Performance in science, epistemic conceptions, and STEM vocations in Spain's autonomous communities: evidence from PISA 2015, improvement policies, and practices

Rendimiento en ciencias, concepciones epistémicas y vocaciones STEM en las comunidades autónomas españolas. Evidencias desde PISA 2015, políticas y prácticas de mejora

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Abstract:

Knowledge plays a vital role as the key to long-term economic development, at both the national and regional levels. Furthermore, the new circumstances require the exercise of mature citizenship at an intellectual level and responsible citizenship in the political sphere. By its very nature, science education can make a decisive contribution towards achieving the two goals of economic development and civic progress. From this dual perspective, this work analyses the data from PISA 2015. Its aim is to provide an empirical analysis of the relative positions of the 17 Spanish autonomous communities in terms of science education. It focuses on three main variables and how they are related: students' performance in science, their epistemic conceptions, and their STEM

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vocations. A number of recommendations for improvement policies and practices relating to this evidence are made.

Keywords: PISA 2015, science education, Spanish autonomous communities, regional economic development, civic progress, improvement policies.

Resumen:

El conocimiento desempeña un papel determinante como clave para el desarrollo económico a largo plazo, tanto en el ámbito de los estados como de sus regiones. Además, el nuevo contexto demanda el ejercicio de una ciudadanía madura en el plano intelectual y responsable en el plano político. Por su propia naturaleza, la educación científica puede contribuir decisivamente al logro de estos dos tipos de metas, de desarrollo económico y de progreso cívico. Desde esta doble perspectiva, el presente trabajo efectúa análisis secundarios sobre la base de datos de PISA 2015. Se pretende generar con ellos un diagnóstico empírico de la situación relativa de las 17 comunidades autónomas en materia de educación científica. Se ha centrado la atención en tres variables principales: el rendimiento en ciencias, las concepciones epistémicas de los alumnos y sus vocaciones STEM. En relación con tales evidencias, se formulan algunas recomendaciones sobre políticas y prácticas de mejora.

Descriptores: PISA 2015, educación científica, comunidades autónomas, desarrollo económico regional, progreso cívico, políticas de mejora.

1. Introduction

Education and training systems have become potentially effective instruments for adapting economies and societies to a complex setting. As a result of the many factors involved and how they interact, non-linear dynamics have been created that accelerate historical time (López Rupérez, 2001).

There is a broad consensus, based on everyday evidence, that the development of science and technology is one of the driving forces behind these rapid processes of change. Klaus Schwab has described the new outlook as follows:

> Unprecedented and simultaneous advances in artificial intelligence (AI), robotics, the internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, quantum computing and others are redefining industries, blurring traditional boundaries, and creating new opportunities. We have dubbed this the fourth industrial revolution, and it is fundamentally changing the way we live, work and relate to one another (Schwab, 2016, p. 1).

This overview of the development of the context clearly underlines the significant interrelationship between technology, economy, and society that characterises this setting.

The most recent studies on teaching and learning focus on cognitive and non-cognitive skills as essential curriculum elements. Cognitive skills include critical thinking skills, problem solving skills, and skills for building and evaluating arguments based on evidence, etc. (NRC, 2012). Non-cognitive skills include perseverance, determination, resilience, self-control, and so on (US Department of Education, 2013; Méndez et al., 2015). As Kautz, Heckman, Diris, Weel, and Borghans (2014) have noted, regarding non-cognitive skills, their predictive power rivals that of cognitive skills in a broad range of results throughout life, including school achievement. In particular,

> conscientiousness —the tendency to be organised, responsible, and hardworking— is the most widely predictive across a variety of outcomes (see Almlund et al., 2011; Borghans et al., 2008; Heckman & Kautz, 2012; Roberts et al., 2007). This ability predicts the number of years of schooling with the same strength as intelligence measurements (Almlund et al., 2011) (Kautz et al, 2015, p. 23).

This OECD working paper notes that:

> Because both cognitive and non-cognitive skills can be shaped and changed over the life cycle, they are properly called skills. An older terminology in psychology refers to them as "traits", conveying a sense of immutability or permanence, possibly due to their heritable nature. The distinction between skills and traits is not just a matter of semantics. It suggests new and productive avenues for public policy (Kautz et al., 2014, p. 10).

In effect, and in line with the evidence, skills can change with age and especially as a result of instruction, and so both factors must be considered in school education (López Rupérez & García García, 2017).

Another concept which is consolidating itself, hand-in-hand with advances in the cognitive sciences, is "deep learning". Cognitive scientists have underlined the importance of deep conceptual comprehension in learning, having found that children retain knowledge better and can apply it in different contexts if they have a *deep knowledge* rather than a *superficial knowledge* (Sawyer, 2008). As the US National Research Council noted in the work cited above,

> the product of deeper learning is transferable knowledge, including content knowledge in a domain and knowledge of how, why, and when to apply this knowledge to answer questions and solve problems (NRC, 2012, pp. 5-6).

Science education is an important area for developing the skills and competences required by the society and economy of the 21st century. The semantic richness of its conceptual frameworks; the variety of types of knowledge it covers; the power of the concepts it transfers, which is often linked to the degree of abstraction and high level of commonality; the natural occurrence of cooperative learning situations associated with the research methodology itself; the development of personal discipline, perseverance, and a sense of effort linked to the cognitive or intellectual demands of its theoretical frameworks; its humanistic background linked to philosophical reflection and its historical evolution, are some of the features that make it a privileged area for acquiring the cognitive and non-cognitive skills required of the student.

Indeed STEM teaching (Science, Technology, Engineering, Mathematics) is an extension of the earlier area of reflection regarding the present and future importance of science education. Thanks to its impact on the economy and employment (WEF, 2016), it has attracted the attention of European institutions (Council of the European Union, 2009; EU STEM Coalition, 2015), and also because the corresponding competences are part of the necessary civic baggage that will enable citizens of the 21st century to participate actively in processes and decisions that will fully affect their lives (European Commission, 2015).

In the face of this complex panorama, the development of science education is a basic element in the potential for economic and social development of Spain's autonomous communities. As noted in the IVIE-Fundación BBVA report on "*La competitividad de las regiones españolas ante la Economía del Conocimiento* (The competitivity of the Spanish regions in the knowledge economy)":

> A growing consensus in Spanish society has emerged regarding the need to modify the features of this model of regional growth to consolidate it on more solid foundations that guarantee an ongoing increase in productivity and, consequently, access to higher levels of social well-being. The idea that attempts to summarise the features of this new model is that it should be inspired by the so-called knowledge economy (Reig Martínez et al., 2016, p. 7).

And, as the authors emphasise further on, citing a variety of sources with a solid empirical base, knowledge has a vital role as the key to long-term economic development.

The 2015 PISA report has opened an unprecedented window of opportunity for Spain by recording the participation of the 17 autonomous communities with a broad and statistically representative sample of the population at a regional level for the first time in the history of this international evaluation programme. This makes it possible to evaluate students' real level of knowledge and competences, in this case in the particular field of science education. The fact that this evaluation takes place in the framework of compulsory education makes it possible to reflect on the extent to which the general population has acquired basic competences and the predictive power of this, in comparative terms, for likely future economic and social development.

This study provides a systematic description of the Spanish autonomous communities with regardvs to students' performance in science, epistemic conceptions[1], and STEM vocations, based on the PISA 2015 data. This makes it possible to perform a comparative analysis with the help of linear regression analysis, and then to formulate reflections and suggestions regarding policies and practices aimed at improving scientific teaching and learning.

2. Methodological framework

2.1. Sample

The samples used correspond with the 17 autonomous regions as data clusters and also with the micro-data —relating to students— from each community that refer to other statistically representative expanded samples of the respective populations of 15-year-old school pupils.

A total of 39,066 Spanish students participated in the PISA 2015 survey. The representative sample for Spain comprises 6,736 students. The sample sizes for each of the autonomous regions, along with the percentages for the corresponding populations, are shown in Table 1 (in the analyses presented, the weighting established for international comparison is used in relation to the representative sample of the Spanish population and for each of the autonomous regions).

2.2. Measurement instruments

The measurement instruments used are the ones that enabled the 2015 edition of PISA to obtain the data, some of the secondary analyses of which will be the object of this study: the science

TABLE 1. Size of the samples of students from each of Spain's 17 autonomous communities and their populations as percentages.

	N	%
Andalusia	1,813	4.6%
Aragon	1,798	4.6%
Asturias	1,790	4.6%
Balearic Islands	1,797	4.6%
Canary Islands	1,842	4.7%
Cantabria	1,924	4.9%
Castile and Leon	1,858	4.8%
Castile-La Mancha	1,889	4.8%
Catalonia	1,769	4.5%
Comunidad Valenciana	1,625	4,2%
Extremadura	1,809	4.6%
Galicia	1,865	4.8%
La Rioja	1,461	3.7%
Madrid	1,808	4.6%
Murcia	1,796	4.6%
Navarre	1,874	4.8%
Basque Country	3,612	9.2%

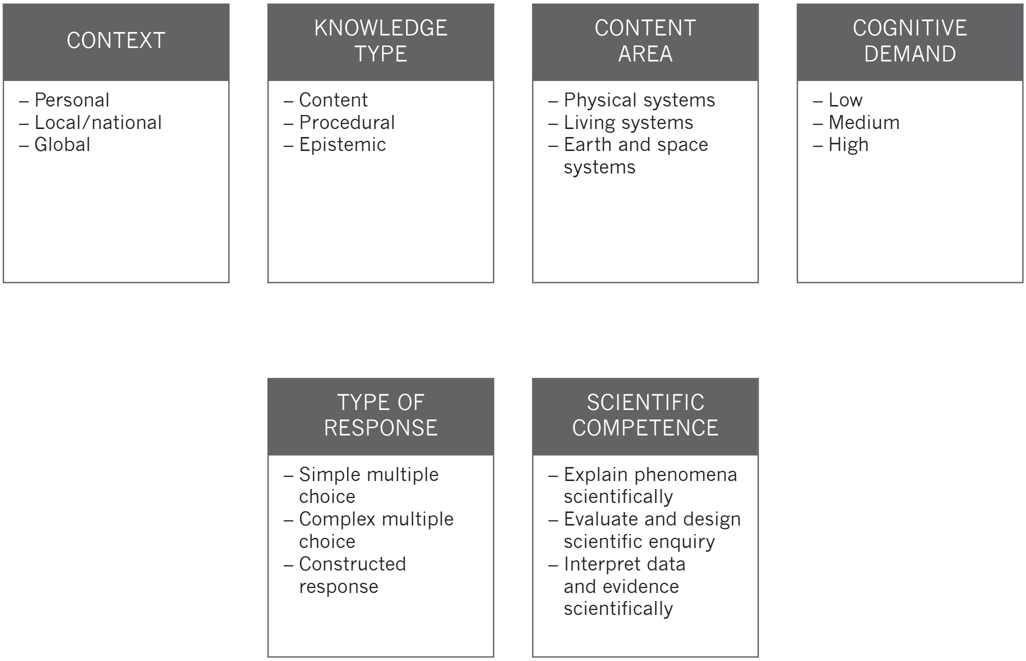
Source: Own elaboration based on data from PISA, 2015.

surveys and the personal context questionnaires, in particular the one referring to students' expectations of having a science-related career in future (when they are 30).

2.2.1. The tests

The complete structure of the properly cognitive area of the PISA 2015 science surveys is available in the report by the OECD and is summarised in Graph 1.

Graph 1. Descriptive categories of the PISA 2015 evaluation elements in the field of science.



Source: Own elaboration based on OECD, 2016a.

The basic structure of the science survey is presented below with the help of descriptive Tables 2 and 3 which have been drawn up by the authors through direct processing of the information contained in tables C2.1 and C2.2 (OECD, 2016a)[2]. These tables clarify the complex distribution of the set of items in the different subscales.

Table 2 presents the distribution of all of the items in the three categories or subscales: namely, types of scientific knowledge, scientific competences, and content areas.

Table 2. Distribution of all items in the three categories or subscales: types of scientific knowledge, scientific competences, and content areas.

Competence	**Type of knowledge**							
Content areas	Content		Procedural		Epistemic		Total	
Explain phenomena scientifically	83	84.7%	4	6.7%	2	7.7%	89	48.4%
Physical	*34*	*41.0%*	*1*	*25.0%*		*0.0%*	*35*	*39.3%*
Living	*30*	*36.1%*	*3*	*75.0%*		*0,0%*	*33*	*37.1%*
Earth and space	*19*	*22.9%*		*0.0%*	*2*	*100.0%*	*21*	*23.6%*
Evaluate and design scientific enquiry	1	1.0%	19	31.7%	19	73.1%	39	21.2%
Physical		*0.0%*	*9*	*47.4%*	*7*	*36.8%*	*16*	*41.0%*
Living	*1*	*100.0%*	*10*	*52.6%*	*7*	*36.8%*	*18*	*46.2%*
Earth and space		*0.0%*		*0.0%*	*5*	*26.3%*	*5*	*12.8%*
Interpret data and evidence scientifically	14	14.3%	37	61.7%	5	19.2%	56	30.4%
Physical	*4*	*28.6%*	*6*	*16.2%*		*0.0%*	*10*	*17.9%*
Living	*3*	*21.4%*	*18*	*48.6%*	*2*	*40.0%*	*23*	*41.1%*
Earth and space	*7*	*50.0%*	*13*	*35.1%*	*3*	*60.0%*	*23*	*41.1%*
Total. Physical	*38*	*38.8%*	*16*	*26.7%*	*7*	*26.9%*	*61*	*33.2%*
Total. Living	*34*	*34.7%*	*31*	*51.7%*	*9*	*34.6%*	*74*	*40.2%*
Total. Earth and space	*26*	*26.5%*	*13*	*21.7%*	*10*	*38.5%*	*49*	*26.6%*
Total	98	100.0%	60	100.0%	26	100.0%	184	100.0%

Source: Own elaboration based on the information from the C2.1 and C2.2 charts (PISA, 2016b).

For its part, Table 3 shows the distribution of the total set of items in the categories, or subscales and the types of scientific knowledge and competences, and also shows the level of cognitive demand of the corresponding items.

Accordingly, 21.2% of the 184 items in the test correspond to the "explain phenomena scientifically" competence, 48.4% to "evaluate and design scientific enquiry", and 30.4% to "interpret data and evidence scientifically". Furthermore, 53.3% of the items correspond to "content knowledge", 32.6% to "procedural knowledge", and 14.1% to "epistemic knowledge". Finally, 31.2% correspond to "physical" systems, 40.2% to "living", and 26.6% to "earth and space". As for the level of exigency or cognitive demand, 30.4% of the items have a low level of cognitive demand, 61.4% a medium level, and just 8.2% a high level.

TABLE 3. Distribution of the total set of items by category or subscale, type of scientific knowledge, and competences showing the level of cognitive demand of the corresponding items.

Type of knowledge	**Cognitive demand**							
Scientific competence	Low		Mean		High		Total	
Content	*44*	*78.6%*	*50*	*44.2%*	*4*	*26.7%*	*98*	*53.3%*
Explain phenomena scientifically	41	93.2%	40	80.0%	2	50.0%	83	84.7%
Evaluate and design scientific enquiry		0.0%	1	2.0%		0.0%	1	1.0%
Interpret data and evidence scientifically	3	6.8%	9	18.0%	2	50.0%	14	14.3%
Procedural	*9*	*16.1%*	*43*	*38.1%*	*8*	*53.3%*	*60*	*32.6%*
Explain phenomena scientifically		0.0%	1	2.3%	1	12.5%	2	3.3%
Evaluate and design scientific enquiry	2	22.2%	13	30.2%	4	50.0%	19	31.7%
Interpret data and evidence scientifically		0.0%		0.0%	6	75.0%	29	48.3%
Epistemic	*3*	*5.4%*	*20*	*17.7%*	*3*	*20.0%*	*26*	*14.1%*
Explain phenomena scientifically		0.0%	2	10.0%		0.0%	2	7.7%
Evaluate and design scientific enquiry	3	100.0%	14	70.0%	2	66.7%	19	73.1%
Interpret data and evidence scientifically		0.0%	4	20.0%	1	33.3%	5	19.2%
Total. Explain phenomena scientifically	5	8.9%	28	24.8%	6	40.0%	39	21.2%
Total. Evaluate and design scientific enquiry	42	75.0%	43	38.1%	4	26.7%	89	48.4.%
Total. Interpret data and evidence scientifically	9	16.1%	42	37.2%	5	33.3%	56	30.4%
Total	56	100.0%	113	100.0%	15	100.0%	184	100.0%

Source: Own elaboration based on the information in the C2.1 and C2.2 tables (PISA, 2016b).

2.2.2. The questionnaire

To measure the proportion of students in each autonomous community and in the national total who report expectations of a science-related career in future (when they are 30), the results obtained from the corresponding PISA 2015 questionnaire have been used (OECD, 2016b).

2.3. Variables and analytical procedures

In line with the objectives of this study, attention has been focussed on the measurements of the performance in science, epistemic beliefs (index), and science-related career expectations (index) variables, all of them referring to the autonomous community level. The first of these is defined by the mean score for each territorial unit in the science survey; it should be noted that PISA's use of the Rasch model when estimating performance has been taken into account, using the 10 plausible values available for each student.

The second variable refers to the separation of the epistemic knowledge sub-scale. According to PISA, "epistemic beliefs" show "the way individuals represent the nature, organisation and source of knowledge, e.g. what counts as 'true' and how the validity of an argument can be established" (OECD, 2016b, p. 100). For example, students' views of the nature of scientific knowledge or of the validity of the scientific methodology used to create knowledge are part of their "epistemic beliefs". This "scientific attitude" in students is manifested as them "seek[ing] knowledge and understanding, adopt a questioning approach to all statements, search for data and their meaning, demand verification, respect logic and pay attention to premises" (OECD, 2016b, p. 100).

The third variable derives from the choice of the options from the corresponding item on the personal context questionnaire that refer to STEM vocations. Therefore, the decision was taken to focus attention particularly on the variable relating to career expectations for the so-called "STEM vocations", using the term coined by the Universidad Politécnica de Madrid and the Fundación Telefónica (Fundación Telefónica, 2014). Consequently, the contribution from the "health sciences" box has been ignored.

Based on the results obtained, which are shown below, two linear regression analyses were performed —performance in science vs. epistemic conceptions and performance in science vs. STEM vocations— with their corresponding ANOVAs in order to test the statistical significance of the respective coefficients of determination. The aggregate results by autonomous region were taken into consideration, along with those obtained for the representative sample for Spain at a national level. Based on this, a comparative study of the different autonomous regions with reference to the national means was performed using *quadrant analyses*, which allow us to identify the autonomous communities that are in the *weakest quadrant*, characterised by values below the national means for both correlated variables; regions that, therefore, require specific intervention policies.

3. Results

3.1. Performance in science

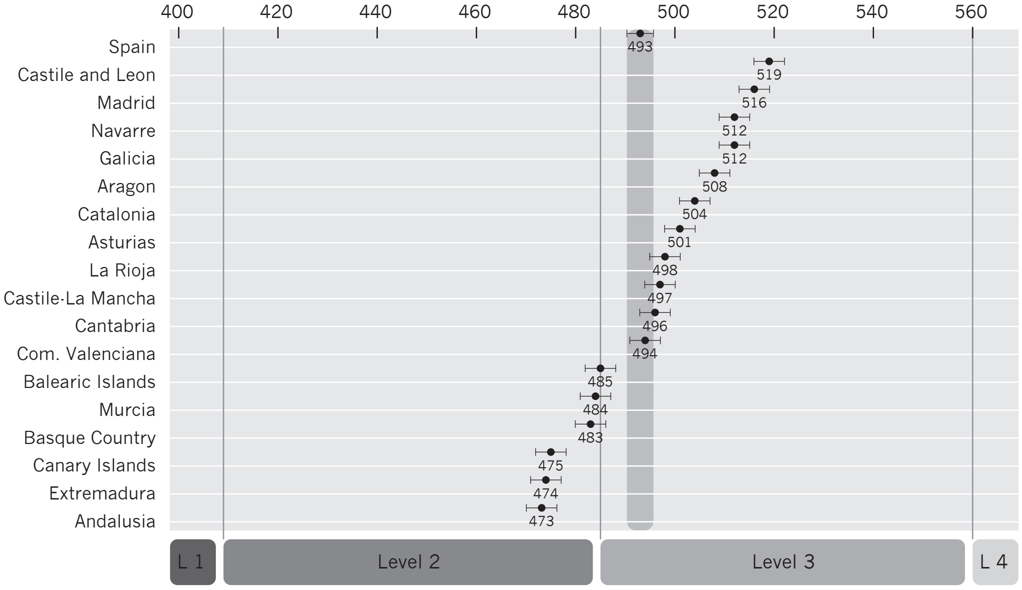
The overall performance in science for each Spanish autonomous community —measured using the mean score in the set of the 184 items included in the PISA 2015 survey— is shown in Graph 2, along with the error intervals for the respective scores. For reasons discussed below, the effects of economic, social, and cultural status (ESCS) on performance have not been corrected in this case in the data in Graph 2. This figure shows the different positions of the autonomous communities with regards to the national mean. Analysis of it shows the special place of Castile and Leon, Madrid, Navarre, and Galicia, in this order, in the field of science, as well as the especially low positions of the Canary Islands, Extremadura, and Andalusia.

In this figure, the size of the regional differences can be seen, reaching a maximum of 46 PISA points when comparing Castile and Leon with Andalusia. This is equivalent to an average educational gap of over one and a half academic years between the two autonomous communities, before controlling for the influence of ESCS[3].

3.2. Epistemic conceptions

Table 4 shows the percentage of students, by autonomous community, who gave affirmative answers to each of the questions in the questionnaire that relate to students' epistemic conceptions, on which basis, and in

Graph 2. Overall science scores in Spain's autonomous communities.



Source: Own elaboration based on the PISA 2015 database.

accordance with the definition provided by PISA (OECD, 2016a), the "epistemic conviction index" is obtained. This is a normalised index, regarding the set of students from OECD countries, with a mean value equal to 0, a standard deviation of 1 and values between −1 and +1. Negative values on this index show that the students answered below this mean and positive values indicates that they answered above it. A preliminary analysis of the data in this table shows differences between autonomous communities that are reflected in the values of the index in question, and which range between a maximum value of 0.21 for Catalonia and a minimum value of −0.03 for Andalusia, with a mean value of 0.11 and a standard deviation of 0.06.

3.3. STEM vocations

Table 5 shows information extracted from the PISA database —which derives from the use of the corresponding context questionnaires— from which the student career expectations that are strictly linked to STEM fields have been selected[4] (science and engineering professionals, including mathematicians, information and communications technology professionals, and science and engineering associate professionals). Based on this, we have a comparative view of the different autonomous communities in what we have called "STEM vocations". A first analysis of the results from the table shows appreciable variability between autonomous communities, with values ranging from a minimum of 11.2% for the Canary Islands to a maximum of 20.4 % for Madrid, with a mean of 15.26 % and standard deviation of 2.24.

3.4. Linear regression analysis

In accordance with the final aims of the study, regression analyses were performed between the previous variables and performance in science, the results of which are presented below. Both regression analyses confirm the assumptions of the respective models.

3.4.1. Performance in science vs. epistemic conceptions

Graph 3 shows the performance in science vs. epistemic conception of the sciences diagram with values at a national level and by autonomous communities. A linear regression analysis carried out on it reveals the existence of a moderate and statistically significant relationship between the two variables ($R^2 = 0.47$; sig. 0.0016). This indicates that 47 % of the variance relating to performance in science can be explained by the differences concerning the epistemic conceptions variable (see Graph 3).

From a strictly civic perspective, in this case it is appropriate to focus particularly on the group of autonomous communities found in what could be called the *weakest quadrant*, characterised by results below the mean for performance and epistemic conception. Andalusia, the Balearic Islands, the Canary Islands, Extremadura, and the Basque Country are the five autonomous regions which are in this quadrant and so require the greatest attention.

TABLE 4. Epistemic conceptions in the autonomous communities PISA 2015.

	A good way to know if something is true is to do an experiment (%)	Ideas in 'broad science' sometimes change (%)	Good answers are based on evidence from many different experiments (%)	It is good to try experiments more than once to make sure of your findings (%)	Sometimes 'broad science' scientists change their minds about what is true in science (%)	The ideas in 'broad science' science books sometimes change (%)	Index of epistemic beliefs
Spain	85.5	82.1	86.9	87.9	81.0	81.2	0.11
Andalusia	81.8	79.4	83.6	85.8	79.3	79.0	–0.03
Aragon	86.4	82.1	86.1	88.6	80.3	82.0	0.12
Asturias	86.8	83.1	88.2	90.8	82.5	84.5	0.18
Balearic Islands	85.3	84.9	86.5	86.5	81.5	83.6	0.10
Canary Islands	83.6	82.1	84.4	86.8	80.1	79.3	0.07
Cantabria	86.5	82.4	87.0	88.7	81.2	81.5	0.14
Castile and Leon	89.4	84.4	89.9	91.8	84.5	81.4	0.20
Castile-La Mancha	87.1	81.4	88.3	90.5	80.0	82.0	0.13
Catalonia	86.5	87.0	88.4	87.2	83.5	84.2	0.21
Com. Valenciana	84.4	81.1	85.4	86.6	80.2	78.9	0.05
Extremadura	84.2	79.6	84.1	88.3	80.3	79.7	0.03
Galicia	89.3	73.1	88.8	91.0	80.5	81.9	0.09
La Rioja	83.9	81.1	83.0	87.2	79.5	81.6	0.08
Madrid	87.3	82.7	89.0	90.8	81.7	81.8	0.19
Murcia	86.2	84.6	87.4	88.8	82.0	82.6	0.13
Navarre	85.6	81.3	86.3	88.7	80.7	79.5	0.09
Basque Country	85.2	83.0	85.9	88.3	82.1	81.7	0.07

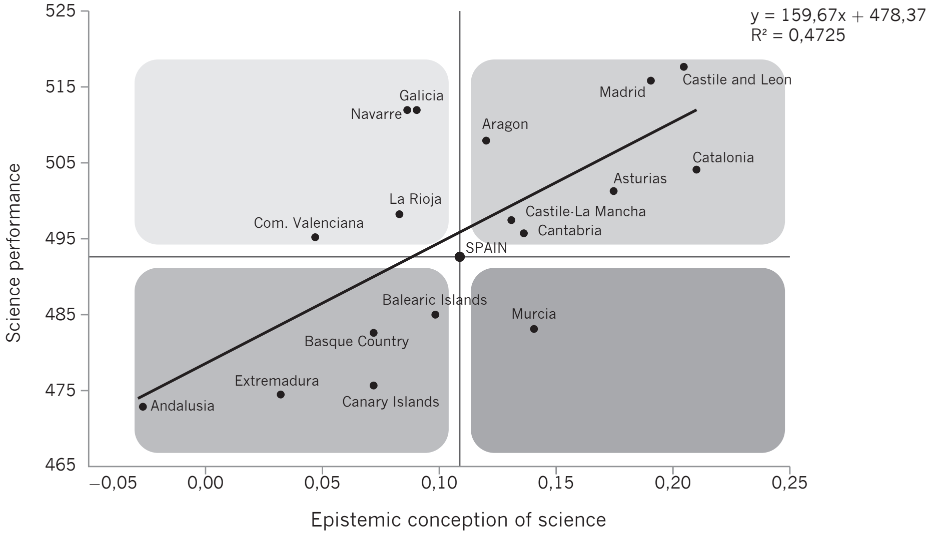
Source: Own elaboration based on the PISA 2015 database.

Table 5. STEM vocations in the autonomous communities PISA 2015.

	Science and engineering professionals (%)	Information and communication technology professionals (%)	Science and engineering associate professionals (%)	STEM vocations (%)
Spain	11.1	3.6	0.6	15.3
Andalusia	8.2	3.7	0.5	12.4
Aragon	11.7	3.5	0.6	15.7
Asturias	11.8	4.7	0.8	17.4
Balearic Islands	9.5	4.8	0.3	14.5
Canary Islands	8.3	2.5	0.4	11.2
Cantabria	10.3	3.6	0.7	14.6
Castile and Leon	11.8	3.1	0.3	15.2
Castile-La Mancha	10.3	3.8	0.5	14.6
Catalonia	12.9	4.5	0.8	18.2
Com. Valenciana	10.9	4.0	0.4	15.2
Extremadura	9.0	3.2	0.4	12.6
Galicia	11.6	4.4	0.6	16.6
La Rioja	9.8	4.3	0.0	14.2
Madrid	16.0	4.2	0.2	20.4
Murcia	9.9	2.9	0.5	13.3
Navarre	12.2	2.7	0.7	15.6
Basque Country	14.4	2.8	0.4	17.6

Source: Own elaboration based on a selection of the information available in the PISA 2015 context database.

Graph 3. Linear regression analysis between performance in science and epistemic conceptions of science in the autonomous communities PISA 2015.



Source: Own elaboration based on the PISA 2015 database.

3.4.2. Performance in science vs. STEM vocations

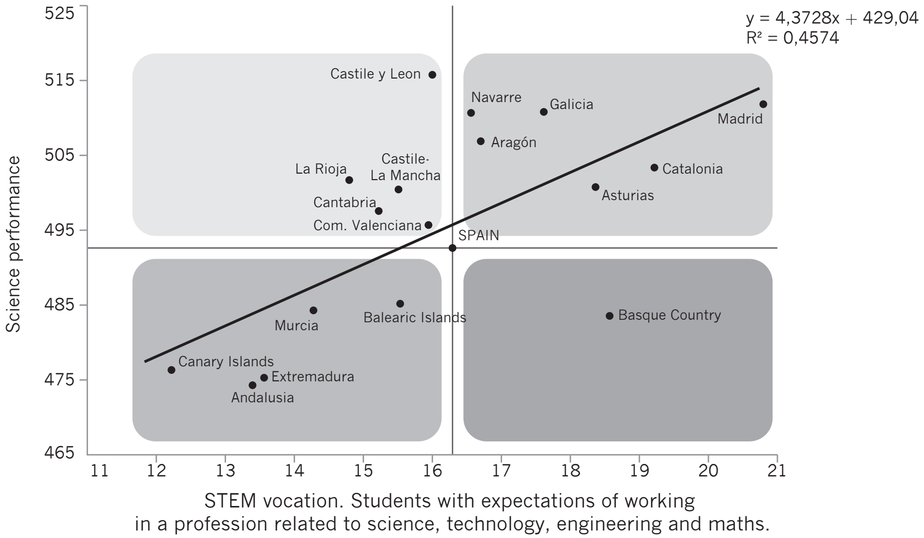
Graph 4 shows the performance in science vs. STEM vocations diagram based on the national and autonomous community samples. The linear regression analysis reveals the existence of a relationship between these two variables which is, again, moderate and statistically significant ($R^2 = 0.46$; sig. = 0.002). This type of analysis has known limitations for unambiguously establishing the direction of the causal link; in this case, it is very likely that there is a feedback loop in which performance in science shapes the STEM vocation and this vocation stimulates scientific learning. However, this result underlines the strength of the relationship between these two variables and is useful for categorising the position of the different autonomous communities regarding two variables that can be considered clearly significant as plausible predictors of the future economic and social development of their corresponding areas.

3.4.3. An overview

Graph 5 provides an overview of the results of this analysis of the relative positions of the 17 autonomous communities with regards to the three variables considered in this work, and shows the distribution of the autonomous regions according to whether they are above the national mean in any of the three aspects considered.

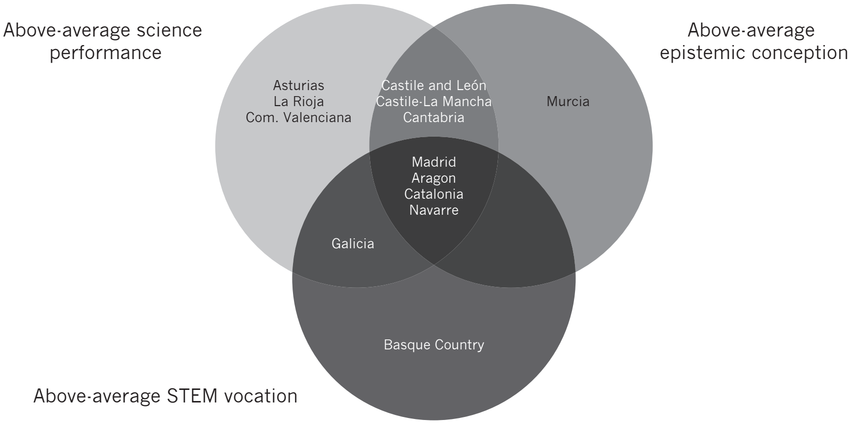
Students from Madrid, Catalonia, Aragon, and Navarre are on average above the national mean in performance in science and in their epistemic conceptions, as well as in their expectations of a STEM-related career in future. However, students from Andalusia, the Balearic Islands, the Canary Islands, and Extremadura were not above the national mean for any of the three variables analysed.

Graph 4. Linear regression analysis between performance in science and STEM vocations in autonomous communities PISA 2015.



Source: Own elaboration based on the PISA 2015 database.

Graph 5. Relationship between performance, STEM vocation, and epistemic conception in the autonomous communities PISA 2015.



Source: Own elaboration.

4. Discussion

Although adjustment of the raw scores for science by controlling for the effect of socio-economic and cultural status on students' performance should be taken into account (López Rupérez, García, & Expósito, 2018 a and b), in the context of this study and its aims, this adjustment would only make sense for reasons of justice, when adjusting the size of responsibilities. It does not reduce the importance of the future challenges that, given the well-known link between science education and economic and social development, face individuals, the public authorities, and society itself in each of these regions, but rather it compounds them.

The 2015 edition of PISA, in the personal context variables, focussed on students' motivation for scientific study —in particular, on the satisfaction they derive from studying the sciences— and on their expectations of a future —at the age of 30— science-related career. This approach is justified by the OECD (2016b) on the basis of expectancy-value theories (Wigfield & Eccles, 2000) and theories relating to the socio-cognitive nature of professional orientation (Lent, López, López, & Sheu, 2008). As the authors of the PISA 2015 report have underlined, in general terms, both variables —motivation and career expectations— are positively correlated with each other and with performance.

Based on this general empirical evidence, we have chosen to consider STEM vocations and epistemic conceptions in addition to performance in science with the aim of describing behaviour in these areas in the different autonomous communities. Furthermore, the relationships between them have been explored to consider the civic dimension and the economic dimension of science education. However, a multi-variable analysis might cast additional light on some of the explanatory factors for performance in science in each of the autonomous communities and on the differences between them.

In this work, we have replaced the term "epistemic beliefs" by "epistemic conceptions". After all, it is a matter of cognitive representations of the truth or validity of the arguments used (Hofer & Pintrich, 1997) which are not *prima facie* connected to the ethical, moral, religious, or political dimensions of the individual, however much they might occasionally and spontaneously be shaped by them.

As PISA notes, there is empirical evidence for the existence of a direct relationship between this variable and the ability of students to learn science, and consequently with their school results in the science areas (Mason, Boscolo, Tornatora, & Ronconi, 2013). Nonetheless, there is one aspect that transcends the school setting to reach the truly civic dimension of future citizens in a context of information overload, proliferating fake news, growing complexity in decision making, and in political judgement or in informed opinion on aspects that concern them.

In this civic field, relating to the exercise of citizenship, a quality science education is mentioned in the PISA report itself from two complementary viewpoints, which could be described here as "intellectually mature citizenship" and "politically responsible citizenship". The first viewpoint can be described as typical of citizens who, in their reasoning about questions of collective interest, can adopt elements and principles relating to science, its endeavour and its processes. This increases the rigour of their approaches to political and social reality and, with a suitable basis, reinforces their critical spirit. The items focussing on epistemic conceptions are particularly aimed at evaluating the fulfilment of this objective.

The second viewpoint relates to "the ability to engage with science-related issues, and with the ideas of science, as a reflexive citizen" (OECD, 2016b, p. 28). In view of the important penetration of scientific knowledge in many social problems and their political solutions, politically responsible citizens must be able to adopt a well-founded position in debates and when faced with political proposals that have, or should have, a scientific or technological basis, of which there are currently many. Satisfactory science performance would ensure, with greater probability, that kind of civic competence.

Furthermore, there is a broad consensus among international institutions (Langdon, McKittrick, Beede, & Khan; Doms, 2011; CEDEFOP, 2016; WEF, 2016) and among specialists (Randstad Research, 2016) when relating the increase in demand for STEM teaching, and the improvement in the corresponding competences, with economic growth, in the context of the fourth industrial revolution, which has already begun and will reach in its zenith in the 21st century. Therefore, the possibility of more closely linking training with economic and social development in Spain's autonomous communities could become clearer if we look towards STEM vocations.

In advanced countries, the shift of the economy and society towards employment contexts that depend strongly on knowledge have moved science education and STEM education into areas regarded as strategic in the current century. The convergence of the predictions and analyses made in this area by organisations from the most developed countries warning of the importance of preparing young people to occupy the many STEM employment niches that are already being created and will be created, more quickly in future (CEDEFOP, 2016; Langdon et al. 2011) is no surprise.

One of the well-known mechanisms explaining regional development in technological industries relates to the establishment of multinational companies which, as well as creating high added-value employment, in the medium term stimulate the development of specialised SMEs and produce knowledge transfers in their setting. This mechanism strongly depends on the existence in the region of human capital with a good basic technological education. In addition, other studies anticipate the important impact of STEM employment on indirect non-STEM employment in the same geographical area (Randstad Research, 2016).

In view of everything stated above, and if the aim is, primarily, to improve performance in science in general and, in particular, students' epistemic conceptions, significant improvement in the quality of science teaching is a necessary condition, to which end the following recommendations at the level of teaching practice are made:

- Explicitly incorporating science curriculum objectives aligned with epistemological aspects of scientific knowledge.
- Organising learning situations, around laboratory practice or virtual simulations to familiarise students with formulating hypotheses and testing them empirically, in light of the data generated in these practical activities.

- Designing experiments that make it possible to test empirically some of the students' spontaneous ideas in order to accustom them —on the basis of first-hand experience— to being cautious when faced with a priori or positions or statements of apparent *common sense* (López Rupérez, 1994).

- Using laboratory reports as exercises to simulate scientific activities at the students' level that are similar to the activity of preparing scientific papers for publication in specialist journals, maintaining a similar structure and focus (López Rupérez, 1986). So, for example, going beyond laboratory reports as mere descriptions of tables of data or of qualitative observations so that discussion of empirical evidence is included in them obliges students to carry out processes of intellectual development in which personal formulations or interpretations have to be consistent with this evidence.

- Using the *project-based learning* methodology as one of the components of science teaching, on the understanding that, in accordance with the available evidence. It should be treated as an instrument part of a broader didactic strategy, whose value for developing critical thinking is widely accepted by researchers, on an empirical basis (Willett, 1983; Thomas, 2000). As the promotors of this methodological option themselves have warned: "Projects typically do not constitute the whole educational program; instead, teachers use them alongside systematic instruction and as a means of achieving curricular goals" (The Project Approach, 2014, p. 1).

All of these basic didactic procedures are also aligned with the goal of achieving *deep learning*, characterised by a high level of comprehension of phenomena and of their conceptual and theoretical bases, their cause-effect mechanisms, and their significance. Deep learning improves performance in science at the same time as facilitating the consolidation in the students' minds of these metacognitive skills which are typical of scientific thought, and in the PISA study are referred to as "epistemic beliefs".

With regards to policies, improved science teaching necessarily means having an effective impact on the teachers and the curriculum. As for teachers, initial selection and training policies are key (López & Rupérez, 2014). Alongside these policies, directed at the medium term, those relating to lifelong learning, the development of which is one of the competences of the autonomous communities, are vital to achieve desirable short-term results (Real Sociedad Española de Física, 2018).

As for the guidance regulations for organising the curriculum, strategies must be promoted that facilitate this deep learning and increase the effectiveness of lessons. To do this, it is necessary to target effective teaching time —a variable that has proven to be empirically important (Downer, 1991; OECD 2016a)— by increasing the number of hours per week, something the educational administrations of the autonomous communities in question have sufficient powers to do (Real Sociedad Española de Física, 2018). Likewise, it is necessary to reduce the breadth of syllabuses in favour of greater depth through, among other measures, the type of learning scenarios described above. This curriculum intervention can be implemented without preventing a sufficiently comprehensive overview of the subject from being achieved at a particular stage by distributing topics in a particular linear direction, and not systematically in a spiral as has been normal in Spain. This requires carefully choosing the items for each year according to their cognitive demand, the internal coherence of the subjects, as far as is possible, and the students' age level (Shayer, 1978; López Rupérez & Palacios Gómez, 1988). This reorientation in the realisation and implementation of science curricula would make it possible to improve results in general, especially those of the autonomous communities located, according to our study, in this *weakest quadrant*.

We shall now, secondly, discuss the results linked to STEM vocations and provide recommendations for policies to improve its relationship with the empirical analyses made for different groups of autonomous communities. Based on Graph 5, four categories for the autonomous communities as a set can be established:

- Category A *(high vocation, high performance),* which includes Asturias, Aragon, Catalonia, Galicia, Madrid, and Navarre. These six autonomous communities occupy the *optimum quadrant* and so are in a relatively noteworthy position to adapt to the regional demands of the fourth industrial revolution, in terms of employment, economic growth, and social progress.

- Category B *(low vocation, high performance)* comprises Cantabria, Castile-La Mancha, Castile and Leon, the Comunidad Valenciana, and La Rioja. Owing to their good or relatively good figures for performance in relation to the national mean, they could easily join the first category — Castile and Leon and the Comunidad Valenciana in particular— by increasing efforts to raise awareness of the appeal of STEM professions through institutional campaigns supported by tools such as Science and Technology Forums, Science and Technology Weeks, etc. particularly aimed at secondary school students. Furthermore, working to improve the professional guidance system in secondary schools is a necessary recommendation, as this is one of the shortcomings identified in the Spanish educational system (Consejo Escolar del Estado, 2012).

- Only the Basque Country is in Category C *(high vocation, low performance).* This anomalous situation could be the result of a socioeconomic situation that encourages people to embrace STEM vocations, combined with an educational system that cannot offer students appropriate intellectual tools to achieve this personal ideal. In such a case, the recommendations for general improvement of school performance described in an earlier piece of research (López Rupérez et al., 2017) (focus on general educational policies intended to raise the performance level of all students, through interventions by the state —teaching profession model, general curriculum organisation, conception of school management, etc.— and by the autonomous community —managing the centres, school atmosphere, continuous teacher training, systems of incentives, complementary academic planning, family-school relationships, etc., which have the greatest impact on results, and implement actions aimed at improving the students' non-cognitive skills) are also applicable to the specific field of the sciences.

- Category D *(low vocation, low performance)* corresponds with the *weakest quadrant*, which includes Andalusia, the Balearic Islands, the Canary Islands, Extremadura, and Murcia. This group of autonomous communities —in particular, the Canary Islands, Andalusia, and Extremadura— is in a precarious position for facing the challenges of the fourth industrial revolution based on education. For this reason, in the framework of a necessary national strategy to clearly adapt the country to the knowledge revolution, educational systems in these autonomous communities should receive special attention. The combination of these two groups of policies described above for categories B and C is a primary recommendation for facing the challenges of the future at the regional level with some chance of success.

Notes

[1] For an explanation of this term, see the Discussion section.

[2] See http://dx.doi.org/10.1787/888933433242

[3] In PISA 2015 a difference of 30 points is equivalent to an average educational gap of a complete academic year (OECD, 2016 a; Box 1.2.1, p.65).

[4] STEM vocations comprise categories 21 (science and engineering professionals), 25 (information and communication technology professionals), and 31 (science and engineering associate professionals) from the International Standard Classification of Occupations, ISCO-88: http://www.ilo.org/public/spanish/bureau/stat/isco/isco08/index.htm

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