Research in Science Education
https://doi.org/10.1007/s11165-024-10187-0

The Pineapple as a Means to Develop Scientific Competence in the Spanish High School Diploma of Research

Jorge Pozuelo-Muñoz[1] · Esther Cascarosa-Salillas[1] · Esther Alonso[2] · Carmen Barba[3]

Accepted: 4 July 2024

Abstract
Every three years, the Organisation for European Cooperation and Development evaluates the scientific competence of European students. Recent results have demonstrated that scientific competence in Spain is somewhat underdeveloped, which underscores the need to apply educational methodologies that favour the development of said competence. This paper analysed the extent to which the implementation of the Spanish high school diploma of research favoured the development of the Scientific Competence of students. The students had to develop a research project, co-tutored by a secondary education teacher and a University teacher/researcher. Both professionals offered the guidance necessary to develop a project that concerned the resolution of a problem of interest. Audio and video data were collected during the 18 months of the high school programme. These data were transcribed and analysed using a rubric designed ad hoc. This assessment instrument is a relevant point of this work as long as it can be used as evaluating tool in the Scientific Competence assessment of future studies. The results revealed that the students had to make use of their knowledge of the research topic, strengthen this knowledge, substantiate the research using the scientific literature, design and develop the experimental methodology, collect, analyse and present data, and, finally, disclose these data. The results indicated high levels of development in the three sub-competences that were explored, which concluded in a high development of scientific competence.

Keywords Scientific competence · Secondary education · Scientific literacy · Science teaching

✉ Esther Cascarosa-Salillas
ecascano@unizar.es

[1] Present Address: Dpto. Specific Didactics, Faculty of Education, BEGLE Research Group, University of Zaragoza, IUCA Research Institute, Pedro Cerbuna 12, 50009 Aragon, Spain

[2] Instituto de Educación Secundaria Plaza de La Cruz, San Fermín, 51, 31003 Pamplona, Spain

[3] ISFOOD - Institute for Innovation & Sustainable Food Chain Development, Public University of Navarre, Campus de Arrosadía, 31006 Pamplona, Spain

Published online: 24 July 2024

Introduction

The Organisation for European Cooperation and Development (OECD) evaluates the scientific competence of secondary school students in Europe every three years. The results are published by the Programme for International Student Assessment (PISA) and are used to compare the development of said competence among students from member countries. In the last three reports (OECD, 2016, 2019, 2022), Spain has been among the countries with the lowest results in the subject of science (if we classify the scores into four quartiles, with the first being the one with the best scores, Spain is in the third quartile). The results of schoolchildren in this type of tests could have a future connection with the economic development of the country (Hanushek & Woessmann, 2011). In seeking a response, experts have pointed to a number of factors that may explain this poor showing. Muñoz and Charro (2023) suggest that teaching in Spain is not based on the development of scientific competence. In order to change this, teaching should be rooted in the development of contextualised teaching–learning sequences (Caamaño, 2018) and based on the development of scientific practice (Muñoz-Campos et al., 2020). Authors such as Sanmartí and Hinojosa (2015) agree that this type of methodology can influence the development of scientific competence in the classroom as it mediates between the motivation of the students and their assimilation of knowledge (Cascarosa et al., 2021). It has been further argued that the lack of tools specifically designed to assess this competence hinders the implementation of this type of teaching in the classroom (Ferrés-Gurt et al., 2015; Osborne et al., 2016).

Two years ago, Spain, in an effort to mitigate this shortcoming, introduced a baccalaureate diploma of research (BdR) to facilitate the development of scientific competence in secondary education. In general, largely due to limited classroom time, experimental laboratory activity in the last two years of secondary education (students aged 16 to 18 years old) is drastically reduced and the sub-competences required for the development of scientific competence are not pursued (Cascarosa et al., 2022). The regulated and intentional BdR is geared to minimise the pressure that teachers suffer in having to integrate the development of scientific competence in a structured high school programme as opposed to a traditional methodology, thereby promoting a working method based on the development of teaching–learning sequences that favour scientific competence (Lijnse & Klaassen, 2004) and also the inquiry process in students (Schwartz et al., 2021).

This paper presents the first study that analyses the extent to which the BdR favours the development of scientific competence among the students. The analysis of the development of scientific competence involved the use of an ad hoc rubric designed to evaluate each of the three sub-competences that were developed. Thus, through a detailed partial analysis, it is possible to reach conclusions on the development of scientific competence of students through this high school programme of research. These results could be decisive for continuing this high school programme or reorienting teaching methodology in Spain.

The research question that guided this project was: To what extent does the baccelaureate diploma of research favour the development of scientific competence among students?

Theoretical Framework

For a number of years, the term *scientific competence* has been used as an equivalent to *scientific literacy,* on the understanding that a person that is scientifically literate is also scientifically competent (Pedrinaci, 2013; Pedrinaci et al., 2012). The foundations of scientific literacy were established in the second half of the twentieth century, when experts began to demand science education for the population to equip them to fully develop in society (Duschl, 2007; Romero-Ariza, 2017; Woods-McConney et al., 2014). In 2015, The European Commission established the need to promote a culture of scientific thinking and inspire citizens to use evidence based reasoning for decision making (European Commission, 2015), in other words, it appealed to train society in scientific competence. Scientific competence does not have a single definition. There has been much discussion about what scientific competence itself encompasses (emotional, volitional, cognitive aspects, required skills, abilities, and attitudes) (Kauertz et al., 2012). Since it is a concept that can be investigated from many perspectives, there are several definitions in this regard. Some researchers defined it from a point of view that links sub-competences with models, for instance, to analyse the scientific reasoning competencies of science teacher education (Krell et al., 2017, 2020), thus providing necessary in-depth knowledge about one of the parts of scientific competence, scientific reasoning (Krell et al., 2022). Other studies have analysed the links that scientific competence has for the students themselves, finding that they consider that a student is more competent the more creative he or she perceives himself to be (Beghetto, 2007).

Originally, the OECD defined the scientific competence as that which is achieved through the development of three science competencies required students to identify scientific issues, explain phenomena scientifically, and use scientific evidence. These three key scientific competencies were selected because of their relationship to the practice of science and their connection to key abilities such as inductive and deductive reasoning, systems-based thinking, critical decision making, transformation of data to tables and graphs, construction of arguments and explanations based on data, thinking in terms of models, and use of mathematics (Bybee et al., 2009). In the last years these three sub-competences have been fine-tuned (OECD, 2016, 2019, 2022).

In order to evaluate scientific competence at an international level, the Programme for International Student Assessment (PISA) (OECD, 2016, 2019, 2022) conducts a three-yearly evaluation of knowledge and skills in the areas of science, reading and maths. The PISA scientific competencies emphasise that students need to prepare for the abilities needed in their future adult life and equip themselves with the basic literacy necessary in modern society (Chun-Yen, 2015). With regards to scientific competence, PISA evaluates whether students are capable of using their knowledge and if they are able of understanding the nature of scientific knowledge (Rosales Ortega et al., 2020). Definitely, it values the application of knowledge rather than memorisation (Gallardo-Gil et al., 2010). The objective of PISA (in the field in question) is to evaluate the level of scientific competence of students, and for that the OECD establishes that a scientifically competent student is who has developed three sub-competencies, thus, the development of scientific competence can be evaluated through the analysis of the development of three sub-competences (1- explaining phenomena scientifically; 2- evaluating and designing scientific research; and, 3- interpreting scientific data and evidence) (Sadler & Zeidler, 2009). These scientific competences result from the development of scientific knowledge (of content (knowing that), procedural (knowing how) and epistemic (knowing why) of content (Kind & Osborne, 2017; Osborne, 2014). These knowledge types correspond with three goals of science education highlighted by Hodson (2014): learning science (content knowledge), learning about science (epistemic knowledge), and doing science (procedural knowledge).

Scientific sub-competences

Definitions of the three sub-competences are presented below.

1- Explaining phenomena scientifically

This sub-competence refers to the ability to recognise, offer and evaluate explanations of a specific range of natural and technical phenomena. To a large extent, this depends on the knowledge of these ideas and theories, that is to say, knowledge of the content. However, it also requires an understanding of the route taken to gain this knowledge, the methods used (procedural knowledge) and the role played by knowledge itself in the justification of said knowledge (epistemic knowledge).

To evaluate the development of this sub-competence, PISA proposes a rubric. However, some authors, conclude that, while the analysis of performance by means of the rubric "helps to understand the level of competence of the student", the PISA rubric is not sufficient for evaluation as it is oriented to multiple-choice answers and does not favour the analysis of the students' explanations (Blanco & Díaz, 2017).

2- Evaluating and designing scientific research

To achieve this sub-competence, the student must be capable of describing and evaluating scientific investigations and offering scientific approaches to certain questions. According to PISA (OECD, 2016, 2019, 2022), rather than knowledge of the content of science, this competence requires an understanding of the way in which scientific knowledge is established and the degree of confidence in the same, in other words, a procedural and epistemic knowledge of science (OECD, 2016, 2019, 2022). Ferrés-Gurt (2017) argued that the student must be capable of designing researchable questions that allow the development of scientific practices (enquiry, argumentation and modelling). In relation to this sub-competence, Crujeiras-Pérez (2017) analysed the development of enquiry among future secondary school teachers as a scientific practice that helps to develop the sub-competence of evaluating and designing scientific research.

3- Interpreting data and scientific evidence

This sub-competence involves the analysis and the evaluation of data and arguments to be able to offer adequate scientific conclusions. As with the previous sub-competence, knowledge of content is necessary, but procedural and epistemic knowledge are of major importance. Thus, scientifically literate citizens, as well as knowing how to represent experimentally obtained data, are expected to understand the uncertainties inherent in data collection and their measurement (procedural knowledge). The students must also know how to assess whether the data are appropriate, with argumentation and criticism playing a significant role in the process (epistemic knowledge). In short, this competence includes access to information and evaluation of arguments and scientific evidence (Kuhn, 2010; Osborne, 2010).

With regards to this sub-competence, authors such as Bell and Linn (2010), Blanco and Lupión (2015), Chun-Yen (2015), Clark and Sampson (2008), Crujeiras and Jiménez (2015), Crujeiras et al. (2020), Muñoz and Charro (2018) analysed the scientific interpretation of data and evidence through activities that developed, for example, the practice of argumentation in the science classroom. In recent years, several research papers have addressed the study of the development of various sub-competences simultaneously. For example, Franco-Mariscal et al. (2017) designed activities for the development of scientific competence within the context of health. These authors outlined activities connected to each of the sub-competences and analysed their scope through the study of the specific objectives initially set for each one, thereby offering specific examples of the evaluation of the sub-competences and assigning a fundamental role to the context of the activity. Muñoz and Charro (2023) conducted a research project on different skills related to the sub-competences proposed by PISA that assists teachers in approaching the sub-competences and guides them their evaluation in the classroom.

In summary, the evaluations carried out by PISA establish the degree of scientific competence of country's students. The OECD establishes to achieve this scientific competence three sub-competences must be developed. Each of these three sub-competences are described and it is known what each one contemplates. However, although there is a guide on how they can be evaluated, the OECD does not establish any concrete instrument the educational centres can use to self-evaluate their students and thus analyse the degree of development of these sub-competences.

Researchers need to provide more experimental data in terms of PISA scientific competencies in order to contribute to educational policies (Chun-Yen, 2015). Therefore, this work investigated to what extent an eminently research baccalaureate favours the development of scientific competence of the students, according the PISA definition of scientific competence. And for this, a rubric has been designed that has allowed us to evaluate in detail the level of development of each of the three sub-competences that make up scientific competency according to the OECD.

Material and Methods

Ethical Approval

Prior to commencing this study, ethical clearance was obtained from the university's Research Ethics Board, which granted ethical approval for data collection. All participants were informed of their role in the study, their rights to freely consent and participate, and their ability to withdraw consent at any time in the process.

Development of the Project

The last two years of secondary education in Spain are dedicated to rehearsing the resolution of the problems that students need to solve to pass the university entrance test. As a consequence, in these courses, science is hardly taught from a competency approach, but rather from more rote teaching and systematic problem solving. In order to redirect and to promote the development of scientific competence and, ultimately, scientific literacy and scientific vocation in Spain, a special secondary education programme has been designed. Thirty students who were scheduled to study science in their last two years of high school were offered to participate in this program (students aged 16 to 18 years old) (convenience sample). The programme is known as the “BdR” and consists of the development of an 18-month scientific project in which the student must work as a genuine scientist in order to resolve a problem. The BdR was developed in collaboration with Spanish organisations such as universities, scientific associations, biomedical research centres, planetariums and technology companies. Groups of three students are tutored by a teacher from their school and a mentor from one of the collaborating organisations (further information can be obtained from the following website: https://sites.google.com/educacion.navarra.es/bachilleratoi/inicio-bi). In addition to the continuous tutoring throughout the programme, every six months the tutors from both organisations conduct a follow-up in which the students must give a report on the status of the project; in other words, the students developed a free enquiry, guided by six-monthly reviews. At the end of the programme, the students must present a final report (a structured, written work) to a tribunal made up of the tutors and of teachers of several subjects from the school. That is, for 18 months, the students in the BdR work on a research project that emerged from a problem to be resolved that becomes the foundation for the design of an experimental procedure that they developed in the facilities of the collaborating organisation (in this case, a university). Thus, the students were trained in situ as scientific researchers that, through the development of the project, collected and analysed data to solve the initial problem.

A total of 30 students participated in the BdR, in collaboration with different organisations. This research work was based on the follow-up of one of the projects (from September 2021 to January 2023). More specifically, this work examined the development of the scientific competence of three students that completed the BdR in collaboration with a tutor/teacher from the area of food technology at the public University of (anonymus).

The project that the students developed was based on a research question posed by the university teacher. The proposal for the research project considered the premise that the students should find the usefulness of the procedure, which in turn motivates learning (Caamaño, 2012; Cobern et al., 2010; Couso, 2020; Guisasola et al., 2021). As a consequence, the university teacher invited the students to investigate the best conditions for the preservation of fruit, as it is a social topic of interest and direct utility for the students. The research question was: “*What is the optimum storage method for minimally processed pineapples?*”. Based on this question, the students had to design a process to find an answer based on scientific evidence. To do this, the students only received one instruction, to work just as a scientist would. During the 18-month period, the students had access to the university laboratory and all the materials necessary for the development of their research. The only guideline for the report the student must present was that they had to capture the development of the project from the beginning to the end, with the maximum degree of detail and taking into account the work of the scientists.

Development of the Research

The strategies, methodologies and perspectives of qualitative studies have developed their own methods to obtain, as results, specific conceptions of reality and of the manner of reaching them (Rodríguez et al., 1996). One of the conceptions for qualitative research and enquiry is the case study. These methodologies arise from the need to apply qualitative techniques to phenomena that quantitative techniques are not able to contemplate (Simons, 2011). The term CS was defined as an “umbrella” term that covered the set of research techniques designed to provide an in-depth understanding of a given case (Adelman et al., 1980). Although the aim is an in-depth analysis of a case, the CS term can also be used to try to give an explanation that goes beyond its own contextual framework. For example, a school could be selected as representative of other schools in order to generalise the case of that school to others (Stake, 2005). In short, CS research is between "the particular and the general, the specific and the generic" (Walton, 1992). In other words, CS research seeks to provide an in-depth understanding of a case in its context (Merriam, 2009; Simons, 2011; Stake, 2005; Yin, 2014), something that a qualitative study does not achieve (Cohen et al., 2007). Merriam (1988) details four fundamental characteristics of the CS: "particularistic", "heuristic", "descriptive" and "inductive". "Particularistic" due to its explicit and specific focus on the subject; "heuristic" because it either extends experience and knowledge or confirms what is already known; "descriptive" because it seeks to offer a global vision of the phenomena that are being investigated; and "inductive" as it is based on an analysis of the data obtained to generate concepts or refute hypotheses. Rodríguez (1996) suggested three fundamental reasons for the selection of the CS: a "critical character", as the case allows researchers to confirm, modify or extend knowledge; an "extreme character", as the case is itself of interest (Stake, 2005); and a "revelatory character" as it analyses a relatively unknown phenomenon that can provide relevant knowledge for education.

The CS validates research studies with a small sample size and a prolonged time scale. The role of the researcher must be delimited (as teacher, evaluator or interpreter) and reflexive (Simons, 2011; Stake, 1994, 2005; Yin, 2014). Simons (2011), one of the authors of reference in the CS as a research model, argued that any research must be based on the criteria of credibility, transferability, dependability and confirmability. Therefore, in order to guarantee the legitimacy of the research, clarity regarding the manner in which the research was designed and the data were collected and analysed is paramount.

In this research, an intentional qualitative research based on Case Study (CS) methodology was conducted in order to draw conclusions on the degree of development of the scientific competence of the students during the project in relation to their learning context, the input and support they were given, and the activities they were engaged in (Justi & van Driel, 2005). In order to provide the reader with the necessary elements to understand the case we have presented contextual information about the design of the project and methodological information. Data were collected by means of semi-structured interviews with the students— two intermediate and one final interviews were carried out during the project which were audio and video recorded and later transcribed—and of the analysis of the final reports. The questions guided the interviews were "what stages have you followed to develop the research? what types of questions have you been asking yourself throughout the stages? do you think you had enough previous knowledge to solve the problem posed? and how have you acted on it? how did you analyse each article read? what relevant information have you extracted and applied from each one? what process did you follow to decide how to treat the data collected in your research? were all the data collected valid? how did you check it? what do you think has you learnt about science been part of this project?".

As commented in the theoretical foundation for this work, the tools offered by the PISA reports are not enough to conduct a reliable evaluation of the development of these sub-competences, therefore, an ad hoc rubric was designed for the present study that categorised the levels of performance in the three sub-competences that comprise scientific competence as defined by PISA (OECD, 2016, 2019, 2022) (see Table 1). The following factors were taken into account in order to translate the results obtained using qualitative methods into the degree of development of scientific competence: that the three sub-competences have the same relative value; that the three categories within each sub-competence also have the same relative value; given that we have established the maximum level

Table 1 Rubric for the evaluation of the scientific sub-competences

Sub-competences and associated dimensions		Cognitive demand					
		Memory (1p)	Comprehension (2p)	Application (3p)	Analysis (4p)	Evaluation (5p)	Creation (6p)
Explaining phenomena scientifically	Scientific knowledge of the problem	Recalls scientific knowledge associated with the problem	Understands the scientific knowledge associated with the problem	Applies suitable scientific knowledge to the problem	Analyses the importance of one's own scientific knowledge of a problem	Evaluates whether one's own scientific knowledge is sufficient to approach the problem	<u>Complements with knowledge necessary to resolve the problem</u>
	Explanatory models or representation of knowledge and implications for society and people	Knows the explanatory models associated with the problem	Understands the role of explanatory models associated with the problem and its implications for society	Applies explanatory models to the resolution of the problem	Analyses the role of explanatory models in the problem and their social implications	Evaluates whether the explanatory knowledge is sufficient to approach the problem	<u>Combines original explanatory models with other models that help to resolve the problem</u>
	Predictions, hypotheses and causal relationships or simple correlations	Knows the basis of scientific methods	Interprets the role of predictions and the formulation of hypotheses	Makes appropriate predictions or hypotheses for a problem but without justifying them	Studies the viability of a hypothesis using evidence	<u>Evaluates scientific predictions and hypotheses supported by evidence</u>	Generates arguments to support or refute hypotheses

Table 1 (continued)

Sub-competences and associated dimensions		Cognitive demand					
		Memory (1p)	Comprehension (2p)	Application (3p)	Analysis (4p)	Evaluation (5p)	Creation (6p)
Evaluating and designing a research project	Objectives of a study and methodology	Knows the different forms of conducting scientific research	Identifies the objectives of a given investigation	Applies the typology of the objectives to the design of the research	Analyses different methods for scientifically exploring the questions	Decides on a methodology in accordance with the objectives	<u>Designs an investigation in accordance with the chosen methodology and the objectives</u>
	Researchable questions	Identifies scientifically researchable questions	Understands the differences between questions that are or are not scientifically researchable	Applies scientifically researchable questions to the design of the research	<u>Analyses whether the questions posed in the research are scientifically researchable</u>	Argues whether a question is scientifically researchable or not	Designs a research in which all the questions are scientifically researchable and explains why, defining possible methodologies to be followed
	Work of scientists	Describes working procedures of scientists	Understands the working methods of scientists	Applies one's knowledge of the work of scientists to the problem	Analyses how to apply the work of scientists to the research in question	Evaluates whether the research project meets the professional standards of scientists	<u>Designs the project in accordance with the main tasks of the scientist (researchable questions, veracity, cooperation, publication)</u>

Table 1 (continued)

Sub-competences and associated dimensions		Cognitive demand					
		Memory (1p)	Comprehension (2p)	Application (3p)	Analysis (4p)	Evaluation (5p)	Creation (6p)
Interpreting data and evidence scientifically	Data and representation	Recalls the processes for collecting data and representation	Relates the typology of the data with its representation	Obtains data and represent them as part of a scientific research	Describes tendencies in the data without extracting conclusions	Evaluates the data by comparing them with similar research studies	<u>Draws conclusions based on collected data</u>
	Validity of data	Knows methods for validating and evaluating data (replicability, error etc.)	Interprets the validation of data as a symptom of consistency in research	Applies different methods of validation of data in a research	Extracts meaning from the results of the validation of data in a research	<u>Evaluates the validity of data (replicability, uncertainty, error)</u>	Generates conclusions about the validity of a group of data in a research
	Argument and evidence	Understands and recalls the value of arguments and evidence in scientific research	Identifies evidence and arguments in a scientific research	Uses arguments but without basing them on evidence or data	Analyses evidence and arguments involved in a scientific research	Validate evidence and arguments found in or emitted by a scientific research	<u>Provides original arguments based on scientific evidence</u>

to be achieved in each category at 6 points, that is, if they achieve the maximum development of a category they obtained 6 points according to the rubric, the maximum reference score for each sub-competence was 18 points (since there are three categories for each sub-competence). Therefore, the maximum total score was 54 points, that equated to a 100% development of scientific competence.

To code the results as levels of development of the sub-competencies, we transcribed all interviews and also reviewed the students' final works. We identified in these results the level of each of the development categories of each sub-competence and marked in the rubric (underlining) the level of said category. For example, in relation to sub-competence 1, category of "scientific knowledge of the problem", the students demonstrated that they knew how to evaluate the basic knowledge they had to face the problem, but they also complemented that basic knowledge with the knowledge necessary to solve the problem they were facing. Therefore, in the first category within the first sub-competence, the researchers considered that their degree of development was the maximum, obtaining 6 points in that category.

Results

The following section examines each sub-competence by means of the evidence collected in the interviews and the analysis of the reports written by the students at the end of the 18-month period.

Sub-Competence: 1- Explaining Phenomena Scientifically

According to PISA (OECD, 2016), this sub-competence involves a series of skills, such as recognising, offering and evaluating explanations of a range of natural and technological phenomena that demonstrate the ability to: remember and apply appropriate scientific knowledge; identify, use and generate explanatory models and representations; make and justify suitable predictions; offer explanatory hypothesis; and explain the potential implications of scientific knowledge for society.

The students were given the research question and they firstly tried to understand the problem they had been confronted with by applying their knowledge.

> *"We reviewed what we had learnt in secondary education about metabolism, photosynthesis, cellular respiration... As well as helping us to outline the project, this served to better understand what we had been taught about the subject. We saw that chemistry is related to everything, for example, kinetic energy is in everything, the Arrhenius equation, the concentration of reactants... And the factors that affect the speed of the reaction, bigger pineapples degenerated sooner, as did those that were at a higher temperature. We also remembered the fermentation processes and we identified them in the experimental section. For example, we observed that when we smelled the pineapples. They smelled of sour apples, and when you measure the atmosphere, you see that there is no oxygen... We used physics, chemistry, English, biology, Spanish, maths, robotics, scientific culture...but all at the same time, not like in the classes where we work on each subject separately".*

The students were aware of the scientific knowledge required for the problem and searched for answers in their previous training in the subjects that they had studied. They identified the need to extend their knowledge and searched in the specialised literature, as explained in the next section. This broadening of their scientific knowledge helped them to construct a more robust model and to analyse the implications for society of the topic they were investigating. As a consequence, they were able to formulate hypotheses and causative correlations.

> *"We read a lot of scientific literature in order to define the procedure to be followed. The procedure that we designed was similar to one that had been published but we thought that something that had been checked years ago, for example, 100 years ago, needed to be demonstrated again, because the circumstances and the context have changed. For example, with climate change, the manner of preserving pineapples may be different... repetition adds something to what has already been done, even if it only confirms the previous results..." "… Just as we can see in daily life, fruit is better preserved at lower temperatures".*

Sub-Competence: 2- Evaluating and Designing Scientific Research

The OECD (2016) establishes that the first step that the students must take to develop this sub-competence is to be able to define the research objectives and methodology. In order to achieve this, they must know how to search, describe and analyse published scientific research studies, evaluating their objectives and methodologies and using them as the basis for designing their own research.

As evidenced in the transcription, once the teacher had posed the research question, the students began the process of free enquiry, examining the scientific literature found on *Google Scholar*. In relation to this point, the students commented:

> *"At the beginning, the most difficult task was searching for the information and understanding the articles and theses that we read. We began by searching the key words 'pineapple' and 'food preservation'. At the beginning, we didn't understand anything that we read in the articles. Then we decided that after reading them we would try to summarise them in our own words, and if we could do that and understand the summaries written by the others, we considered that we had understood the content of the scientific article. Each article led us to many more and we ended up reading an enormous amount, not only about pineapples, but also about other foodstuffs, for example, borage. In the end, we combined the information from all the readings and designed our procedure. For example, from the article on borage we got the idea of trying a different acid, ascorbic acid... At the start, we read all the articles from beginning to end, but as reading was a constant activity during the 18 months, at the end we realised that searching for the relevant information in the body of the article was enough".*

These data revealed that the students have learnt to seek information in the scientific literature in order to provide a foundation for their research. They have understood how to transform that information in their own words, evaluate it and use it to tackle the problem scientifically. In other words, they have identified the objectives of several research projects, have analysed different methods of researching topics related to their own project, they have evaluated them and decided on the best methodology for their project, maintaining coherence with the objectives that had been set.

Another dimension established by the OECD (2016) as a determinant of the development of this scientific sub-competence was the posing of researchable questions. In this project, the research question was set by the university teacher; however, in order to conduct the research, the students had to contemplate partial questions. Some examples that were noted during the control sessions and the final report are: "*What factors influence the preservation of the pineapple?*". And, once the possible factors were identified, the students selected two of them and then enquired: "*How does the type of cut influence the duration and method for preserving the pineapple?*", and "*How does temperature influence the shelf life of the pineapple?*". The students posed these research questions to be resolved in the project, but without reasoning or substantiating their selection or the reason why they were researchable.

Finally, as part of this sub-competence, there was another dimension that relates the project to the work of a scientist. The final reports written by the students reveal that the students designed their research in accordance with scientific principles and working methods: the research question was clearly understood; other partial researchable questions were posed; scientific information on the subject was searched to design the research and substantiate the results; the students worked as a team during the project; they disseminated and communicated the results.

On this basis, the students designed a research project focused on analysing the preservation of pineapple (*Ananas Sativus*) through the study of two variables: *type of cut* and *temperature of preservation* (Fonseca et al., 2002). Three types of cut were considered: in half, the two halves cut vertically and each half cut vertically into three sections. Three temperatures of preservation were tested: 5ºC, 8ºC and 20ºC. The sections of pineapple were kept in glass jars and CO_2 and O_2 measurements were taken twice a day using Fonseca's statistical method (Fonseca et al., 2002) for a week.

The Fig. 1 shows the development of the experiments at the University.

According to PISA (OECD, 2016, 2019, 2022), this sub-competence, rather than knowledge of the content of science, involved the understanding of the process of establishing scientific knowledge and the degree of confidence in it; in other words, procedural and epistemic knowledge of science.

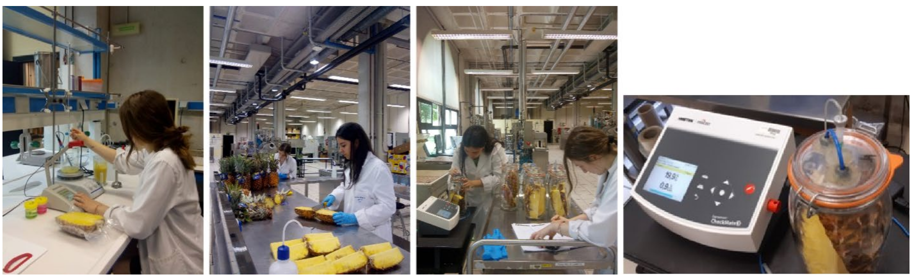
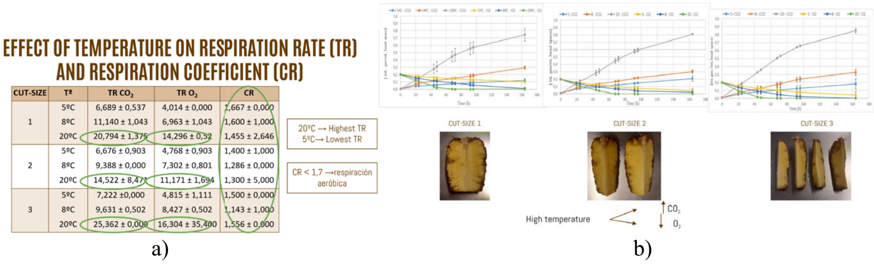
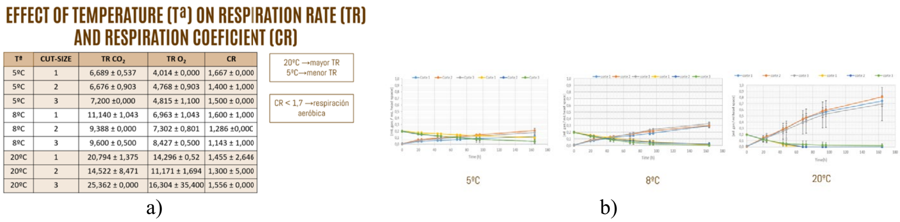


Fig. 1 Images of the development of the experimentation. The images show different moments of the experimentation of the students at the university installation



CUT-SIZE	Tª	TR CO_2	TR O_2	CR
1	5ºC	6,689 ± 0,537	4,014 ± 0,000	1,667 ± 0,000
	8ºC	11,140 ± 1,043	6,963 ± 1,043	1,600 ± 1,000
	20ºC	20,794 ± 1,375	14,296 ± 0,52	1,455 ± 2,646
2	5ºC	6,676 ± 0,903	4,768 ± 0,903	1,400 ± 1,000
	8ºC	9,388 ± 0,000	7,302 ± 0,801	1,286 ± 0,000
	20ºC	14,522 ± 8,471	11,171 ± 1,694	1,300 ± 5,000
3	5ºC	7,222 ±0,000	4,815 ± 1,111	1,500 ± 0,000
	8ºC	9,631 ± 0,502	8,427 ± 0,502	1,143 ± 1,000
	20ºC	25,362 ± 0,000	16,304 ± 35,400	1,556 ± 0,000

Fig. 2 Data and representation of data for the variable *Type of cut* on the respiration rate: a) Data represented in the form of a table; b) Data represented in the form of a graph



Tª	CUT-SIZE	TR CO_2	TR O_2	CR
5ºC	1	6,689 ± 0,537	4,014 ± 0,000	1,667 ± 0,000
5ºC	2	6,676 ± 0,903	4,768 ± 0,903	1,400 ± 1,000
5ºC	3	7,200 ±0,000	4,815 ± 1,100	1,500 ± 0,000
8ºC	1	11,140 ± 1,043	6,963 ± 1,043	1,600 ± 1,000
8ºC	2	9,388 ± 0,000	7,302 ± 0,801	1,286 ±0,000
8ºC	3	9,600 ± 0,500	8,427 ± 0,500	1,143 ± 1,000
20ºC	1	20,794 ± 1,375	14,296 ± 0,52	1,455 ± 2,646
20ºC	2	14,522 ± 8,471	11,171 ± 1,694	1,300 ± 5,000
20ºC	3	25,362 ± 0,000	16,304 ± 35,400	1,556 ± 0,000

Fig. 3 Data for the variable *Temperature* on the respiration rate: a) Data represented in the form of a table; b) Data represented in the form of a graph

Sub-Competence: 3- Interpreting Data and Evidence Scientifically

Based on the principles established by the OECD (2016), students had developed this sub-competence if they were capable of analysing and understanding scientific data, the demands and the arguments of a variety of representations, and were able to draw pertinent conclusions.

The students collected data on the respiration rate, modifying the variables *type of cut* (see Fig. 2) and *temperature* (see Fig. 3). In this point, they stated that "*It is of relevant importance to note what is happening at each moment, otherwise, you forget it and it's like it never happened*". The results were presented in tables and graphs that give a visual representation.

Once the data were represented the students explained that:

> "*We have been very conscious of the replicability of the data. For that reason, we have taken all the measurements three times. If we measure three times we minimise the possibility of human error and get more reliable and robust results... It is also useful if, for example, we had only one jar and it had been opened and, therefore, the atmosphere had changed. Well, if you have two more you realise something has happened, otherwise it's impossible to notice it.*"

After contrasting the evidences with the evaluation´ rubric (Table 1), below we briefly show the level of development of each of the three sub-competencies (see Table 2).

Table 2 Results of the sub-competences´ development

Sub-competence	Dimensions	Cognitive demand	Evidences
Explaining phenomena scientifically	**Scientific knowledge of the problem**	Complements with knowledge necessary to resolve the problem	According to this data, the students evaluated their scientific knowledge of the problem and they completed it; this helped them to combine their explanatory models with others and to formulate hypotheses that they would later confirm or refute based on the experimental evidence they obtained in the literature. These results, evaluated by means of the rubric (Table 1), indicated that the three dimensions that were developed as part of the sub-competence "explaining phenomena scientifically" had achieved high levels of cognitive demand, as we have emphasised in Table 1. The score that the students obtained for the development of this sub-competence was 17 out of 18 points
	Explanatory models or representation of knowledge and implications for society and people	Combines original explanatory models with other models that help to resolve the problem	
	Predictions, hypotheses and causal relationships or simple correlations	Evaluates scientific predictions and hypotheses supported by evidence	
Evaluating and designing scientific research	**Objectives of a study and methodology**	Designs an investigation in accordance with the chosen methodology and the objectives	In relation to the second sub-competence, and in the light of the results, the students have designed the research in accordance with the selected methodology and their objectives, they have analysed whether the questions were scientifically researchable or not and they have designed a research project in due consideration of the principal tasks and responsibilities of scientists. Based on the evaluation rubric, the students have developed this competence to a degree of 16 of a maximum of 18 points
	Researchable questions	Analyses whether the questions posed in the research are scientifically researchable	
	Work of scientists	Designs the project in accordance with the main tasks of the scientist (researchable questions, veracity, cooperation, publication)	

Table 2 (continued)

Sub-competence	Dimensions	Cognitive demand	Evidences
Interpreting data and evidence scientifically	**Data and representation**	<u>Draws conclusions based on collected data</u>	In this step of the project, the students collected data, ensuring that the measurements were replicable and reliable, thus minimising possible uncertainty and errors. Through the repetitions, they evaluated the validity of the data, represented them to facilitate visual interpretation and compared them with the scientific literature they had read. They reached conclusions based on the data and presented the results through reasoned explanations to the project tutors. Therefore, in accordance with the dimensions established in Table 1, the results demonstrated that this sub-competence had been developed in 17 of a maximum of 18 points
	Validity of data	<u>Evaluates the validity of data (replicability, uncertainty, error)</u>	
	Argument and evidence	<u>Provides original arguments based on scientific evidence</u>	

Discussion

This work has analysed the extent to which the BdR has favoured the acquisition of scientific competence among the students who took the course. The research was structured in the analysis of the three sub-competences that comprise the scientific competence evaluated in the PISA reports (OCDE 2016; 2019; 2022). A qualitative analysis of the development of the three sub-competences was conducted by means of data collection. In order to achieve that, an ad hoc rubric was designed, which allowed the researchers to quantify the final development of scientific competence through the analysis of the three dimensions that form each sub-competence. The design and application of this rubric can also be considered a result of this research. This is because, as discussed before, although PISA establishes sub-competences as something to be developed to achieve scientific competence, it does not offer a specific instrument to evaluate them. In other words, due to the limitations of PISA evaluation resources, the design of this rubric can be very useful for the evaluation of scientific competence in future studies (Blanco Anaya and Díaz de Bustamante, 2017).

The results for the sub-competence “Explaining phenomena scientifically” reveal that the students learnt how to identify their own knowledge of the subject to be researched. They were able of complements with knowledge necessary to resolve the problem broadening it, thus combining their explanatory models with others. Furthermore, they also learnt how to evaluate predictions through substantiation using evidence and data. However, they did not generate arguments to support or refute hypotheses.

The results for the sub-competence “Evaluating and designing research” show that the students searched for, read, described in their own words and evaluated several scientific research studies. They also offered proposals for approaching scientific questions, which demonstrated their ability to identify the question examined in a scientific study, recognise questions that could be scientifically investigated, propose a method for scientifically exploring a given question, evaluate the methods for scientifically exploring a given question, and describe and evaluate the way in which scientists ensure the reliability of data, objectivity and the generalisation of explanations. The students also posed researchable scientific questions that formed the basis for their research, although they have not established arguments to justify the said questions.

As regards the sub-competence “Interpreting data and evidence scientifically”, the data demonstrate that the students acquired the ability to identify assumptions, evidence and reasoning in the texts about science. They were also able to differentiate arguments that were based on theory and scientific evidence from those based on other considerations. They were able evaluate arguments and scientific evidence from different sources and transform the data from one type of representation to another. Finally, they could further analyse and interpret data and draw pertinent conclusions.

These qualitative results have been quantified through the rubric designed for that purpose. Attending to the punctuation of the rubric, the students developed the first sub-competence in 17 of the 18 maximum points, the second sub-competence in 16 of 18 maximum points and the third sub-competence in 17 of the 18 maximum points. As a result, the degree of development of scientific competence of the students gained through the BdR was 92.6% (50 points of 54 maximum punctuation).

In summary, the results proved the students demonstrated their scientific knowledge of content, procedural and epistemic (Kind & Osborne, 2017), which correspond with three goals of science education highlighted by Hodson (2014): learning science (content knowledge), learning about science (epistemic knowledge), and doing science (procedural knowledge). They demonstrated this knowledge by means of the development of the three sub-competences along the project (explaining phenomena scientifically; evaluating and designing scientific research; and interpreting scientific data and evidence) thus, the project favoured their scientific competency (Sadler & Zeidler, 2009).

Conclusions

Compulsory science education must train scientifically competent students. According to the OECD, a scientifically competent student is one who demonstrates having developed the three sub-competences that this organization has established (Sadler & Zeidler, 2009). This same organization, through PISA evaluations, is responsible for evaluating the competence of students from different countries every three years. In Spain, where science results are not among the best, science education in the last two years of high school focuses in the opposite direction. This teaching is limited to training students in solving problems that allow them to pass the University entrance test. In this sense, a type of baccalaureate that focused on the teaching of competency skills was identified as necessary.

This work has analyzed the development of scientific competence of a convenience sample, who for 18 months have developed a scientific project, tutored by their high school teacher and a university teacher/researcher. The students were free to design and develop a methodology, which had to be based on the work of scientists, to answer a research question. Throughout the project, data was collected through interviews and a final report, to what extent it helped the development of each of the three sub-competencies, concluding the following. To evaluate development, a rubric was designed based on PISA guidelines. This rubric has turned out to be valuable for the evaluation of these sub-competencies. Each of the three sub-competencies were put into play throughout the development of the project, reaching high levels of development in each of them. It can be concluded that the students were able to design their own research, search for work to support their own, search for necessary information, identify their partial research questions, establish what materials they needed, decide variables to analyze, collect and represent the data found, draw conclusions and present their results. It can be concluded that they have approached the knowledge of the nature of science (Rosales Ortega et al., 2020) and that, without a doubt, they have applied knowledge itself more than memorization (Gallardo-Gil et al., 2010).

However, another of the conclusions reached was that its design favors the development and scientific practice of argumentation to a lesser extent. That is to say, the students have not found space to establish arguments, at least sufficiently founded arguments and this is important since it is related to the identification of scientific reasoning, as established (Krell et al., 2020). We propose that, as a future study, a control test be incorporated to facilitate this, such as, for example, instead of one of the interviews, the tutors would propose holding a debate on specific aspects of the research. Debates are educational tools that promote argumentation in the classroom (Cascarosa et al., 2019).

Another relevant conclusion is in relation to the research design: This research follows a case study methodology, which offers a framework for validating the research in the context in which it has been carried out (Justi & van Driel, 2005), but research would be necessary in a different context that would allow validate the generalization of the results found. There is also a limitation on the sample number of this study, due to the small number of participants in the project. In the future, the sample should be expanded to be able to make a more robust treatment of the research results.

In relation to the implications of this research for high school science, this research shows an example of how science can be worked on, in the last years of secondary education, developing scientific competence. Therefore, it is demonstrated that an alternative way of teaching and learning science is possible in such complex courses.

Limitations

This paper presents a study that is relevant to understanding how the high school diploma of research favours the development of scientific competence in students. The study involved a structured, systematic analysis of the sub-competences that define scientific competence. The quantitative and qualitative results are undoubtedly promising (the results showed 92.6% development of scientific competence), the study has limitations that should be taken into account. The most relevant limitation is that the study was developed using case study methodology; consequently, the results are only valid for the context in which the project was developed. Therefore, the sample and the context of analysis should be generalised in order to consolidate statistically significant results. For this reason, an extension of the study with a sample consisting of all the students of the high school diploma of research is being considered, but given that each group of students develops a different project with different collaborating organisations the work would require a considerable amount of time.

Acknowledgements The authors would like to thank the Beagle Research Group into the Didactics of the Natural Sciences and the University Institute for Research in Environmental Sciences of Aragon (IUCA), both depending on the University of Zaragoza. We are pleased to thank the support of the DGA (Gobierno de Aragón) project GOP2024002300 “Alianza Agroalimentaria Aragonesa: Comunicación para la mejora de la reputación y puesta en valor de la producción de alimentos.”

Author Contributions All authors contributed to the study conception and design. Material preparation, and data collection were performed by CB and EA. The data analysis was performed by JP and EC. All the authors co-write, reviewed and approved the present version of the manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. Open Access funding enabled and organized by the University of Zaragoza (Spain).

Data Availability The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval and Informed Consent Confidential and anonymous treatment of participants’ data has been considered for the conduct of research. Informed consent under no coercion or bribery of any kind, in accordance with the principles outlined in the University of Zaragoza Good Practice Guidelines, has been obtained from the participants.

Conflict of Interest The authors have no conflict of interest to declare that are relevant to the content of this article.

References

Adelman, C., Jenkins, D., & Kemmis, S. (1980). *Rethinking case study: Notes from the second Cambridge conference*. In H. Simons (ed.), Towards a Science of the Singular, pp. 47–61. Norwich: University of East Anglia.

Beghetto, R. A. (2007). Factors Associated with Middle and Secondary Students' Perceived Science Competence. *Journal of Research in Science Teaching, 4*(6), 800–814. https://doi.org/10.1002/tea.20166

Bell, P., & Linn, M. C. (2010). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797–817. https://doi.org/10.1080/095006900412284

Blanco Anaya, P., & Díaz de Bustamante, J. (2017). Análisis del nivel de desempeño para la explicación de fenómenos de forma científica en una actividad de modelización. [Performance level analysis for explaining phenomena scientifically in a modelling activity]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 14*(3), 505-520. 10498/19504

Blanco A., & Lupión T. (2015). *La competencia científica en las aulas. Nueve propuestas didácticas*. [Scientific competence in the classroom. Nine didactic proposals]. Andavira Editora.

Bybee, R., McCrae, B., & Laurie, R. (2009). PISA 2006: An Assessment of Scientific Literacy. *Journal of Research in Science Teaching, 46*(8), 865–883. https://doi.org/10.1002/tea.20333

Cascarosa Salillas, E., García Andreu, M., & Pozuelo Muñoz, J. (2019). El debate en ciencias: Gana el equipo que mejor argumente [The debate in science: the team that argues the best wins]. *ReidocreA, 8*(3), 15–20. https://doi.org/10.30827/digibug.54424

Cascarosa Salillas, E., Pozuelo Muñoz, J., & Feringán, B. (2021). Old instruments in the physics and chemistry cabinet at Goya Secondary School. Analysis of their didactic use in teaching physics today. *Culture and Education, 33*(3), 556–572. https://doi.org/10.1080/11356405.2021.1949113

Cascarosa Salillas, E., Pozuelo Muñoz, J., Jiménez, M., & Fernández Álvarez, F. J. (2022). Analysis of the mental model about the atom concept in Spanish 15- to 18- years old students. *Educación Química, 33*(2). https://doi.org/10.22201/fq.18708404e.2022.2.79895

Caamaño, A. (2012). ¿Cómo introducir la indagación en el aula? [How to introduce enquiry in the classroom]. *Alambique: Didáctica de las Ciencias Experimentales, 70*, 83–92.

Caamaño, A. (2018). Enseñar química en contexto: Un recorrido por los proyectos de química en contexto desde la década de los 80 hasta la actualidad. [Teaching chemistry in context: A review of chemistry projects in context from the 1980s to the present day]. *Educación Química, 29*(1), 21–54. https://doi.org/10.22201/fq.18708404e.2018.1.63686

Chun-Yen, T. (2015). Improving Students' PISA Scientific Competencies Through Online Argumentation. *International Journal of Science Education, 37*(2), 321–339. https://doi.org/10.1080/09500693.2014.987712

Clark, D. B., & Sampson, V. D. (2008). Assessing dialogic argumentation in online environments to relate structure, grounds, and conceptual quality. *Journal of Research in Science Teaching, 45*(3), 293–321. https://doi.org/10.1002/tea.20216

Cobern, W. W., Schuster, D., Adams, B., Applegate, B., Skjold, B., Undreiu, A., Loving, C. C., & Gobert, J. D. (2010). Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technological Education, 28*(1), 81–96.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. Routledge.

Couso, D. (2020). Aprender ciencia escolar implica construir modelos cada vez más sofisticados de los fenómenos del mundo. [Learning science in school involves building increasingly sophisticated models of world phenomena]. En *Enseñando Ciencia con Ciencia* (FECYT&Fundación Lilly). Penguin Random House.

Crujeiras-Pérez, B. (2017). Análisis de las estrategias de apoyo elaboradas por futuros docentes de educación secundaria para guiar al alumnado en la indagación. [Analysis of support strategies developed by prospective secondary school teachers to guide students in enquiry]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 14*(2), 473–486. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2017.v14.i2.13

Crujeiras-Pérez, B., Martín-Gámez, C., Díaz-Moreno, N., & Fernández-Oliveras, A. (2020). Trabajar la argumentación a través de un juego de rol: ¿debemos instalar el cementerio nuclear? [Work on the

argument through a role-playing game: Should we install the nuclear cemetery?]. *Enseñanza De Las Ciencias, 38*(3), 125–142. https://doi.org/10.5565/rev/ensciencias.2888
Crujeiras Pérez, B., & Jiménez Aleixandre, M. P. (2015). Análisis de la competencia científica de alumnado de secundaria: respuestas y justificaciones a ítems de PISA. [Analysis of the scientific competence of secondary school students: responses and justifications to the PISA items]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 12*(3), 385-401. 10498/17598
Duschl, R. A. (2007). Science education in three-part harmony: Balancing conceptual, epistemic and social learning goals. *Research in Education, 32*, 268–291. https://doi.org/10.3102/0091732X07309371
European Commission. (2015). *Science education for responsible citizenship*. Brussels: European Commission Retrieved from http://ec.europa.eu/research/swafs/pdf/pub_science_education/KI-NA-26-893-EN-N.pdf.
Ferrés-Gurt, C. (2017). El reto de plantear preguntas científicas investigables [The challenge of posing researchable scientific questions]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 14*(2), 410–426. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2017.v14.i2.09
Ferrés-Gurt, C., Marbà-Tallada, A., & Sanmartí, N. (2015). Trabajos de indagación de los alumnos: Instrumentos de evaluación e identificación de dificultades [Students' enquiry projects: Evaluation tools and identification of difficulties]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 12*(1), 22–37. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2015.v12.i1.03
Fonseca, S. C., Oliveira, F. R. A., & Brecht, J. K. (2002). Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages. *A Review. Journal of Food Engineering, 52*, 99–119.
Franco-Mariscal, A.J., Blanco-López, A., & España-Ramos, E. (2017). Diseño de actividades para el desarrollo de competencias científicas. Utilización del marco de PISA en un contexto relacionado con la salud. [Design of activities for the development of scientific competence. Using the PISA framework in a health-related context]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias 14*(1), 38-53. 10498/18845
Gallardo-Gil, M., Fernández-Navas, M., Sepúlveda-Ruiz, M. P., Serván, M. J., Yus, R., & Barquín, J. (2010). PISA y la competencia científica: Un análisis de las pruebas de PISA en el Área de Ciencias. [PISA and science competence: An analysis of PISA tests in the field of science]. *Relieve, 16*(2), 1–17.
Guisasola, J., Ametller, J., & Zuza, K. (2021). Investigación basada en el diseño de Secuencias de Enseñanza-Aprendizaje: Una línea de investigación emergente en Enseñanza de las Ciencias [Research based on the design of teaching-learning sequences: An emerging line of research in science education]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 18*(1), 1801–1801. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i1.1801
Hanushek, E., & Woessmann, L. (2011). How much do educational outcomes matter in OECD countries? *Economic Policy, 26*, 427–491. https://doi.org/10.1111/j.1468-0327.2011.00265.x
Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education, 36*, 2534–2553. https://doi.org/10.1080/09500693.2014.899722
Justi, R., & van Driel, J. (2005). A case study of the development of a beginning chemistry teacher's knowledge about models and modelling. *Research in Science Education, 35*, 197–219. https://doi.org/10.1007/s11165-004-7583-z
Kauertz, A., Neumann, K., & Haertig, H. (2012). Competence in Science Education. In B.J. Fraser et al. (eds.), Second International Handbook of Science Education, Springer International Handbooks of Education 24. https://doi.org/10.1007/978-1-4020-9041-7_47
Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education? *Science Education, 101*, 8–31. https://doi.org/10.1002/sce.21251
Krell, M., Walzer, C., Hergert, S., & Krüger, D. (2017). Development and Application of a Category System to Describe Pre-Service Science Teachers' Activities in the Process of Scientific Modelling. *Research in Science Education, 333*, 1096. https://doi.org/10.1007/s11165-017-9657-8
Krell, M., Redman, C., Mathesius, S., Krüger, D., & van Driel, J. (2020). Assessing Pre-Service Science Teachers' Scientific Reasoning Competencies. *Research in Science Education, 50*, 2305–2329. https://doi.org/10.1007/s11165-018-9780-1
Krell, M., Vorholzer, A., & Nehring, A. (2022). Scientific Reasoning in Science Education: From Global Measures to Fine-Grained Descriptions of Students' Competencies. *Education in Science, 12*, 97. https://doi.org/10.3390/educsci12020097
Kuhn, D. (2010). Teaching and learning science as argument. *Science Education, 60*(3), 299–312. https://doi.org/10.1002/sce.20395

Lijnse, P. L., & Klaassen, C. W. J. M. (2004). Didactical structures as an outcome of research on teaching–learning sequences? *International Journal of Science Education, 26*(5), 537–554. https://doi.org/10.1080/0950069031000161475З

Merriam, S. B. (1988). *Case study research in education a qualitative approach*. Jossey-Bass.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Muñoz-Campos, V., Franco-Mariscal, A. J., & Blanco-López, Á. (2020). Integración de prácticas científicas de argumentación, indagación y modelización en un contexto de la vida diaria. Valoraciones de estudiantes de secundaria. [Integration of argumentation, enquiry and modelling scientific practices in an everyday context. Assessments of secondary school students]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 17*(3), 3201. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2020.v17.i3.3201

Muñoz Martínez, J. I., & Charro Huerga, E. (2023). El desarrollo de Competencias Científicas a través de una línea de saberes: Un análisis experimental en el aula. [The development of scientific competences through a line of knowledge: An experimental analysis in the classroom]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 20*(2). https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2023.v20.i2.2101

Muñoz, J., & Charro, E. (2018). La Interpretación de Datos y Pruebas Científicas vistas desde los Ítems liberados de PISA []. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 15*(2), 2101. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2018.v15.i2.2101

OECD. (2016). *PISA 2015 Assessment and Analytical Framework: Science, Reading*. OEDC Publisching.

OECD. (2019). *PISA 2018 Assessment and Analytical Framework [PISA]*. https://doi.org/10.1787/b25efab8-en

OECD. (2022). *PISA 2021 Assessment and Analytical Framework [PISA]*. https://doi.org/10.1787/53f23881-en

Osborne, J. (2010). Arguing to learn in science. *Science, 328*(5977), 463–466. https://doi.org/10.1126/science.1183944

Osborne, J. (2014). Scientific practices and inquiry in the science classroom. In N. Lederman & S. Abell (Eds.), *Handbook of research on science education* (pp. 579–599). Routledge.

Osborne, J., Henderson, J. B., MacPherson, A., Szu, E., Wild, A., & Yao, S. Y. (2016). The development and validation of a learning progression for argumentation in science. *Journal of Research in Science Teaching, 53*(6), 821–846. https://doi.org/10.1002/tea.21316

Pedrinaci, E. (2013). Alfabetización en ciencias de la Tierra y competencia científica. [Literacy in Earth science and scientific competence]. *Enseñanza de las Ciencias de la Tierra, 21*(2), 208–214.

Pedrinaci, E., Caamaño i Ros, A., Cañal, P., & Pro Bueno, A. de. (2012). *El desarrollo de la competencia científica: 11 ideas clave*. [Development of scientific competence: 11 key ideas]. Barcelona: Graó.

Rodríguez Gómez, G., Gil Flores, J., & García Jiménez, E. (1996). *Metodología de la investigación cualitativa*. [Qualitative research methodology]. Ediciones Aljibe.

Romero-Ariza, M. (2017). El aprendizaje por indagación: ¿existen suficientes evidencias sobres sus beneficios en la enseñanza de las ciencias? [Enquiry learning: Is there sufficient evidence of its benefits in science education?]. *Revista Eureka sobre enseñanza y divulgación de las Ciencias, 14*(2), 286–299. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2017.v14.i2.01

Rosales Ortega, E. M., Rodríguez Ortega, P. G., & Romero Ariza, M. (2020). Conocimiento, demanda cognitiva y contexto en la evaluación de la alfabetización científica en PISA. [Knowledge, cognitive demand and context in the evaluation of scientific literacy in PISA]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 17*(2), 2302. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2020.v17.i2.2302

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*(8), 909–921.

Sanmartí, N., & Hinojosa, J. (2015). La autorregulación metacognitiva como medio para facilitar la transferencia en mecánica [Metacognitive self-regulation as a means of promoting mechanical transfer]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 12*(2), 249–263. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2015.v12.i2.02

Schwartz, I., Adler, I., Madjar, N., & Zion, M. (2021). Rising to the Challenge: The Effect of Individual and Social Metacognitive Scafolds on Students' Expressions of Autonomy and Competence Throughout an Inquiry Process. *Journal of Science Education and Technology, 30*, 582–593. https://doi.org/10.1007/s10956-021-09905-4

Simons, H. (2011). *El estudio de caso: Teoría y práctica*. [The case study: Theory and practice]. Morata.

Stake, R. E. (1994). *Case studies*. En N. K. Denzin & Y. S. Lincoln, Handbook of qualitative research (pp. 236–247). Sage Publications.

Stake, R. E. (2005). *Investigaciones con estudio de caso.* [Case study research]. Morata.
Walton, J. (1992). *Making theoretical case*. En Ragin & Becker. What is a case. Exploring the Foundations of Social Inquiry (pp. 121–137). Cambridge University Press.
Woods-McConney, A., Oliver, M., McConney, A., Schibeci, R., & Maor, D. (2014). Science Engagement and Literacy: A retrospective analysis for students in Canada and Australia. *International Journal of Science Education, 36*. https://doi.org/10.1080/09500693.2013.871658
Yin, R. (2014). *Case Study Research*. Sage Publications.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.