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Scientific creativity in secondary students and its relationship with STEM-related attitudes, engagement and work intentions

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The role of creativity in education is pivotal, since it is regarded as an essential skill enabling students to cope with future challenges, not only at their professional, but also at their daily life. Consequently, the assessment and improvement of creativity skills among secondary school students has been tackled both at international (OECD reports and the recent inclusion of creativity in the 2022 PISA tests) and national spheres (such as the LOMLOE law at Spain, in which this study is framed). In this context, this longitudinal quasi-experimental study explores the scientific creativity performance of Spanish secondary students (N=780) and its relationship with their attitudes and engagement towards science, and work intentions in STEM-related careers. Results show a noteworthy deficiency in scientific creativity, in terms of problem-finding abilities, alongside with moderately accurate and positive perceptions about how science works and its individual and collective implications. In addition, limited engagement in science-related activities and a low rate of expectations in pursuing STEM-related careers have also been detected. Gender differences were found in scientific creativity, as well as perceptions and career expectations related to science. No differences were found in the scientific creativity across the levels of compulsory secondary school, but an improvement in perceptions about science was observed as the students progressed in the educational system. Nevertheless, a decrease in the rate of engagement and willingness to embracing a STEM-related pathway has also been detected in higher levels. Positive correlations between engagement and career expectations related to science were also found. The importance of nurturing scientific creativity is discussed in terms of enriching learning experiences and the design of interventions and specific policies. Finally, the impact of implementing creativity-focused educational strategies is highlighted in order to promote interest in pursuing STEM careers beyond the obligatory boundaries of education.

KEYWORDS

scientific creativity, attitudes, engagement, STEM, secondary education

1 Introduction

One of the main issues dealing with students' engagement with STEM (science, technology, engineering and mathematics) subjects is the deeply rooted perception that those are complex and detached from reality. This is directly related to a lack of concentration and perseverance, which contributes to expand the barrier for diving into a STEM-related academic journey

(Tinto, 2010). This challenge hinders the scientific literacy, specifically at secondary school levels. In this context, conventional teaching methods that emphasize memorization, often divorced from real-life contexts, persist despite their drawbacks (Allchin, 2014). This approach fails to engage students with scientific concepts, leaving them uninterested and struggling with comprehension. Bridging these concepts to everyday life is crucial; dismissing this approach solidifies disinterest in STEM subjects, and particularly in science (Chambers et al., 2019).

According to the recently published results of the Program for International Student Assessment (PISA), there is a notorious general decrease of the performance at science, mathematics and reading, since the implementation of the program (OECD, 2023). Considering the case of Spanish data, mean performance in all three subjects was significantly lower in 2022, when compared to 2012 and 2015 editions. Indeed, the number of 15-year-old students scoring below the basic level of performance (Level 2) increased in all three subjects (over the 2012–2022 period). However, over 79% of Spanish students achieve, at least, this level. Consequently, those students are supposed to be able to recognize the correct explanation for familiar scientific phenomena and can use such knowledge to identify, in simple cases, whether a conclusion is valid based on the data provided. Nevertheless, they were not able to creatively and autonomously apply their knowledge of and about science to a wide variety of situations, including unfamiliar ones (OECD, 2023). Hence, students are not thought to be equipped with the necessary creativity skills and competencies to cope with the current society paradigm, in which uncertainty and change are the main characters. Within this landscape, there is predominant research focused on evaluating student learning outcomes and performance in light of the widely recognized 21st-century skills (Xia et al., 2022). Among these essential competencies, creativity stands out as a subject of considerable interest across diverse disciplines, since it embodies a pivotal human capacity, encompassing intra and inter-psychological processes that profoundly influence individuals personally and collectively (Beghetto, 2016; Sawyer, 2021). Moreover, creativity has been strongly related with problem-solving abilities, divergent thinking, metacognition processes and remote-associations construction (Jia et al., 2019), which are essential in STEM-related endeavors.

In this context, the present study contributes to the understanding of scientific creativity among Spanish secondary school students, shedding light on their performance and its interrelation with attitudes towards science and STEM career aspirations. By using a longitudinal quasi-experimental methodology, potential variations across different educational levels and gender differences are explored. Moreover, the integration of scientific creativity assessment with the assessment of students' STEM attitudes and career intentions offers a novel perspective and a holistic understanding of the challenges and opportunities faced by students in pursuing STEM-related pathways.

Firstly, literature review and theoretical framework sections outline the research background, exploring the nature of creativity with emphasis on scientific creativity, as well as the diversity of assessment methodologies, and their implications for educational practices. Afterwards, the methodology section describes the longitudinal quasi-experimental design employed in this study, detailing the participant characteristics, data collection procedures, and analytical techniques. Results are then presented, highlighting key findings regarding scientific creativity of students, their perceptions about science, and their STEM career aspirations. Finally, discussion and conclusion sections synthesize these findings, emphasizing the importance of nurturing scientific creativity through targeted educational interventions and policies.

1.1 Literature review

Despite the existence of a vast number of creativity definitions at the literature, those commonly embody two pivotal traits: novelty and utility (Stein, 1953). Novelty is associated to uniqueness or originality, while utility is referred to meaningfulness or appropriateness (Runco and Jaeger, 2012). Moreover, it is widely accepted that the nature of creativity is multi-componential (Barbot et al., 2019). Hence, diverse theoretical and empirical frameworks, stemming from various psychological perspectives, delve into this phenomenon. Additionally, understanding the mechanisms underlying creative performance is critical. Models such as the "Four P model" (Rhodes, 1961) or the more recent "Four C model" (Kaufman and Beghetto, 2009) help to delineate different levels of creative expression. Those frameworks capture various manifestations of creativity during the learning process, emphasizing the intertwined nature of creativity and learning (Lemmetty and Collin, 2021). Particularly, by providing access to diverse perspectives, knowledge and experiences, STEM education plays a crucial role in developing creativity in conjunction with other essential skills, such as communication, teamwork, and adaptability (Harris and De Bruin, 2018), which in turn broad personal, professional, and collective objectives (Vincent-Lancrin et al., 2019).

The relationship between creativity and education is often addressed by assessing the influence of personality traits, cognitive factors, or educational programs on creative processes. These studies often rely on diverse instruments and settings to assess creativity (Hernández-Torrano and Ibrayeva, 2020; Sahin et al., 2023). The assessment methodologies primarily include three major approaches: evaluating creativity through accomplishment, profiling individual characteristics related to creative potential, and evaluating creativity potential via predefined tasks (Thornhill-Miller et al., 2023). Techniques employed in these approaches range from expert evaluations to self-report questionnaires, divergent thinking tasks, such as the Torrance Tests of Creative Thinking (TTCT) (Torrance, 1972), to personality tests (Costa and McCrae, 1992), among others. Several reviews have been published aiming to provide a comprehensive overview of creativity assessment approaches (Acar and Runco, 2019; Cotter and Silvia, 2019; Karwowski et al., 2019; Snyder et al., 2019). Furthermore, emphasis on accuracy, homogenization, and transparency in reporting creativity results is regarded as critical for advancing on creativity research, despite its complex and multidimensional nature (Barbot and Said-Metwaly, 2021).

Indeed, the existence of creativity domains has been extensively discussed since the early stages of this research field (Guilford, 1950). Nevertheless, in recent years a consensus has grown acknowledging the multi-componential nature of creativity, compiling both domain-specific and general features and also including social and cultural interconnections (Baer, 2012; Glaveanu et al., 2020). From a theoretical point of view, the well-known Amusement Park Theory (APT) (Kaufman and Glaveanu, 2019) states that there are four hierarchical stages that allow creative processes to occur. These include from initial requirements that must be present, such as a supportive environment or a basic level of intelligence and interest; knowledge at general thematic areas, such as science or arts; to specific domains and microdomains, which correspond to concrete sub-themes and tasks (Baer and Kaufman, 2005).

In this regard, there are numerous studies in the literature focused on specific areas of creativity (Said-Metwaly et al., 2017), such as scientific creativity (Hu et al., 2010; Chen et al., 2016; De Vries and Lubart, 2019), linguistic creativity (Bowdle and Gentner, 2005; Bergs, 2019), and other knowledge areas like music, art or mathematics (Erbas and Bas, 2015; Mansour et al., 2018; Kladder and Lee, 2019; Leikin and Sriraman, 2022). Therefore, even though divergent thinking tests, are still the most commonly used (Kapoor et al., 2021), researchers are recently more prone to adopt a more comprehensive approach by evaluating multiple areas of creativity. This implies not only evaluating isolated creativity domains, but considering the relationships between them and exploring how they influence each other (Long et al., 2022), as well as taking into account further key aspects that forge one's individual creativity profile (Glaveanu et al., 2020), such as life satisfaction, engagement, positive emotions and academic preferences and performance (Conner and Silvia, 2015; Caballero-García and Sanchez Ruiz, 2021; Bekker et al., 2023). In this context, the impact of teaching strategies that allow students to express their creativity have been proved to be remarkably relevant, not only at learning outcomes, but also at their attitudes towards science (Aguilera and Perales-Palacios, 2020; Bi et al., 2020). Regarding STEM-related subjects, some studies proved that project-based STEM learning enhances the creativity of students (Hanif et al., 2019; Salmi et al., 2021), while other studies point out to the influence of creativity in STEM-related career choices (Conradty and Bogner, 2019; Higde and Aktamis, 2022).

1.2 Theoretical framework

As mentioned above, despite not having a standard definition of creativity, its multi-dimensional character is well-acknowledged among researchers of the field, and it is considered to include specific-domains, general-domains and further aspects related to personal, social and cultural traits (Baer, 2012; Glaveanu et al., 2020). Among all the possible dimensions, relatively limited attention has been paid to scientific creativity in comparison to artistic or linguistic domains of creativity (Raj and Saxena, 2016; Hernández-Torrano and Ibrayeva, 2020), for example. Nevertheless, scientific creativity differs from other dimensions, since specific knowledge and skills are needed to perform creatively in any given scientific creativity endeavor, such as experimental practices or problem finding and solving. Consequently, general/specific knowledge and skills, as well as divergent and convergent thinking, are considered to play a key role when approaching science education creatively (Zulkarnaen et al., 2018; Yildiz and Yildiz, 2021). In this regard, scientific creativity may be conceptualized as an interplay of knowledge, skills and divergent/convergent thinking, which provides a creative pathway to science (Klahr, 2000; Heller, 2007; Mukhopadhyay and Sen, 2013). Particularly, Hu and Adey (2002) develop the three-dimensional Scientific Structure Creativity Model (SSCM) in order to conceptualize scientific creativity, within the context of science education. This model consists of three scientific dimensions: process (scientific thinking and imagination); product (scientific knowledge, phenomenon, technical artifacts and problems) and personality (fluency, flexibility and originality). Although this approach is highly in line with the perspective of Guilford (1950) and Torrance (1972), it also includes scientific creative endeavors such as generating and corroborating hypothesis as well as problem finding and solving (Aschauer et al., 2022).

In addition, the students' ability to think creatively and to produce creative outcomes at STEM subjects is thought to be analogous to professional scientists' endeavors, regardless the evident differences between formal scientific work and scientific education (Kind and Kind, 2007). Those are the reasons why nurturing and cultivating scientific creativity of students is essential, not only to enhance their academic performance, but also to increase their self-efficacy/self-concept and in turn encouraging them to pursue a science-related academic journey (Lent et al., 1986; Taskinen et al., 2013; Tytler, 2014; Xu, 2023).

In this context, prior to developing interventions and curricular programs addressed to promote creativity in the scientific dimension it is essential to explore the scientific creativity of secondary students, their potential and limitations (Alves-Oliveira et al., 2022; Hu et al., 2023). Several instruments have been used for measuring scientific creativity (Hu and Adey, 2002; Hu et al., 2010; Ayas and Sak, 2014) based on different creativity aspects, such as curricular science knowledge and skills related to experimenting and managing data from observation, generation of scientific products and analysis of scientific processes, or formulation of questions of scientific nature. They converge in the idea that scientific discovery stems on different aspects of the scientific method, such as searching for possible hypothesis, performing experiments, etc. (Aschauer et al., 2022). These instruments have been used not only to assess secondary school students' creativity (Hu et al., 2010; Pont-Niclòs et al., 2023), but also to get insight into the impact of teaching experiences in STEM subjects at creativity performance (Jia et al., 2017; Demirhan and Sahin, 2019).

Considering the imminent publication of the 2022 PISA creativity results and the still recent law modification within the Spanish educational system, which praises creativity as a key transdisciplinary pillar of students' formation (LOMLOE, 2020), it is imperative to reckon on studies assessing the scientific creativity of secondary school adolescents. This will serve to gain a better understanding of the prospects and chances in the design of specific interventions and programs, targeting the development of scientific creativity and the encouragement of students to pursue a science-related pathway. Thus, the main aim of this study is to assess the scientific creativity of Spanish compulsory secondary school students, and its relationship with their attitudes towards science, in terms of perceptions, engagement and career expectations. Particularly, the research questions that nurture this investigation are the following:

- What is the performance in scientific creativity of Spanish secondary school students?
- Which is the predominant nature of their perceptions, engagement and career expectations with regard to science?
- Are there any differences depending on the student's level or gender?

- Is there any correlation between scientific creativity and attitudes towards STEM subjects (particularly Sciences) in Spanish secondary school students?

To answer these questions, this study encompasses a quasi-experimental research evaluating students' scientific creativity, perceptions about science, engagement in science-related activities, and STEM career expectations, exploring potential variations across different educational levels and gender differences via statistical analysis, as described in the following section.

2 Materials and methods

2.1 Participants

A total of 780 Spanish students pertaining to four different high schools from the eastern region of Spain participated in the study. The sample was selected through non-probabilistic and convenience sampling, which is one of the most common sampling protocols used when the aim of the research is to obtain insights about a particular aspect within a group of individuals. Hence, the selection of the sample maximizes the understanding of the underlying studied phenomena (Onwuegbuzie and Collins, 2007).

The levels of the secondary school involved in this research correspond to the compulsory stage of the secondary education in Spain. Of the total sample, 210 participants were studying the first level of that stage (52.4% male, and 47.6% female); 207 students correspond to the second level (53.6% male and 46.4% female); 169 of them were studying the third level (49.7% male and 50.3% female), while 194 participants were adscripted to the last level of compulsory secondary education (51.0% male and 49% female). Regarding the ages of students of each level, those were between the typical ranges within the educational system in Spain, being 12 for the first ($M = 12.3$; SD = 0.6); 13 for the second ($M = 13.4$; SD = 0.5); 14 for the third ($M = 14.3$; SD = 0.5); and 15 for the fourth level ($M = 15.3$; SD = 0.6).

2.2 Design and procedures

This study corresponds to an exploratory and semi-empirical research (Cohen et al., 2002), carried out during the 2021–2022 academic year. Specifically, previously reported, and validated instruments were used to perform a quantitative analysis. The procedure began by explaining our research project to the headmasters of a selection of high schools situated in the Valencian Community. Those willing to participate received more detailed information about the research, protocols and data processing. That information was appropriately distributed to parents and legal tutors of students, which signed an informed agreement form to collaborate in the study. After that, one class session (c.a. 50 min) was used for students to complete paper-based questionnaires. During the session both the teacher in charge of the students' group and a researcher were present. The combination of informed consent with the anonymity and confidentiality of responses ensures the ethical principles and requirements established by the Ethics Committee of the University of Valencia. Hence, ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements.

2.3 Instruments and data collection

Both daily (DSCI) and specific (SSCI) scientific creativity were assessed by means of the questionnaire developed by Hu et al. (2010), which is based on problem-finding abilities and combines two types of instruction: opened and closed (see Supplementary Table S1). This set-up is addressed to evaluate all potential creativity outcomes related to scientific problem-finding, whether those stem on every-day observations or specific knowledge about science-related matters. Hence, the questionnaire includes two subsequential items, one corresponding to the opened and other to the closed instruction. Directions were shown as slides during the session and the researcher was available for participants to ask any further inquiry. Students had a total of 16 min (8 min for each item) to complete the questionnaire. Firstly, students were asked to generate science-related questions, based on their life/daily experiences and their own curiosity, from as many perspectives as they could, and as unique as possible (opened instruction). Secondly, participants were asked to generate as many scientific questions as possible related to an image of an astronaut at the moon (closed instruction). The scoring process is based on the TTCT conceptualization of creativity (Torrance, 1972). Consequently, the questions generated by students were assessed by means of a three-folded framework consisting on fluidity, flexibility and originality: fluidity corresponds to the number of questions generated by each student; flexibility is scored as the number of knowledge areas used in order to generate those questions, with 12 categories included for DSCI and 7 categories for SSCI (Pont-Niclòs et al., 2023; see Supplementary Tables S2, S3); and originality emerges from a statistical treatment of the data, since it is related to the frequency percentage of a particular generated question within the whole sample (2 originality points if the frequency percentage is lower than 2%, 1 point if the frequency is between 5 and 10%, and 0 points if above 10%). The total score for each scientific dimension is calculated as the sum of the fluidity, flexibility and originality scores.

The perceptions and engagement of students regarding science were assessed with a questionnaire adapted from a validated scientific literacy survey (Huang, 2012; Wu et al., 2019). On one hand, items corresponding to the "perceptions" dimension were based on epistemological and ontological concepts in conjunction with assumptions about the influence of both science and technology on society (Osborne et al., 2003). On the other hand, the "engagement" dimension was rooted on the conceptualization of enjoyment and intrinsic motivation on leisurely science learning (Ryan and Deci, 2009) and involvement on scientific activities as a source of pleasant life experiences (Nugent et al., 2015). Finally, the expectation to pursuing a science-related career was evaluated via items at the section ST113 (students' attitudes towards science and expectations of science-related careers) from the PISA 2015 tests (OECD, 2016). Those items are based on the instrumental motivation to learn science, in terms of usefulness for students to pursuing their future studies or careers (Wigfield and Eccles, 2000). Items 1 to 6 correspond to the "perceptions" dimension, whereas items 7 to 12 correspond to the "engagement" dimension, and items 13 to 16 assess the willingness to develop a scientific career (see Supplementary Table S4).

A four-point Likert scale was used to score each of the items. The final score for each of the above-mentioned dimensions was calculated as the mean/median value of the items included in that dimension.

2.4 Data analysis

The statistical analysis of the data was carried out with the software IBM SPSS Statistics (version 28). Firstly, descriptive analysis of the sociodemographic and assessed variables was performed (frequencies, percentages, mean, standard deviation, median and IQR) to elucidate the general characteristics of the sample. Secondly, Kolmogorov–Smirnov test was applied to get insight into the normality of the sample distributions. Since the normality assumption was not corroborated for any of the studied variables ($p < 0.001$ for all variables), non-parametric tests were used. Particularly, Kruskal-Wallis test was applied to investigate differences among levels of compulsory secondary education, whereas Mann–Whitney U test was used to explore gender differences. The effect size was calculated using the formula described by Field (2018) for non-parametric samples. The magnitude of the effect size was evaluated according to Cohen's (1988) classification for behavioral sciences, being small (up to 0.2), medium (from 0.2 to 0.5) and large (higher than 0.5). Finally, the correlation among variables was estimated by means of Spearman correlation coefficient. In all cases, the level of statistical significance was 0.05.

3 Results

3.1 Assessment of daily (DSCI) and specific (SSCI) scientific creativity

Scores corresponding to daily and specific dimensions of scientific creativity of Spanish secondary school students are shown at Table 1. Regarding fluidity (number of questions generated by student), the mean value is lower for the DSCI ($M = 6.8$, SD = 3.9, Me = 7.0) than for SSCI ($M = 8.1$, SD = 4.0, Me = 9.0), although the former corresponds to an opened instruction and the latter to a closed one. Considering the flexibility parameter (the quantity of knowledge areas included by each student in their questions), the value for daily ($M = 3.8$, SD = 1.7, Me = 4.0) and specific dimensions ($M = 4.1$, SD = 1.4, Me = 5.0) are analogous. Nevertheless, it is essential to note that the areas defined for each dimension differ from each other (see Supplementary Tables S2, S3), since the spotlight of DSCI and SSCI encompasses distinct scopes of science.

Particularly, Figures 1, 2 show the knowledge areas mostly used by students, for DSCI and SSCI, respectively. As it can be observed, with the open instruction of DSCI test, students resort to the fields of astronomy or human body/health in order to formulate their scientific inquiries, while the areas related to the Moon's composition and meteorology, spatial technology/communications and physics (gravity, space motion) are mainly used in order to create questions related to the image of the astronaut at the moon (SSCI test). Concerning the originality scores, the scarcity of unusual or unique questions generated by students, for both DSCI ($M = 2.5$, SD = 1.5, Me = 2.0) and SSCI (M = 1.7, SD = 1.0, Me = 1.0) must be highlighted. Some examples of original questions produced by students at the DSCI dimensions are "why is the snow white if water is transparent?" or "why are we addicted to sugar?," while some examples of original SSCI questions are as follows: "is it possible to set a fire at the moon?" or "which sort of fuel did they use?"

Finally, the total value for creativity at each of the assessed dimensions, calculated as the addition of the three parameters mentioned above, is remarkably lower than those reported by Hu et al. (2010) for the equivalent grades assessed in this study.

3.2 Assessment of the perceptions, engagement and career expectations related to science

Table 2 shows the results of the descriptive analysis corresponding to each of the items used to assess perceptions, engagement and career expectations related to science of Spanish secondary students. Regarding perceptions, students display moderate awareness of the influence of science, individually and collectively, as well as sufficient knowledge about the epistemological and ontological principles of science ($M = 3.0$, SD = 0.4, Me = 3.0). It must be highlighted that from all items included in that category, the one corresponding to the versatility and dynamism of scientific knowledge (item 4) have the lower score ($M = 2.5$, SD = 0.9, Me = 3.0). With respect to the engagement category, values are slightly lower than the ones for perceptions ($M = 2.3$, SD = 0.6, Me = 2.2). This fact may indicate that students rarely enjoy or are prone to engage in science-related learning, activities, or events. Particularly, item 12 shows a notably low score ($M = 1.5$, SD = 0.8, Me = 1.0), indicating that students scarcely participate on divulgation events. The scores of item 11 ($M = 1.9$, SD = 0.9, Me = 2.0), which is associated with non-formal and autonomous processes of learning, are also low. Finally, the expectations to pursuing a science-related career are also low to moderate ($M = 2.7$, SD = 0.8, Me = 2.7), which may be correlated to the instrumental motivation of students. Therefore, values for all three

TABLE 1 Descriptive statistics for the studied dimensions of scientific creativity.

	Daily scientific creativity (DSCI)						Specific scientific creativity (DSCI)					
Parameter	Min	Max	M	SD	Me	IQR	Min	Max	M	SD	Me	IQR
Fluidity	0	27	6.8	3.9	7.0	5.0	0	28	8.1	4.0	9.0	5.0
Flexibility	0	9	3.8	1.7	4.0	2.0	0	7	4.1	1.4	5.0	1.0
Originality	0	8	2.5	1.5	2.0	3.0	0	6	1.7	1.0	1.0	1.0
Total	0	39	12.5	6.5	14.0	7.0	0	39	13.0	5.5	15.0	7.0

M, mean; SD, standard deviation; Me, median; IQR, interquartile range.

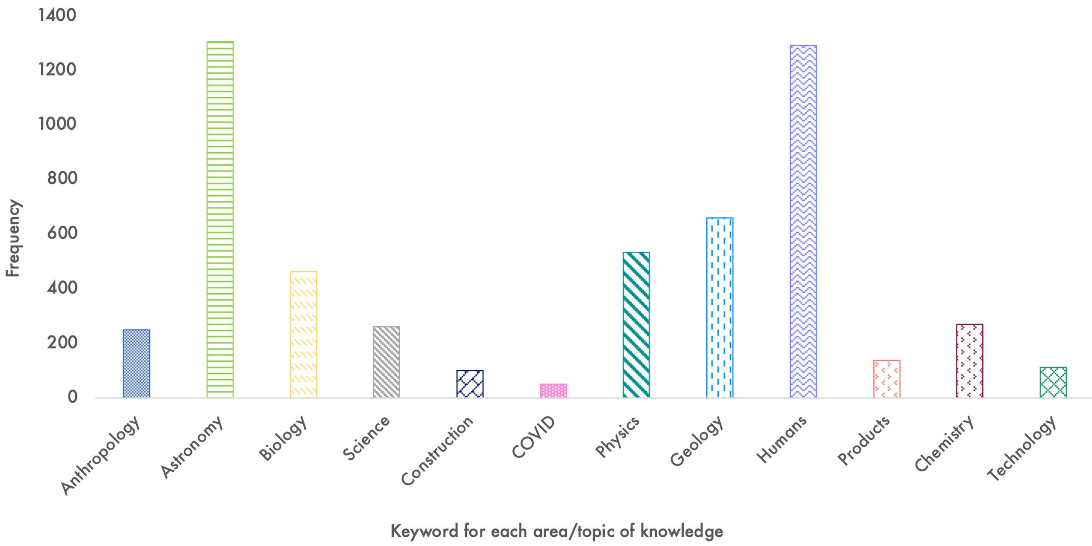

FIGURE 1
Number of questions formulated by students depending on the area of knowledge for DSCI. Keywords for each area/topic of knowledge are described at Supplementary Table S2.

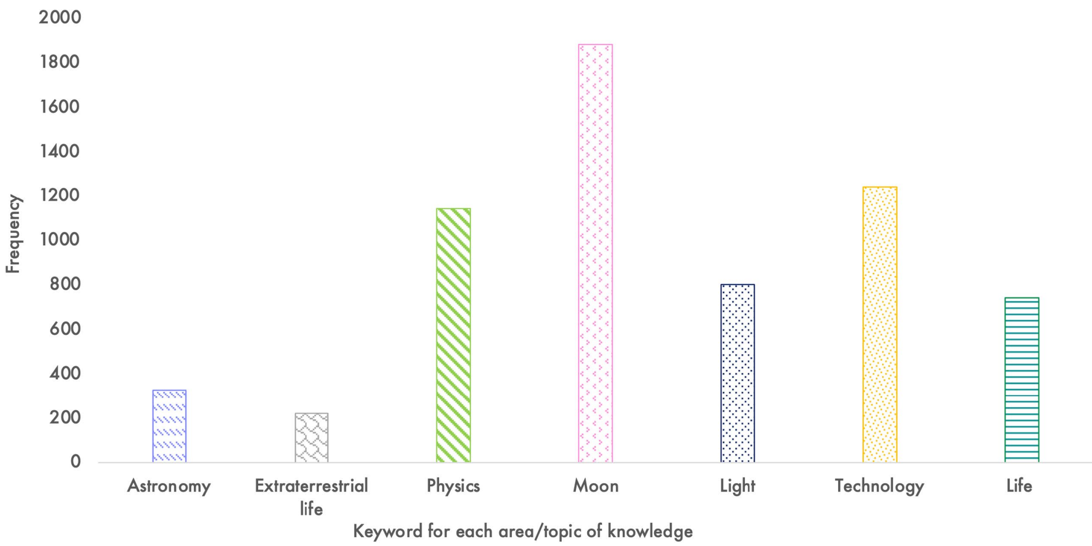

FIGURE 2
Number of questions formulated by students depending on the area of knowledge for SSCI. Keywords for each area/topic of knowledge are described at Supplementary Table S3.

considered categories are analogous, meaning that students are equally likely to understand the principles of science knowledge and perceive it as enjoyable as useful, when they expect to work in science-related occupations.

3.3 Differences according to gender

Aiming to get insight into the role of gender on the scientific creativity performance and the perceptions, engagement and career expectations related to science, inferential analysis was carried out. Since none of the studied variables displayed a normal distribution, non-parametric Mann–Whitney U test was applied (Table 3). As it can be observed, statistically significant differences have been found for performance on both dimensions of scientific creativity. Further analysis of the data reveals that girls outperform boys at DSCI (males: $M = 11.7$, $SD = 6.4$, $Me = 11.0$; females: $M = 13.4$, $SD = 6.4$, $Me = 13.5$) and SSCI (males: $M = 12.0$, $SD = 5.6$, $Me = 12.0$; females: $M = 14.0$, $SD = 5.2$, $Me = 14.0$). Regarding the attitudes towards science, there are statistically significant differences across genders for perceptions and career expectations, while there are not statistically significant differences on engagement. Specifically, girls have more positive and accurate

TABLE 2 Descriptive statistics for the perceptions, engagement and career expectations.

Attitudes towards science	Item	Min	Max	M	SD	Me	IQR
Perceptions	1	1	4	3.2	0.7	3.0	1.0
	2	1	4	2.8	0.9	3.0	1.0
	3	1	4	3.5	0.7	4.0	1.0
	4	1	4	2.5	0.9	3.0	1.0
	5	1	4	3.2	0.7	3.0	1.0
	6	1	4	3.0	0.8	3.0	2.0
	Total	-	-	3.0	0.4	3.0	0.5
Engagement	7	1	4	2.4	0.9	2.0	1.0
	8	1	4	3.2	0.9	3.0	1.0
	9	1	4	2.3	1.0	2.0	1.0
	10	1	4	2.2	0.9	2.0	1.0
	11	1	4	1.9	0.9	2.0	1.0
	12	1	4	1.5	0.8	1.0	1.0
	Total	-	-	2.3	0.6	2.2	0.8
Career expectations	13	1	4	2.8	1.0	3.0	2.0
	14	1	4	2.6	1.0	3.0	1.0
	15	1	4	2.8	0.9	3.0	1.0
	16	1	4	2.6	1.0	3.0	1.0
	Total	-	-	2.7	0.8	2.7	1.0

M, mean; SD, standard deviation; Me, median; IQR, interquartile range.

TABLE 3 Descriptive statistics for the studied variables according to gender ($N_{male} = 404$; $N_{female} = 376$) and results of the Mann–Whitney U test.

	Gender	Mean	SD	Median	IQR	z	*p*	g
DSCI	M	11.7	6.4	11.0	7.0	4.0	<0.001***	0.1
	F	13.4	6.4	13.5	9.0			
SSCI	M	12.0	5.6	12.0	7.0	5.5	<0.001***	0.2
	F	14.0	5.2	14.0	6.3			
Perceptions	M	2.9	0.5	3.0	0.7	4.75	<0.001***	0.2
	F	3.1	0.4	3.2	0.6			
Engagement	M	2.2	0.6	2.3	0.8	0.83	0.4	–
	F	2.3	0.6	2.2	0.8			
Career expectations	M	2.5	0.8	2.7	1.0	3.8	<0.001-	0.1
	F	2.8	0.8	3.0	1.2			

M, male; F, female; SD, standard deviation; IQR, interquartile range.
***There are statistically significant differences at the 0.001 level.

perceptions of science (males: $M = 2.9$, $SD = 0.5$, $Me = 3.0$; females: $M = 3.1$, $SD = 0.4$, $Me = 3.2$) and unexpectedly they are also more prone to pursing a science-related career (males: $M = 2.5$, $SD = 0.8$, $Me = 2,7$; females: $M = 2.8$, $SD = 0.8$, $Me = 3.0$). However, it must be taken into account that the size effect for all those differences is small ($g \approx 0.2$).

3.4 Differences according to level

Tables 4, 5 show the statistical descriptives for the scientific creativity performance and the perceptions, engagement and career expectations related to science of Spanish compulsory secondary school students. As it can be observed at Table 4, the values for both scientific creativity dimensions (DSCI and SSCI) are remarkably similar across levels.

However, some differences are apparent between students at the first level of Spanish compulsory secondary school and those at the upper levels, for the perceptions, engagement and career expectations variables (Table 5). Further analysis highlights an increase of the positive and accurate perception of science from the first level ($M = 2.9$, $SD = 0.5$, $Me = 2.9$) up to the fourth level ($M = 3.2$, $SD = 0.4$, $Me = 3.2$) and at the same time a decrease in the engagement category

TABLE 4 Descriptive statistics for the studied dimensions of scientific creativity according to level ($N_1 = 210$; $N_2 = 207$; $N_3 = 169$; $N_4 = 194$) and results of the Kruskal-Wallis test.

	Level	Mean	SD	Median	IQR	z	p
DSCI	1	11.5	6.5	12.0	9.8	6.3	0.097
	2	13.1	6.6	12.0	7.0		
	3	12.4	5.6	12.0	7.0		
	4	13.2	6.9	13.0	8.0		
SSCI	1	12.8	5.4	13.0	7.0	1.2	0.75
	2	13.4	5.8	13.0	7.0		
	3	13.3	4.8	14.0	6.0		
	4	12.7	5.8	13.0	7.0		

SD, standard deviation; IQR, interquartile range.
Ages corresponding to each level: first (M = 12.3; SD = 0.6); second (M = 13.4; SD = 0.5); third (M = 14.3; SD = 0.5); and fourth level (M = 15.3; SD = 0.6).

TABLE 5 Descriptive statistics for the studied variables related to science attitudes according to level ($N_1 = 210$; $N_2 = 207$; $N_3 = 169$; $N_4 = 194$) and results of the Kruskal-Wallis test.

	Level	Mean	SD	Median	IQR	z	p
Perceptions	1	2.9	0.5	2.9	0.7	32.5	<0.001***
	2	3.0	0.4	3.0	0.7		
	3	3.1	0.4	3.2	0.5		
	4	3.2	0.4	3.2	0.7		
Engagement	1	2.4	0.6	2.3	0.7	9.4	0.024*
	2	2.3	0.6	2.3	0.7		
	3	2.2	0.6	2.2	0.8		
	4	2.2	0.6	2.1	1.0		
Career expectations	1	2.9	0.7	3.0	1.0	12.4	0.006**
	2	2.8	0.8	2.8	1.0		
	3	2.6	0.8	2.5	1.0		
	4	2.5	0.9	2.7	1.0		

SD, standard deviation; IQR, interquartile range.
*There are statistically significant differences at the 0.05 level.
**There are statistically significant differences at the 0.01 level.
***There are statistically significant differences at the 0.001 level.

(1st level: $M = 2.4$, SD = 0.6, Me = 2.3; 4th level: $M = 2.2$, SD = 0.6, Me = 2.1) and the career expectations related to science positions (1st level: $M = 2.9$, SD = 0.7, Me = 3.0; 4th level: $M = 2.5$, SD = 0.9, Me = 2.7), from the first to the fourth level. Hence, the results of the non-parametric Kruskal-Wallis test revealed statistically significant differences among levels for the three categories (perceptions: $p < 0.001$; engagement: $p < 0.05$; career expectations: $p < 0.01$). To gain better understanding of those differences, a *post hoc* analysis (Bonferroni test) was performed. As expected by the inspection of the mean/median values, differences are mainly between the first level of compulsory secondary school and the higher levels. Specifically, for the perceptions category, there are differences between the first level and either the second ($p = 0.02$; $g = 0.2$), the third ($p < 0.001$; $g = 0.4$) and the fourth ($p < 0.001$; $g = 0.7$) level. In the case of the engagement category there are differences between the first level and either the third ($p = 0.02$; $g = 0.3$) and the fourth level ($p = 0.005$; $g = 0.3$). Finally, for the career expectations dimension, there are differences between the first level and either the third ($p = 0.03$; g = 0.4) and the fourth level ($p < 0.001$; $g = 0.5$).

3.5 Correlation between scientific creativity and perceptions, engagement and career expectations of secondary school students related to science

Lastly, to explore the potential correlation between the studied dimensions of scientific creativity (DSCI and SSCI) and the variables related to the students' attitudes towards science (perception, engagement and career expectation), Spearman's correlation coefficients (r_s) were calculated (Table 6). As it can be observed, there are strong positive correlations between both dimensions of scientific creativity ($r_s = 0.52$, $p < 0.001$), meaning that a student with high performance in the DSCI task, also display an analogous ability at the SSCI task. Conversely, DSCI and SSCI have no significant correlation with neither the engagement nor the career expectations categories, although there is a positive correlation between the perception one with DSCI ($r_s = 0.12$, $p < 0.001$) and SSCI ($r_s = 0.12$, $p < 0.001$). Finally, there are strong correlations among the three categories exploring the attitudes towards science of students ($p < 0.001$ in all cases).

TABLE 6 Spearman's correlation coefficients between the studied variables.

	DSCI	SSCI	Perceptions	Engagement	Career expectations
DSCI	–	0.52***	0.12***	0.05	0.06
SSCI	0.52***	–	0.12**	0.04	0.08*
Perceptions	0.12***	0.12**	–	0.33***	0.34***
Engagement	0.05	0.04	0.33***	–	0.5***
Career expectations	0.06	0.08*	0.34***	0.5***	–

*There are statistically significant differences at the 0.05 level.
**There are statistically significant differences at the 0.01 level.
***There are statistically significant differences at the 0.001 level.

Nevertheless, from those the highest value of the Spearman's coefficient corresponds to the duet engagement-career expectations variables ($r_s = 0.5$, $p < 0.001$).

4 Discussion

This study explores the scientific creativity of Spanish compulsory secondary school students. Particularly, two dimensions have been assessed: one related to every-day experiences (DSCI) and one to specific knowledge (SSCI). In addition, attitudes towards science have also been evaluated, aiming to shed light into any possible correlation between scientific creativity and perceptions, engagement and career expectations related to science of those students.

Found data have pointed out the low performance of students in scientific creativity (both DSCI and SSCI), particularly at the originality category. These results are in line with previously reported studies (Hu et al., 2010; Huang and Wang, 2019; Pont-Niclòs et al., 2023). Nevertheless, it must be considered that the assessment process has been mainly based on problem-finding abilities, and scientific creativity include several microdomains related to general/specific scientific knowledge and skills, as well as general/specific creativity competencies (Hu and Adey, 2002; Hadzigeorgiou et al., 2012; Barbot et al., 2016). Hence, scientific creativity may be assessed not only in function of problem-finding abilities, but also as performance on generating and testing hypotheses or problem-solving (Sternberg et al., 2020). Considering all the above stated, scientific creativity performance depends on multitude of factors related not only to the subjects' cognitive (De Vries and Lubart, 2019; Zhu et al., 2019) or metacognitive abilities (Jia et al., 2019), but also their science formation, personal experiences, interests and motivation (Collins and Amabile, 1999; Yang et al., 2016).

In this context, it is crucial to explore the potential influence of attitudes towards science on scientific creativity performance, as these attitudes may correlate with how people approach and engage with creativity and learning tasks (Conradty et al., 2020; Hernández-Torrano and Ibrayeva, 2020). However, it is important to recognize that this relationship may be influenced by other factors such as interest and effort, and causality has yet to be established. The assessment conducted at this study, regarding perceptions, engagement and career expectations, has revealed students' moderate willingness and interest in science-related matters. Specifically, their conceptualization and thinking about the scope of science have been found to be relatively accurate and positive, which may be related to the teaching style that they have been confronted (Lumpe et al., 2000; Southerland et al., 2001; Bereczki and Kárpáti, 2021). Despite that, the obtained data have indicated a low rate of students that genuinely enjoy science, especially when referred to voluntarily participate at divulgation or non-formal learning activities (Christidou et al., 2022). Those factors, alongside with the learning processes that they have experienced at the science classroom (Hampden-Thompson and Bennett, 2013; Steidtmann et al., 2023), are directly related to the interest and motivation of students in pursuing a science-related professional pathway (Drymiotou et al., 2021). That may be the reason why the rate of students that are prone to follow a science-related professional life has been found to be relatively moderate as well (Jack and Lin, 2018).

Without underestimating the fact that these results may be influenced by sociodemographic factors, gender and level differences have been also assessed in this study. Specifically, gender differences have been found at both dimensions of scientific creativity (DSCI and SSCI), which is in consonance with similar studies (Hu et al., 2010; Pont-Niclòs et al., 2023). These results sum up to the evidence of the role of gender in creative performance, even though the nature of that role is not fully understood, since it depends on additional personal and sociocultural factors (Nakano et al., 2021). Regarding attitudes towards science, no gender differences have been detected at the engagement category, although girls have slightly more accurate and positive perceptions about science, and they are barely more prone to pursuing science-related careers. Nevertheless, it must be taken into account that effect sizes are small, and scores hardly exceed 2 points (in a 4-point Likert scale), meaning that girls' expectations to embrace a science professional pathway are still moderate. These results are heavily influenced by what students perceived as a science-related career (medical doctor, software engineer, artist, architect or journalist) and the worthiness of school science at the daily and professional spheres. Consequently, data may highlight the narrow view of students about the usefulness of procedural or epistemic scientific knowledge at the real/professional world (OECD, 2016). In addition, it has to be considered that female traditionally have been associated to caring and non-time-consuming careers, while males are more prone to outcome-oriented occupations (Kang et al., 2019). Regarding students' level differences, researchers suggest that creativity can be, and must be, nurtured by appropriated training within the classroom to prepare students to cope with future demands of society (Beghetto, 2019; Alves-Oliveira et al., 2022). In this regard, statistically significant differences were expected among the levels of secondary school education. Unfortunately, no differences between levels have been identified on any of the dimensions of scientific creativity. That continuity in the creative performance throughout compulsory secondary education underpins the need to promote specific actions that carry policies and international efforts effectively into classroom routines, which translates to the intentional curriculum design and the formation of pre-service and in-service teachers in creativity conceptualization and development (Bereczki and Karpati, 2018; Echegoyen-Sanz and Martín-Ezpeleta, 2021; Echegoyen-Sanz et al., 2024). In addition, engagement and willingness to pursuing a science-related pathway of students show a decrease from the first level of compulsory secondary school to the higher level. This fact may be related to the disparity in approaching science learning from the beginner levels, generally stem on curiosity and experimenting; to the advanced levels, typically more theoretical and disconnected from daily experiences (Yang et al., 2016), as also happens for other STEM-related subjects.

The interplay of scientific creativity and attitudes towards science has also crucial implications for any effort to promote creativity, scientific learning, and aspirations to continue studying sciences beyond the limits of compulsory secondary education (Conradty et al., 2020). In this paper, the correlation between scientific creativity and an accurate and appreciative perception of science has been found to be slightly positive. However, scientific creativity performance was not correlated to engagement or career expectations of a science-based professional position. These findings may be related to the fact that scientific creativity requires of specific knowledge about the nature of science, its processes, and influences on society (Ozdemir and Dikici, 2017; Huang and Wang, 2019), although it may not be related to a particular scientific professional orientation, but the learning experiences that students have been confronted to (Chi and Wang, 2023). However, the three dimensions analyzed with respect to the attitudes towards science (perceptions, engagement and career expectations) show positive correlations, being the one between engagement and career expectations the strongest, indicating that an individual's choice of a future occupation is hugely influenced by personal preferences, interests and motivations, in spite that the whole decision process include intricated further factors (Taskinen et al., 2013; OECD, 2016; Vinni-Laakso et al., 2022).

5 Conclusion

This study explores the scientific creativity of Spanish secondary school students and its correlation with perceptions, engagement, and career expectations related to science. Findings shed light on several significant aspects dealing with scientific creativity performance and attitudes towards science. Firstly, the assessment of scientific creativity, encompassing both daily and specific dimensions, revealed a considerable shortfall among students (Hu et al., 2010; Pont-Niclòs et al., 2023). While the study primarily focused on problem-finding abilities, the multi-faceted nature of scientific creativity is emphasized, suggesting that a more comprehensive evaluation including various creativity competencies could offer a deeper understanding (Kaufman, 2012; Barbot et al., 2016; Elisondo, 2021). Secondly, students exhibited moderately positive and accurate perceptions about science, yet demonstrated limited interest and engagement in science-related activities outside, and even within, the classroom. Moreover, their willingness to pursue science-related careers remained relatively low, suggesting a need for more effective strategies to incite interest and motivation in science learning, as well as in other STEM subjects, beyond compulsory stages of education (Conradty et al., 2020). These may be addressed by contextualizing contents by incorporating real-world applications of science in daily life and professional scenarios, since perceiving the usefulness of science has been demonstrated to positively influence students' attitudes towards STEM-related topics (Wijaya et al., 2022). Regarding gender differences, those were appreciable in scientific creativity, aligning with some prior research (Nakano et al., 2021), while differences across levels of secondary education were not apparent. These findings highlight the necessity for targeted interventions that integrate policies promoting creativity and science education into classroom practices, ensuring continuity and enhancement throughout secondary education (Yang et al., 2016; Cotter et al., 2022; OECD, 2023). In addition, the correlation between scientific creativity and attitudes towards science pointed out a strong relationship between engagement and career expectations in science-related fields (Ainley and Ainley, 2011), suggesting that fostering scientific creativity and enhancing the learning experiences, while learning specific scientific knowledge, may result in higher enrolment rates in science-related matters (Struyf et al., 2019; Drymiotou et al., 2021).

Despite its insights, this study has limitations that must be taken into account. The assessment was primarily focused on problem-finding abilities, overlooking other dimensions of scientific creativity. Additionally, the cross-sectional design limits the depth of understanding longitudinal effects between creativity and attitudes towards science. Moreover, the study sample was confined to a specific geographical area, which might restrict the generalizability of the findings. Further research may broaden the scope of this study, such as expanding the sample to other Spanish regions or including additional assessment tools addressed to evaluate diverse general and specific creativity domains, in conjunction with other tests dealing with self-perceptions in creativity endeavors or life satisfaction (Caballero-García and Sanchez-Ruiz, 2021; Ivcevic, 2022). This multi-approach may help to construct a more accurate and complete creativity profile of students, as a starting point to design effective teaching approaches, especially at STEM subjects (Tran et al., 2021).

It seems clear that integrating creativity into teaching methodologies could revitalize the engagement and interest in scientific matters, offering students a more solid connection between conceptual learning and real-world applications. Moreover, this may reinforce the attitudes towards facing STEM subjects, which in turn benefits students' satisfaction willingness to embrace a STEM-related education (Zhao et al., 2022). For instance, teachers may provide examples of creative behaviors that students would be able to emulate (Jonas and Chambers, 2017). In addition, the use of Artificial Intelligence offers a novel framework to nurture creativity among students by its proper usage (Miao and Holmes, 2023). Indeed, fostering creativity equips students with essential skills, such as problem-finding/solving, divergent thinking, and metacognition, which are essential for coping with future challenges, particularly in STEM-related fields where adaptability and innovation are imperative (Perignat and Katz-Buonincontro, 2019).

In conclusion, providing engaging and holistic learning experiences could not only nurture scientific creativity, but also enrich the interest and motivation in pursuing science-related careers. Effective integration of creativity-focused educational strategies is needed for the training of a generation ready to embrace future challenges at a rapidly evolving world. However, further studies are needed to get more integrative insights, thereby bridging the gap between creativity, science education and career aspirations. This is a global and historical problem, but the present and future of STEM careers have creativity, a key competence of the 21st century, as their best ally.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements because of the nature of the research and the anonymization procedure followed. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

IP-N: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. AM-E: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing. YE-S: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1382541/full#supplementary-material

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