	2,97

The blank rows correspond to countries not shown here.

A. A good way to know whether something is true is to do an experiment;
B. The ideas of sciences sometimes change,
C. Good answers are based on the evidence of many different experiments;
D. It is good to try experiments more than once to ensure their findings;
E. Sometimes, scientists change their minds about what is true in sciences;
F. Ideas in science books sometimes change.

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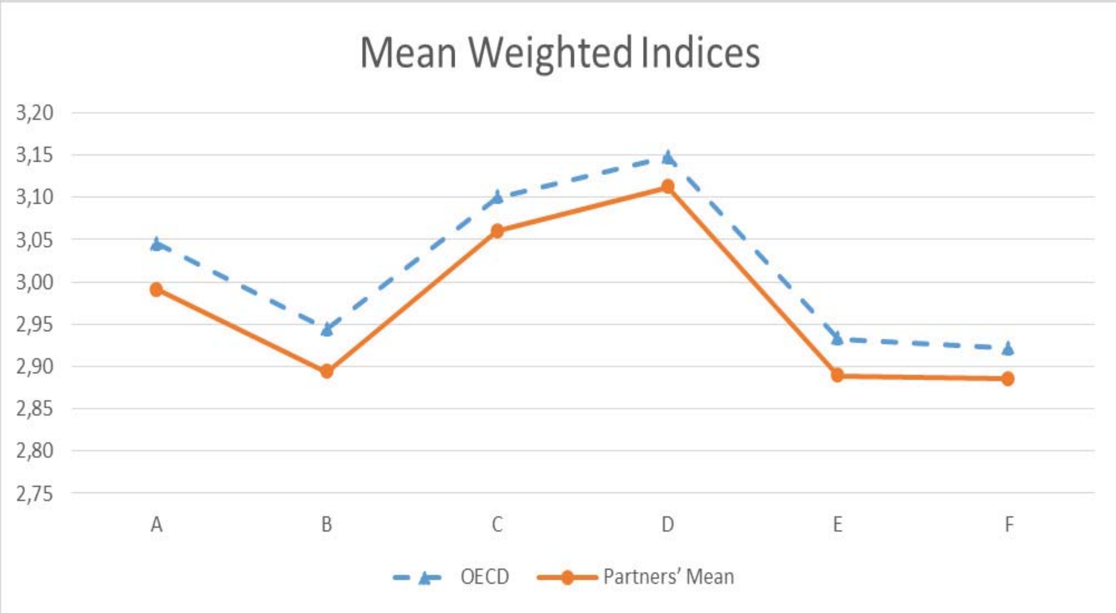
FIGURE II. Mean weighted indices in the OECD countries and participant partners in the PISA 2015 study in the six questions (A, B, C, D, E, and F) of epistemic knowledge (elaboration of authors)



The differences by gender in the students' EK are usually small. When they are relevant, the most frequently observed pattern is that girls support empirical approaches to research as a source of knowledge more than boys and they also agree more strongly that scientific ideas are provisional and subject to change. The largest difference between girls and boys occurs in Jordan (86% of the girls agreed that a good way to know whether something is true is to do an experiment versus only 62% of boys). Other countries with large differences in favor of girls are Georgia, Lithuania, and Slovenia.

Epistemic knowledge: relations with other contextual variables.

This section explores the relations between EK and diverse contextual school variables, such as the school resources dedicated to science and the teaching practices within classrooms, extracted from the questionnaires of antecedents answered by headmasters and students.

The school resources examined include the quality and availability of science laboratories, the qualifications of the teaching staff, and the availability of extracurricular activities related to science. The science teaching practices methods include variables such as instruction, feedback, adaptive instruction, and research-based instruction.

Teacher-directed instruction

The PISA 2015 results show that when teachers frequently explain and demonstrate scientific ideas and discuss the students' questions (teacher-directed instruction), the students obtain the highest results in science performance, stronger epistemic beliefs about the value of scientific research, and they hold higher expectations of future work in a science-related job.

According to students' reports, in the OECD countries, the teachers of advantaged schools explain or demonstrate a scientific idea (teacher-directed instruction) with greater mean frequency than the teachers of disadvantaged schools. The students who reported that their science teachers frequently use these methods and adapt their teaching to meet the students' needs have a higher science score and show stronger EK.

The equipment of the science department

In the OECD countries, the average general data indicate that the students achieve better science results and show stronger EK when the school headmasters report that the Science Department of the school is better equipped in material and staff.

The students of schools whose headmasters reported that the Science Department is well equipped and has a good staff, in general, perform better in science (an average of three points more for each positive statement of the headmaster about the equipment of the Science Department) after controlling for the socio-economic profile of the students and the schools. However, a well-equipped and well-staffed science department is less closely related to the students' beliefs about EK; only in 12 countries do the students have strong EK when the science department of their school is well equipped. Spain is not in this group, in spite of achieving a relatively high EK index.

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The qualification of the science teaching staff

This factor is considered in PISA 2015 by means of two variables: the general teaching qualification and the specialization in science through a university title. In the majority of the educational systems, the proportion of certified science teachers does not show any relation with the students' science performance.

In all the OECD countries, for every ten percentage points of increase in the number of fully certified science teachers, the students' science performance only improved 1.2 points, after controlling for the socio-economic profile of the students and schools. The relation between the proportion of fully certified science teachers and students' EK seems to be even weaker, and there are few countries where the relation is perceptible.

In the majority of educational systems, the percentage of teachers with a university title and scientific qualifications is not related to the students' results. Similarly, in the OECD countries, a greater proportion of qualified teachers does not necessarily translate into stronger epistemological beliefs among the students of a school. However, on average, in the OECD countries and in another 13 countries, the students achieve better science results when their schools have a greater proportion of science teachers with a Bachelor's degree and a specialty in science. In some cases, as the Netherlands and Qatar, for example, an increase of ten percentage points in the number of science teachers with a university title and specializing in science is associated with an improvement of nearly eight points in science performance, after controlling for the socio-economic profile of students and schools.

Adaptive instruction

Adapting the teaching to the students' needs by providing individual help to the students who make an effort, or changing the lesson structure a about a theme that most of the students find difficult is related to higher science scores and stronger EK.

It is interesting to observe that, in almost all educational systems that participated in PISA 2015, the students who reported that their science teachers use adaptive instruction frequently achieve higher scores in the

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scientific assessment of PISA, and these students also have stronger EK. The association with the students' performance is particularly strong in the Nordic countries and the Netherlands, Qatar, Singapore, and the United Arab Emirates, whereas the association with EK is stronger in the Dominican Republic, Qatar, and the United Arab Emirates.

The students of disadvantaged and rural schools are more likely to report that their teachers provide feedback; however, in these schools, the science teachers' perception of feedback is associated with a poorer science performance, probably because the less capable students receive more feedback than students who perform better.

In the OECD countries, students who attend schools where there are extracurricular activities related to science have stronger EK beliefs.

Inquiry-based instruction

A surprising outcome is that in any educational system where the students reported that they were frequently exposed to research-based teaching (experimentation and practical activities are practiced), they obtained higher science results. On the other hand, after controlling for the socio-economic profile of the students and schools, a greater exposure to research-based instruction is even associated negatively with science performance in 56 countries. However, in the OECD countries, research-based teaching is positively related to students' stronger EK.

Discussion and conclusions

As a novelty regarding former evaluations in scientific competence, PISA 2015 asked the students some questions about the nature and the validity of scientific knowledge and research (epistemic knowledge, EK). The relevance of the theme as a center of interest for this study of PISA 2015 arises not only due to its novelty, but also to the fact that EK, whose referents are the contents of philosophy, sociology, and history of science, currently constitutes an important research line in science education (Matthews, 2014).

As shown by the data of Table III, Spain achieved good results in the EK index –among the first countries– a fairly important place, much better

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than the place achieved in the results for the global science performance, as compared with other countries.

The main finding of PISA 2015 is the sound positive relation between students' EK and their science performance. The students whose EK agrees more with the current conceptions about the nature of science achieve higher global science performance. This outcome shows an undisputable and close association between the two variables that is very important for the research on the nature of science, because it provides empirical evidence for a widespread thesis among researchers, namely: a better understanding of the EK themes leads to an improvement in the understanding of other science themes (procedural and knowledge contents). Therefore, the positive relation between science performance and EK found in PISA 2015 is relevant because it adds unequivocal and systematic empirical evidence of this widely held hypothesis (Lederman, 2008). However, this outcome cannot be interpreted as evidence of a causal relation between them.

The six sentences that valued EK in PISA 2015 are simple and easy, as some researchers suggested for EK (Matthews, 1998), but this characteristic can also make them susceptible to criticisms. Their wording is so simple that it would allow the students to easily find examples to confirm their agreement with each sentence, thus eliciting easy agreement; in contrast, the students would not so easily find counterexamples that might induce their disagreement. This interpretation could explain the high rates of agreement obtained, whose proximity to unanimity turns them also into a surprising outcome in research. A similar answer of high agreement about change in science was also obtained in another study with a related, though more elaborated, sentence (Scientific knowledge changes because old knowledge is reinterpreted in the light of new discoveries; therefore, scientific facts may change) about the same issue (Vázquez-Alonso, Manassero-Mas & Talavera, 2010).

At the same time, the design of the EK assessment exhibits some limitations (scarce number of measurement items), whose consideration should contribute to a better contextualization of the results. It is well known that a low number of measurement items decreases the assessment reliability; overall, EK is assessed through six phrases that cover two EK issues (change and empirical evidence), whose improvement requires increasing them, obviously.

The results about EK should also be taken with caution due to the potential lack of linguistic equivalence of the six phrases, among the multiple languages of the many countries to which they were translated to assess students' EK. These elements could not have been understood in the same way across the different languages, which may have an unknown impact on the mean index and, as a consequence, on the classifications of the countries. In addition, the lower response rate to the questionnaire of antecedents, where the six EK phrases were placed, could be affecting the international comparisons to an unpredictable extent. For this reason, the measures and differences among the countries derived from the EK scale should be interpreted with caution, as it is not possible to ensure its concurrent validity across languages and countries with the same rigor as for the tests.

The forced amalgamation of EK and procedural knowledge in a single variable, which PISA 2015 justifies by not ensuring its validity and reliability by taking them separately, due to its low number of items (barely 10% of the total), could be controversial. From the perspective of research, procedural knowledge and knowledge about the nature of science (EK) are considered clearly different concepts. Consequently, their confusion is detrimental to clarify their respective teaching and learning, as well as the potential results of research (Lederman & Lederman, 2012).

The results referring to the relation of EK with other variables show that it is positive, in particular, with research-based teaching in educational systems where the students reported they were frequently exposed to it. As research-based teaching enables students to perform more scientific practices, it seems very likely interpreting that these practices may induce students' better epistemic understanding, although epistemic issues had not been taught explicitly. However, it should be noted that these students do not achieve better science content knowledge, reproducing the same PISA 2006 pattern; a more extensive justification of this apparently contradictory outcome can be seen in Romero-Ariza (2017).

Lastly, the lack of relation between the teaching staff's qualification and the students' performance is consistent with studies that claim that having highly qualified teachers is not sufficient to enhance learning (Hanushek, Piopiunik & Wiederhold, 2014; Palardy & Rumberger, 2008).

In sum, although the positive association between students' EK and their science performance seems consolidated, the problematic reliability, the cross-sectional nature of the data and the uncertainty about the

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cross-cultural validity of the EK scale suggest room for methodological improvements and do not allow supporting a possible cause-effect relationship.

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