STEM talent in k-10: a systematic review

El talento STEM en la educación obligatoria: una revisión sistemática

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Mª Pilar Herce-Palomares
UNED
Marcos Román González
Carmen Jiménez Fernández
UNED

Abstract

STEM talent (science, technology, engineering and mathematics) is a current research topic both for the renewed understanding of giftedness in specific talent domains and the recent interest in STEM education. This research conducts a systematic review to delve into a specific talent, STEM talent. It intends to illustrate the trajectory of STEM talent during the stage of compulsory education. In particular, it aims to explore the state of the art of this field of research, the set of personal and contextual variables, which affect the trajectory of STEM talent during compulsory education, the most relevant methodologies for the advancement of STEM talent, and the milestones/stages that students go through during this developmental stage. To this end, a protocol for this review of research was developed based on the guidelines of the PRISMA declaration (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) and the Campbell collaboration. Following the application of said protocol, a total of 225 studies were obtained, of which 108 were finally included after reviewing the eligibility criteria. The results not only show the state of the field of research, but also a set of dispositional (cognitive, psychosocial, and sociodemographic) and contextual variables (in formal, non-formal, and other scenarios) that interact with each other to advance or hinder the course of the trajectory; that *hands-on* methodologies are the most implemented to promote STEM talent and finally,

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brief guidelines regarding the stages and milestones that take place during the STEM talent trajectory, which offer new lines of research. These results contribute to understanding the most relevant educational policies and practices for the advancement of STEM talent during compulsory education, so some guidelines are given.

Key words: talent, talent development, giftedness, compulsory education, STEM education, STEM

Resumen

El talento STEM (ciencia, tecnología, ingeniería y matemáticas) es un tema de plena actualidad en la investigación tanto por la renovada comprensión de las altas capacidades en dominios específicos del talento, como por el reciente interés hacia la educación STEM. Esta investigación conduce una revisión sistemática para indagar en un talento específico, el talento STEM. Se pretende ilustrar su trayectoria durante la educación obligatoria. En concreto, se busca conocer el estado de la investigación del campo, los conjuntos de variables personales y situacionales que inciden en la trayectoria del talento STEM durante la educación obligatoria, la identificación de las metodologías más pertinentes para la promoción del talento STEM y los hitos/estadios que atraviesa el alumnado durante este momento madurativo. Para ello, a partir de las directrices de la declaración PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) y de la colaboración Campbell se elaboró un protocolo para esta revisión de la investigación. Tras su aplicación se obtienen un total de 225 estudios, de los que finalmente se incluyen 108 tras la revisión de los criterios de elegibilidad. Se concluye cómo se encuentra la investigación del campo, un conjunto de variables disposicionales (cognitivas, psicosociales y demográficas) y contextuales (en la educación formal, no formal y en otros escenarios) que interaccionan entre ellas para favorecer o dificultar el curso de la trayectoria; que las metodologías *hands-on* son las más implementadas para favorecer el talento STEM y, por último, unas tenues orientaciones sobre los estadios e hitos que acontecen en la trayectoria del talento STEM, que dibujan nuevas líneas de investigación. Dichos resultados contribuyen a la comprensión sobre las políticas y prácticas educativas más pertinentes para la promoción del talento STEM durante la educación obligatoria, por lo que se proporcionan algunas orientaciones.

Palabras clave: talento, desarrollo del talento, altas capacidades, educación obligatoria, educación STEM, STEM

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Introduction

After a century of research, the study of giftedness has advanced notably. The first approaches that focused on measuring intelligence as a stable trait in a homogeneous set of subjects, have given way to renewed ways of understanding it.

Despite being a construct that can be defined from different perspectives, there seems to be a certain consensus in the field of giftedness in terms of considering human potential as being shaped in a much more plural, contextual, and evolutionarily manner than what was suggested by those who founded the field of research (Dai, 2018). It is a complex phenomenon of genetic and environmental nature, multidimensional, diverse, malleable, dynamic, and in constant development, a result of covariation throughout life (Sastre-Riba, 2020). High intellectual abilities are understood from this complexity, given that the mere general cognitive abilities with which they were associated are integrated with new factors that contribute to later success.

Subotnik et al. (2011, p.7) define giftedness as “the manifestation of performance that is clearly at the upper end of the distribution in a talent domain even relative to other high-functioning individuals in that domain”. They add that it involves both cognitive and psychosocial variables, which are malleable and need to be deliberately fostered at each developmental moment and in each talent domain.

Two key considerations emerge from this definition. First, giftedness is understood from an evolutionary perspective throughout the life cycle (Dai, 2017; Subotnik et al., 2011; Ziegler et al., 2019). Abilities are necessary, but not sufficient (Subotnik, et al., 2011) for each individual to successfully complete the trajectory of a specific talent domain. Regarding trajectory, Olszewski-Kubilius et al., (2015, 2016) suggest that: it is necessary to offer opportunities and that these be taken advantage of, psychosocial variables play a determining role in the effective development of talent, developing eminence is the end result to which talent education aspires, skills are important, especially those related to specific domains, and talent domains differ in evolutionary trajectories starting at different ages.

Second, a large number of definitions about giftedness include references to specific talents (Callahan and Price, 2021). The multidimensional reality of giftedness has focused its attention on specific skills and abilities in particular areas of talent (Tourón, 2020). Among the specific talents, STEM talent (science, technology, engineering, and mathematics) is substantially valuable, given its role in the economic growth of countries (Beasley and Fisher, 2012) and how instrumental it is to achieve the Sustainable Development Goals, SDG (MacDonald and Huser, 2020).

STEM talent is understood in adulthood as "transformative discovery or innovation in STEM" (Subotnik et al., 2009, p. 1315). The probability of successfully reaching one's talent potential is conditioned by the acquisition of the necessary skills at each developmental moment (Olszewski-Kubilius et al., 2019), so that compulsory education becomes the first link in the chain to achieve this result.

Despite the existence of different ways of understanding STEM in educational practice, those who defend it claim that:

> Boon (2019):
> "the practice should embrace an interdisciplinary teaching approach, which removes the learning and development barriers between the four disciplines of Science, Technology, Engineering and Mathematics.… They consider that bringing the four disciplines together as STEM is theoretically sound and valid, since science and mathematics are generally considered to form the basis of applied science, which includes technology and engineering" (p.7).

In addition to defending the integration of STEM disciplines, although still with a certain lack of empirical evidence (Martín-Páez et al., 2019), disciplinary integration is part of good practices for talent education (VanTassel-Baska and Brown, 2007).

If the development of talent is an indispensable condition to lead innovation and community development (Pérez and Jiménez, 2018), educational and social policies must educate for excellence (Jiménez and Baeza, 2012). In addition, one of the main objectives of education is to respond to social demands by promoting social, economic, scientific, and technological development (Türk et al., 2018), which means that STEM talent development will be an essential resource of 21st century societies and a priority for every educational system. For all these reasons, understanding how student's STEM talent is facilitated in compulsory education must be a priority in educational systems.

Research motivation and objectives

Despite the relevance of STEM talent development in compulsory education, research in this field is still scarce. Olszewski-Kubilius et al. (2019) identify a set of psychosocial variables that favor the development of all talent trajectories, including STEM, at different stages. In this regard, Subotnik et al. (2019) explore the factors that favor graduating from STEM trajectories during post-compulsory secondary education. However, this focus of research has not been applied yet to compulsory education.

Opportunities for developing this talent can be found during the primary and secondary education stages through inquiry-based learning, collaboration among equals, open methodologies with less restrictions, and real-life problem solving (Robinson et al., 2014). Early abilities are transformed into competence when students receive appropriate educational experiences with family support and quality teacher-student learning (Subotnik and Jarvin, 2005).

Therefore, the objective of this research is to deepen the knowledge of the STEM talent trajectory during compulsory education.

The specific objectives are:

- Describe the state of the art in STEM talent research.
- Understand the variables that modulate the STEM talent trajectory.
- Identify the methodologies that favor STEM talent education.
- Determine the milestones and/or stages that mark the learning progress of STEM talent

To address these objectives, a systematic review of the scientific literature was carried out following the methodology described below.

Method

This systematic review was carried out following the international guidelines established in the health sciences guide of the *Preferred Reporting Items for Systematic reviews and Meta-Analyses*, PRISMA (Moher et al., 2015) to assess research quality; and the Campbell Collaboration's Guide to the Social Sciences (Petticrew & Roberts, 2006), which provides steps for conducting systematic reviews in this field.

The method goes through this sequence: systematic review protocol registration, search strategy, inclusion and exclusion criteria, assessment of the quality of evidence of the included research articles, and the process of collecting and processing data for its interpretation.

Protocol registration

Developing and registering protocols is suggested by international organizations that promote good practices (suggested in the aforementioned guidelines). However, it is not yet a widespread practice in the social sciences.

The protocol for this systematic review was prepared and notified before the start of said review, in June 2020, to improve the quality of the procedure, favor its replicability, and increase the confidence of its results (Herce, in press). It specifies the methodological process described below.

Search strategy

The strategy includes search equation selection, database selection, and finally, the specification of the search strategy for each database, which was carried out at the beginning of the second semester of 2020 and following the guidelines of the protocol.

– Search equation: the terms that define the equation were identified using the European Education Thesaurus (ERIC). In addition, they were reviewed in an exploratory search after which the Boolean operator "NOT" was introduced to exclude three concepts and reject the terms "science", "mathematics", "engineering", and "technology", given that in both cases a high level of 'noise' was generated with these terms. The resulting equation was: ("STEM talent" OR "STEM gifted*") AND ("Elementary*" OR "Primary*" OR "Secondary*" OR "middle*" OR "K-12" OR "K-5" OR "K-6" OR "K-8") NOT ("cell" OR "stem cells" OR "plants").
– Databases: social science (education), science (engineering and technology), and multidisciplinary ACM Digital Library, IEEE

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Xplore, ScienceDirect, EBSCOhost, Scopus, and WOS (core collection) databases were included
– Specification of the search strategy: the strategy for each database was defined in the protocol, with each algorithm and field operators (Herce, in press).

Eligibility criteria

The eligibility criteria (Table 1) comply with what is specified in the protocol of this systematic review (Herce, in press) and to the PICOC format (Petticrew and Roberts, 2006):

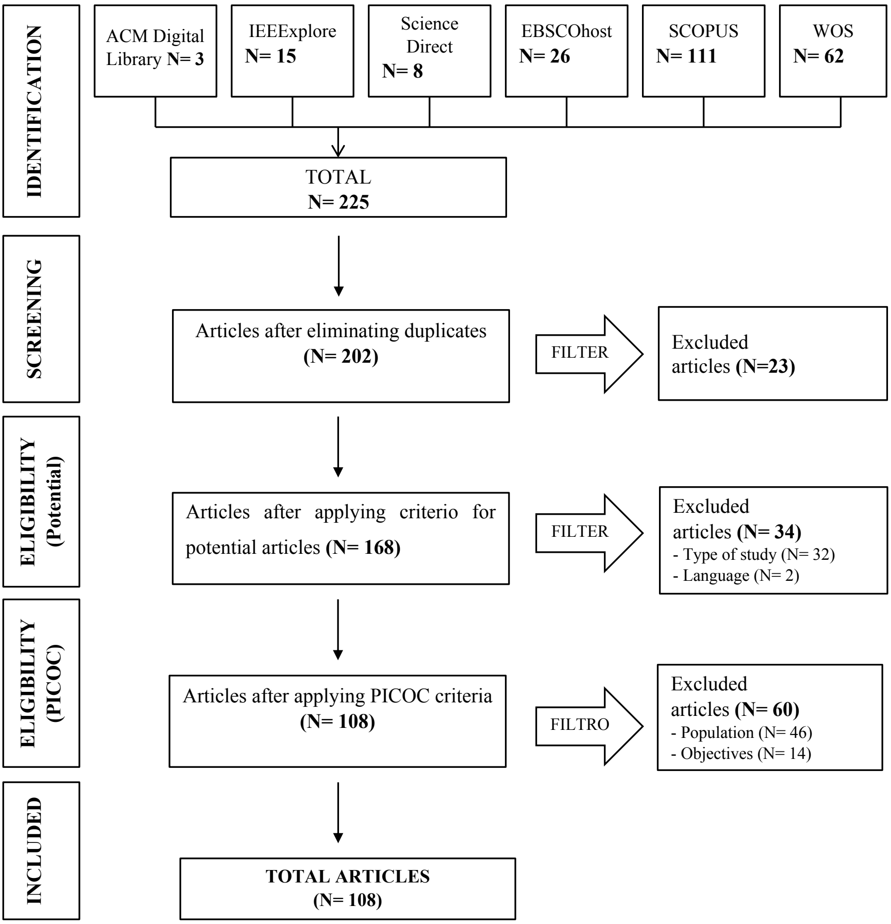
TABLE 1. Selection criteria (own elaboration)

Criteria for identifying potential articles	Article selection criteria (PICOC)
Quantitative and qualitative primary studies	The direct or indirect population is the student body at any educational level in the stages of primary and/or compulsory secondary education
Articles published in peer-reviewed scientific journals or conference communications in indexed proceedings in defined databases	At least one of the objectives must be addressed
Access to research	In the context of formal and non-formal education
In English or Spanish language	

After the initial search, a total of 225 articles were obtained from the databases. Duplicates were eliminated with the reference management software “Refworks 2.0”, resulting in 202 studies. After applying the criteria for potential items, 34 were excluded and 60 more were eliminated after applying the PICOC criteria. The total number of publications resulted in N=108 (available at: https://tinyurl.com/yb27uvg7). The search was carried out by the first researcher, the second researcher reviewed 15% of the set of articles until an agreement was reached between both of them.

Figure 1 illustrates this process of searching and applying the eligibility criteria, with an adaptation of the PRISMA-P flow diagram (Moher et al., 2015).

FIGURE 1. Flowchart of search results and eligibility process (adapted from PRISMA-P, from Moher et al., 2015)



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Assessment of the evidence quality of the research articles

To assess the quality of the evidence, the *Standard quality assessment criteria for evaluating primary research papers from a variety of fields* (Kmet et al., 2004) applied to quantitative, qualitative, and mixed research was completed. The results show high quality evidence (between 0.75 and 1) in all quantitative studies except two moderate ones (between 0.5 and 0.74); high quality evidence in all qualitative studies, except in two moderate ones; and high quality evidence for studies in which both types of research designs apply (Herce et al., 2020). With this, the selection of the set of studies for the review was concluded, after being verified by the three researchers.

Data collection and processing

Following the protocol of this review, data extraction and treatment began at three levels: descriptive analysis with an Excel table that included authorship, date, journal, abstract, eligibility criteria (potential articles and selection) with a list of the embedded articles; an Excel table with the quality of the evidence of each study according to the different type of design; and an Excel table with the answer to the questions asked (Herce, in press).

The data was analyzed using the deductive method, starting from three general dimensions (with percentages) that are then broken down into categories. For each category, percentages over the total of each dimension were calculated (not over the total of all articles). Overlaps existed due to the fact that the same article could be considered for different variables.

The analysis was structured into three dimensions that correspond to the last three objectives of this research:

– Modulating variables dimension: percentage of dispositional variables (cognitive and non-cognitive variables of the individual), contextual variables (opportunities in the environment) and the combination of both.
– Methodology dimension: percentage of the methodologies being implemented.

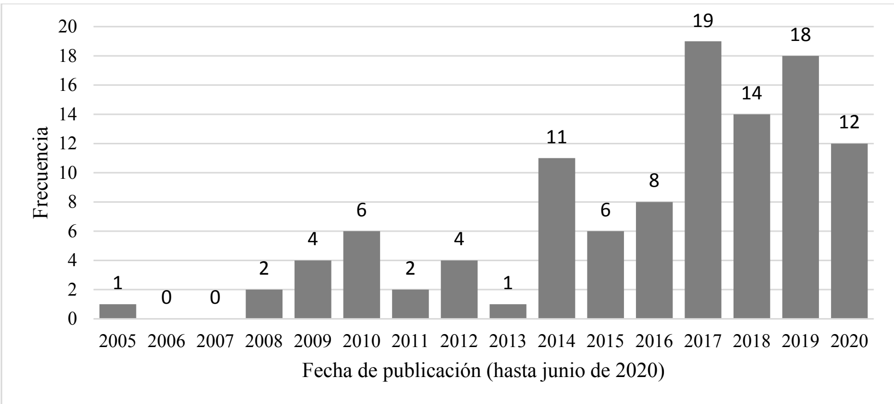
– Milestones/stages dimension: percentage of milestones (critical variables for the progress of talent) and developmental stages that are experienced during the STEM trajectory.

Results and discussion

Descriptive analysis

The systematic review places STEM talent development research into the 21st century and illustrates the growing interest it has received in recent years. Until 2014 the evolution had been slow, but as of 2017 publication output increased considerably (Figure 2).

FIGURE 2. Evolution of scientific output regarding STEM talent (own elaboration)



This evolution can be attributed to two different reasons. First, a renewed vision of giftedness. Currently, the study of talent goes beyond abilities and embraces a wider audience in which it is not only about understanding the "nature" of individuals, but how to create productive and satisfying life paths that are beneficial for the individual and society. The key lies in understanding how to advance potential through trajectories that take into account how and why some individuals reach eminence as a consequence of endogenous and exogenous factors and

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the interaction between both (Dai, 2018). Second, the novelty of the STEM education movement, which is still in the initial stage of its development (Martín-Páez et al., 2019).

Although the STEM trajectory has become of utmost interest for the advancement and prosperity of nations, commitment to research in this field has not been equally assumed worldwide (Figure 3).

FIGURE 3. Distribution of STEM talent research worldwide (own elaboration based on displayr)

	Porcentaje
GERMANY	7.3
AUSTRIA	.9
CANADA	.9
CHINA	2.8
COLOMBIA	.9
SOUTH KOREA	2.8
SPAIN	.9
US	68.8
NETHERLANDS	.9
ITALY	.9
MALAYSIA	1.8
UNITED KINGDOM	.9
RUSSIA	.9

The US is home to almost three-quarters of the total scientific output. The American continent is at the forefront of scientific output with the US, Canada, and Colombia. Regarding Europe, except for Germany, few countries conduct research in this field and those who do it are still shy, like Spain which to date has only published one study. However, it is a European priority to attract talent to science and technology as indicated in the action plan for gifted students of the Lisbon strategy (Hausamann, 2012), following the work of the *European Cooperation in Science and Technology* (COST, 2007).

Finally, the Asian continent appears in third place with a publication percentage slightly lower than the European one.

Regarding educational stages, it is during compulsory education when the foundations of competence are laid, driving the trajectory of talented STEM individuals (Subotnik et al., 2011). Figure 4 represents the interest given to the different educational stages.

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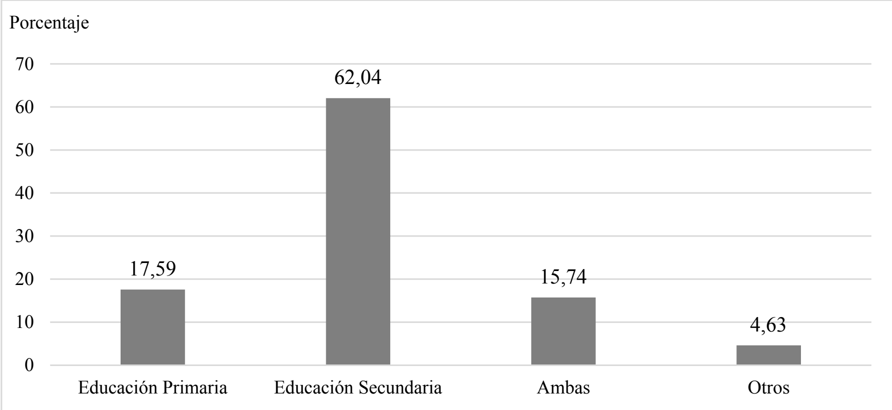
FIGURE 4. STEM talent research by educational stages (own elaboration)

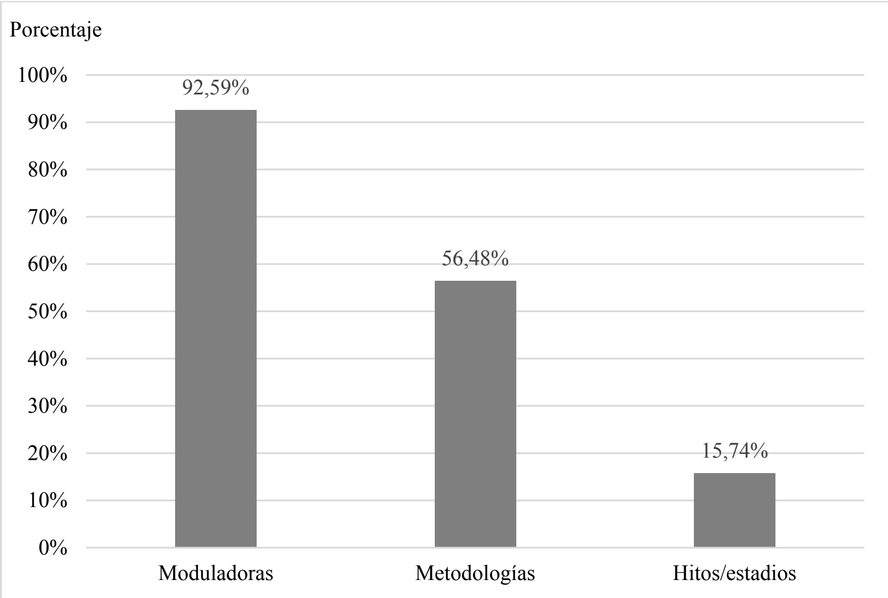


In terms of the direct or indirect population of educational interventions, the majority of the studies focus on compulsory secondary education (known as ESO in Spain). A total of 62.04% of the articles address only this stage and, in addition, 15.74% include both secondary and primary education. Primary education is only included in 17.59% of the total. Finally, 4.63% cover broader developmental stages (from early childhood education to university or adulthood).

Therefore, it is necessary to carry out in-depth research of STEM talent education during primary education, to identify the skills and guidance that talented students need at this stage, given that it is in this period when STEM talent competences are developed. In this sense, early STEM experiences are essential (Cannady et al., 2014) and it is necessary to train students in a variety of skills from each specific talent domain, so that they are able to act efficiently and be guided towards vocational options in said domain (Preckel et al., 2020).

Regarding the research of the other objectives, they have received unequal interest (Figure 5).

FIGURE 5. Attention paid to the research objectives (own elaboration)



The variables that influence the STEM talent trajectory can be found in the vast majority of the scientific publications (92.59%). More than half (56.48%) study methodologies for promoting STEM talent, and a small percentage (15.75%) focus on the milestones and stages that students go through during compulsory education.

The detailed results regarding each objective topic are presented below. These results are presented as percentages over each subtotal.

Modulating variables in the development of STEM talent in compulsory education

In all talent trajectories, the individual's dispositional variables and the context opportunities both intervene. In addition, both groups of variables interact with each other (Dai, 2021; Subotnik et al., 2021). Regarding STEM talent, these variables are found in N=100 articles (92.59%) and are grouped into: dispositional and contextual. Of all the publications addressing modulating variables, dispositional variables are found in 87% and contextual variables in 90%. In addition, 75% of the studies highlight the existence of relationships between both sets of variables, so that the combination of both groups of factors also contributes to progress in the STEM trajectory of students.

TABLE 2. Variables that modulate the trajectory of STEM talent in compulsory education (own elaboration)

Variable Groups	Variable	Percentage
DISPOSITIONAL VARIABLES (87%)	Genes	1%
	Cognitive variables	38%
	Psychosocial variables	65%
	Sociodemographic variables	51%
CONTEXTUAL VARIABLES (90%)	Formal education	63%
	Non-formal education	41%
	Others	12%
INTERACTION (75%)	Yes	75%

Dispositional variables

According to the research, among the characteristics of students with STEM talent we find genetic disposition (1%), cognitive variables (38%), psychosocial variables (65%), and sociodemographic variables (51%), with most studies reporting more than one of these characteristics in their subjects.

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- Genetics and cognitive variables: genetics and, in a substantially higher percentage, cognitive variables emerge as predictors of STEM talent. They contribute to favoring STEM talent together with polygenic scores, high performance/competence, especially in math and science, abilities/skills, especially visuospatial and mathematical reasoning, prior knowledge, interdisciplinary thinking, and the individual's learning resources. Among these cognitive variables, the greatest weight is given to mathematical (Lubinski et al., 2014) and visuospatial abilities (Lakin and Wai, 2020; Sisman et al., 2020) together with academic performance. Regarding talent trajectory, abilities must be transformed into STEM talent competence, and this competence into expertise (Subotnik, et al., 2010), so assessing performance becomes important, especially in terms of national assessments of curricular competence in math and science.
- Psychosocial variables (non-cognitive): those that arouse the greatest attention in research. Within the psychosocial variables, those that favor the STEM trajectory are: STEM interests (69.23%), STEM attitudes (18.46%), motivation (13.85%) and perception of efficacy/ competence in STEM (13.85%). Factors that are represented less include self-regulation, commitment to the task, knowledge about engineering (usefulness and importance), persistence in STEM itineraries, expectations of success (for example, graduation), self-concept, locus of control, emotions, personality, creativity, learning resources, feeling social and emotional support, leadership, identity, security and definition of one's own goals, good interpersonal relationships, tacit knowledge of the field, working hard rather than believing in abilities (*growth mindset*), and the perception of being able to combine scientific work with the family in adult life (in women). Negative-risk behaviors and behavior problems and anxiety towards mathematics have a negative effect. Unlike cognitive variables (more difficult to modify), these variables are malleable and need to be deliberately promoted, as they are a critical factor for staying on the trajectory course (Olszewski-Kubilius et al., 2015, 2016). STEM talent educational interventions must focus on this set of variables to promote a successful STEM talent trajectory.
- Finally, the sociodemographic variables highlight a set of characteristics that limit the STEM talent trajectory. Among them,

gender is the most significant variable (60.78%). The number of women who access STEM university studies has been decreasing over the last 20 years (López-Iñesta et al., 2020), despite female adolescents performing the same or even better than their peers in terms of science, mathematics, and literacy (Gagnon and Sandoval, 2019). For them and for other disadvantaged groups, staying on the STEM path becomes a personal and social challenge.

– Other characteristics that hinder the advancement of STEM talent are in this order: race/cultural diversity (29.41%), with certain races and cultures having greater opportunities (for example, white and native people); socioeconomic status (23.53%), with fewer resources come fewer opportunities; age (11.76%), primary education provides fewer options; rural/urban environment (7.84%), with urban environments offering a wider range of services and resources. In addition, other variables in a lower percentage that hinder the trajectory are: belonging to minority or disadvantaged groups, students at risk of dropping out of the educational system, being twice exceptional (high ability and disability), certain types of family environment and, the profession and educational level of their parents in non-STEM fields. The research seeks to identify the mechanisms that contribute to closing these gaps, for example, with educational programs that provide equal opportunities (Olszewski-Kubilius et al., 2017) or experiences that contribute to overcoming the barriers from the family and school context (Burt y Johnson, 2018).

Contextual variables

These variables refer to the opportunities for developing talent in specific settings and external to each individual. The context variables have been organized into three categories: formal education (63%), non-formal education (41%), and other contexts (12%). Opportunities provided to students on the talent trajectory from the educational system are crucial, but so are all those non-formal educational opportunities within their reach.

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In the first place, formal education is the most studied context, and it includes:

- *Teachers*: teacher training (lifelong learning, sustained professional development, institutional support for training), collaboration between educational centers, universities, and STEM professionals, sharing experiences among teachers, high qualification, perception of their competence, and active involvement in the teaching process all contribute favorably to the advancement of the STEM talent trajectory.
- *Methodologies*: described in the following section.
- *Type of center*: the opportunities offered by the different types of centers are contrasted according to their rural/urban environment, the role of STEM boarding schools in the US, and the results of public schools, Catholic or *homeschooling,* and specialized STEM schools as opposed to the traditional ones.
- *Material resources of the center*: talent is encouraged by having STEM material resources, such as laboratories either at the center itself or external.
- *Attention to diversity*: students with STEM talent need to have the possibility of attending advanced courses (mathematics and science, especially) and extracurricular activities, mentoring, differentiation, acceleration, and enrichment.
- *Curriculum*: on the one hand, the advancement of STEM talent is favored by bringing STEM interests into the curriculum at an early age, offering an advanced and/or affective curriculum, access to engineering content and integration of STEM content, intense exposure to mathematics and science content in primary and specialized content in secondary school, perceiving the usefulness of the subjects, visibility of STEM role models in the classroom, different groupings, tacit knowledge of the STEM disciplines, use of technology, the possibility of showcasing classroom projects to the public, interpersonal relationships in the classroom, feedback to students and recognition of achievements, STEM learning environment, guidance, institutional support for the STEM curriculum, and high-quality lesson plans. On the other hand, disruptions in the classroom are negatively related, as they cause anger and boredom.

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The differences between the teaching staff, the methodologies that are implemented in the classroom, the type of center, its resources, and the access it has to other resources, attention to diversity for students with STEM talent, and the curriculum that is developed, translate into differences in opportunities for the advancement of STEM talent.

Second, non-formal education can fill many of the shortcomings of formal education, highlighting:

– *Extracurricular activities (92.68%)*: to bring content and skills that are not accessible in formal education (delve into specific interests, learn about new fields, interact with peers who share interests...). In addition, these activities are critical in subjects with sociodemographic characteristics that hinder the STEM trajectory (Subotnik et al., 2019) such as students residing in rural settings (Ihrig et al., 2018) or the female gender (Holmes et al., 2012). Race and offering interests from non-formal education are two factors positively and significantly related to success in STEM (Steenbergen-Hu and Olszewski-Kubilius, 2017).
– *Family and equals*: family is fundamental in promoting early STEM interests and providing support (Burt and Johnson, 2018; Garriot et al., 2014; Steenbergen-Hu and Olszewski-Kubilius, 2017), and so is the support of peers with whom interests are shared (Subotnik y Rickoff, 2010).

Despite this classification of the context, formal and non-formal education should not be separated. Formal education offers some opportunities and non-formal education others, with each of them bringing advantages and disadvantages to the advancement of STEM talent (Olszewski-Kubilius, 2009). Zeng, Zhang, and Wang (2019) suggest building bridges between the two for the development of this talent.

Macro context variables appear subtly and include: educational capital, economic resources of the country, educational policies (scholarships, bridges between the different educational levels and between formal and non-formal education), linking talent education with the objectives of the society, analysis in each society of the impact that STEM talent education has on the incorporation into STEM professions and on the number of people reaching STEM eminence, state of STEM research in the country, population health and survival (life expectation) in less developed countries, national standardization of the curriculum, recognition of

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exceptional achievements in students with STEM talent (national awards), cultural value given to the STEM field (norms and values associated with STEM professions), and gender role models and political empowerment of women.

In this way, the STEM talent trajectory is not only affected by the characteristics of the individual and their close educational contexts. Talent has to be understood in the broader context of a culture that values specific lines of human development and transforms it in the course of individual development. Individual and culture are not two separate entities, but are constituents of each other (Dai, 2019). Individual's personal and environmental resources and the access they have to these are associated with high abilities, with the interaction between endogenous and exogenous forces capturing the understanding of giftedness from a systemic perspective (Ziegler et al., 2019).

To summarize, dispositional variables interact with the opportunities offered by the context, they form trajectories that can favor or limit the advancement of talent and the combination between both types of variables appears repeatedly in research (75%). Therefore, STEM talent education needs to be understood from a systemic and dynamic lens characterized by complexity and the interaction between different sets of factors.

Methodologies to promote STEM talent in compulsory education

The methodologies that promote STEM talent during compulsory education have been grouped into thirteen categories, although more than half of the publications (64%) opt to address more than one.

The findings place independent/autonomous learning in the first position (26.23%). This methodology allows curricular differentiation for gifted students, given that by delving into and advancing in STEM subjects, thinking and problem-solving skills can be fostered. Independent learning is one of the most frequently recommended methodologies for gifted students and included in most manuals for differentiation and individualization. In addition, it is preferred by the most capable students (Yu and Jen, 2020).

In addition to independent learning, project-based learning is confirmed as another one of the most relevant methodologies for the

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advancement of STEM talent also with 26.23%. They are followed in percentage by problem-based learning (18.03%), inquiry-based learning and the engineering design process (16.39% each), and experiments/ demonstrations (14.75%).

This set of cited methodologies, the *hands-on* methodologies, are the most widely implemented for the advancement of STEM talent during compulsory education. They allow the integration of STEM disciplines by applying practices of scientific inquiry, mathematical logic, and problem-solving skills, trial and error, creativity, and visualization skills for students who collaborate, design, prototype, invent, optimize, and document unique product or project designs. Along with them, the *maker* approach favors authentic teaching-learning experiences (Banks-Hunt et al., 2016). In addition, all of them contribute to solving real-life problems while integrating the STEM disciplines.

Visits to laboratories (Itzek-Greulich et al., 2015), attending round tables, and conferences (Holmes et al., 2012) improve STEM learning, bring knowledge and skills closer to those who otherwise do not have access and offer guidance towards STEM vocations.

Finally, mentoring (14.75%), role models (8.2%), as well as other sets of methodologies (42.62%) with a wide range of techniques such as the use of narratives and stories from successful STEM professionals, gamification, learning based on video games or bibliotherapy and cinematherapy, among others, offer important benefits. The findings suggest that these methodologies not only favor students in general, but specifically benefit vulnerable groups in the STEM talent trajectory due to their sociodemographic characteristics (women, low socioeconomic status, race ...). It is worth noting the scarce use of traditional methodologies based on lectures (3.28%) which are presented together with other methodologies.

Milestones/stages of STEM talent development in compulsory education

Of the various topics of the research objectives, it is the one that receives the least attention. In terms of publication output within the topic, milestones are studied in 76.47% and stages in 23.53%, the second hardly appears given the novelty of the subject. Models of talent development and STEM education are recent topics in research.

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Among the milestones, indicators are defined based on STEM talent competence (46.15%), especially mathematics, but also on computational talent and engineering design, or programming skills, recognitions (both in academic achievements, such as awards or winning tournaments, 30.77%), academic performance on state tests (30.77%), completion of advanced courses (15.78%) in the countries that offer them, and evidence of creativity (7.69%).

The few milestones are mostly related to the processes of identifying students with high abilities or for access to programs in formal or non-formal education, rather than as indicators of progress in the stages they go through in the STEM talent trajectory. Skills and, above all, competence and performance results are usually taken as a reference. The rest of the indicators, such as obtaining prizes or recognitions in STEM contests or tournaments, evidence of creativity and participation in advanced courses, are not presented in all educational systems and when they do occur, they are not available to all students.

The stages are based on Bloom's taxonomy (1985) and earlier research (Subotnik et al., 2011; Subotnik and Jarvin, 2005). Three moments are proposed: in the first stage, people need to be guided to "fall in love" with a topic, idea, or discipline. The second involves teaching the skills, knowledge, and values of the domain. In the third, talented people apply their passion and technical expertise to create a unique style and explore new problems. In the first stage, skills/abilities are transformed into competences and then competences into expertise, the psychosocial abilities becoming essential in the transitions. Regarding STEM talent, suggestions are offered according to age: in 3rd and 4th grade, non-formal education experiences must stimulate STEM enjoyment, promote confidence in spaces such as laboratories, ensure literacy, and develop solid basic mathematical skills. By 6th grade, students should participate in advanced courses and in 8th and 9th grade, curricular gaps must be covered such as significant laboratory practice, "leveling the ground", and coordinating with families.

Recently, Preckel et al. (2020) proposed the *Talent Development in Achievement Domains* (TAD) approach specifying the model of Subotnik et al. (2011). The talent trajectory crosses four moments: potential (individual constellations of psychological factors); competence (related and systematically developed skills); expertise (high level of performance sustained over time) and, transformational achievements (high level of creative achievement that breaks the limits of the domain or sets new questions). The TAD approach offers a foundation to understand the sequence and empirical evidence regarding the increase in the level of specialization and the relationships between the predictors and indicators that favor the talent trajectory; through a set of steps in which initial skills culminate in transformational achievements upon completion. Despite this, more efforts are still needed to identify milestones and stages in STEM talent.

Conclusions, implications, limitations, and future lines

In gifted education, the "21st century talent models" call for an evolutionary and renewed approach focused on specific domains. Among the talent domains, STEM acquires substantial relevance today, although it is still under study.

This review is a starting point to understand the trajectory of STEM talent in compulsory education outlined in these conclusions:

- The results suggest a growing interest in STEM talent research since the late second decade of this century. Following North American leadership, research is distributed heterogeneously at an international level and in terms of the educational stages it addresses (focusing on secondary education).
- Among dispositional *variables*, cognitive variables are seen as predictors of STEM talent, although by themselves they do not optimize the successful completion of the STEM talent trajectory. In the considered body of research, psychosocial variables acquire much greater relevance than the previous ones. This is consistent with current conceptions of talent development that understand the psychosocial as a more critical element than the purely aptitude-cognitive when progressing through the different stages of said development. Regarding the sociodemographic variables, gender is the most decisive because it concentrates the interest of the research. In addition, a set of characteristics warn of vulnerability in some groups of students. Finally, regarding the contextual variables, they are presented in the form of opportunities for the advancement of STEM talent from formal education, and in a high percentage from non-formal education. It seems that, at

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least until now, the development of STEM talent in compulsory education requires complementing formal contexts with non-formal experiences, and even the combination of both. The family also appears as an educational agent that favors the trajectory of STEM talent, especially for some student profiles.

- An overwhelming presence of *hands-on methodologies* is reported for the advancement of STEM talent: active, practical, focused on problem solving, and that allow student autonomy in combination with peer support and expert mentorship. There is a clear relationship between STEM talent education and a certain methodological style, which is also possibly associated with the high presence of non-formal learning (less rigid) in STEM talent education, especially with students who present certain sociodemographic characteristics.
- *Milestones and/or stages* of STEM talent development are the topics with the most palpable research gap, and to which we will dedicate our future efforts. The stages of development of STEM talent in compulsory education have not yet been clearly established, nor the milestones that mark the passage from one to another, despite the interest it arouses to cultivate STEM talent in compulsory education.

To summarize, some guidelines for training STEM talent in the educational system can be suggested. They are based on the premise of the interaction between personal characteristics and although they are presented in a segmented way, they need to be understood from a systematic, holistic, evolutionary, ecological, and dynamic vision:

- Observe the cognitive characteristics of students that predict success in the STEM talent trajectory. High visuospatial skills, high mathematical reasoning ability, and high proficiency in STEM talent stand out in the early years of primary education.
- Deliberately and systematically promote the psychosocial variables that favor the smooth course of the STEM talent trajectory. A top priority while training this talent should be to bring together STEM interests and perseverance in these vocational trajectories, favorable STEM attitudes, motivation towards the field and commitment to it, and a perception of adjusted competence.
- Carefully monitor the most disadvantaged students with STEM talent, both to detect their potential and to offer specific educational

interventions applying the principle of equity. More specifically, the most vulnerable students in STEM are female students, racial and cultural minorities, students with low socioeconomic status, twice exceptional students, individuals at risk of dropping out of the educational system, unstructured family environments, or parents without studies or jobs in STEM fields.

– Provide learning experiences from educational centers that advance the trajectory of STEM talent. The training of teachers throughout their lives and in contact with other teachers, universities, and STEM professionals, knowledge of the most pertinent methodologies to implement in the classroom, specialized resources (such as laboratories or access to external laboratories), attention to diversity programs with differentiated educational responses that allow the most capable students to specialize, and a curriculum with a range of sufficiently challenging opportunities all contribute to the advancement of STEM talent.
– Assess the available resources and opportunities of the educational center and the families to advance talent through an analysis of the immediate context. Opportunities from each setting do not only contribute to the development of psychosocial skills, but can compensate for both personal and contextual shortcomings, both critical issues for advancing the STEM talent trajectory. This implies the participation of the family and identifying services and resources from non-formal education in terms of STEM extracurriculars. It is necessary to build bridges between formal and non-formal education.
– Offer different types of methodologies to enable the curricular differentiation needed by gifted students, especially *hands-on* and learning in real STEM contexts. In addition, for each student, depending on their sociodemographic characteristics, some methodologies may be more appropriate, such as mentoring and role models for female students.

Despite having these guidelines for STEM talent education in compulsory education, challenges remain both in this research and in the field of study in general.

First, some limitations that emerge from this research are outlined. Given that the aim has been to collect as many studies as possible, including qualitative research, the advantage of amassing a large body

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of knowledge translates into the limitation of not being able to calculate the size of the effect of the interventions. Furthermore, the guidelines followed in this research suggest the convenience of reviewing the entire process by at least two researchers and, in this work, the classification and coding was carried out by the first researcher, with the second and third researchers only reviewing a percentage of the included studies. However, the development and communication of the protocol of this review allows its replicability for the advancement of research, as proposed by the guidelines that guide this review.

Second and as a future line of research, we plan to continue in this field of research and specify a model for the development of STEM talent in compulsory education. The "talent models of the 21st century" call for a systemic approach, loaded with the interaction of different endogenous and exogenous variables/forces, dynamic, evolutionary, and renewed of the specific talent domains. Within this framework, the STEM talent trajectory variables and the most appropriate methodologies to favor it have been identified. Despite this, based on the conclusions collected, it is necessary to delve into the milestones and stages that occur during compulsory education, in order to predict a successful STEM trajectory and delve into the educational interventions that favor it.

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Contact address: Mª Pilar Herce Palomares. UNED, Escuela Internacional de doctorado, Facultad de Educación. Calle de Juan del Rosal, 14, C. P. 28040, Madrid. E-mail: mherce2@alumno.uned.es

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