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Children's literature didactics and reading promotion in STEAM projects: Effects of a transdisciplinary training program for early childhood and primary school teachers

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Abstract: This study examined the effectiveness of an online course for integrating children's literature didactics and reading promotion into transdisciplinary STEAM education projects. The intervention was based on the design and validation of the TALES-STEAM scale. Using a one-group pretest-posttest design, five experiential modules, focusing on storytelling, engineering, science, mathematical comics, narrative robotics, and picturebooks were delivered to a sample of 2,136 in-service early childhood and primary education teachers from Spain, Portugal, Italy, Mexico, Chile, and Ecuador, selected through a mixed non-probability sampling. Post-intervention results revealed a statistically significant increase in all items, with large effect sizes and no overlap between pre- and post-distributions. Participants reported enhanced creativity, mathematical accessibility, scientific inquiry, aesthetic-technical balance, and inclusive practices, positioning literature as the central axis for transdisciplinary pedagogies. Given the program's demonstrated effectiveness and the feasibility of adopting STEAM frameworks that transcend mere disciplinary juxtaposition, future research should replicate these findings through controlled experimental designs and longitudinal follow-ups to confirm the stability of attitudinal change and its transferability to classroom practice.

Keywords: STEAM, Literary education, Teacher training, Teacher attitudes, Early childhood education, Primary education

1. Introduction

Recent literature on integrating the arts into science and technology education agrees that a transdisciplinary approach is needed to address the educational challenges of our contemporary world (UNESCO, 2025). The Janus model proposed by Ben-Horin et al. (2023) provides a conceptual framework that 0balances the pedagogical principles of both science and art within the context of the Global Science Opera (GSO), to illustrate how the disciplines can interrelate without one dominating the other. This approach also highlights the urgent need for empirical studies to test its effectiveness in real-world settings and confirm its potential for addressing complex problems from multiple perspectives.

The GSO re-emerges as a paradigmatic pedagogical

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laboratory in the work of Strakšienė et al. (2022), who define it as a distinctive transdisciplinary pedagogy structured around the phases Feel–Imagine–Create–Share, inspired by design thinking. This sequence simultaneously mobilizes aesthetic sensitivity and scientific inquiry to foster deep, collaborative learning that transcends the boundaries between academic knowledge and community practices, offering an operational model that can be adapted to other educational contexts. In this regard, Chowdhury et al. (2024) synthesize five key attributes of transdisciplinarity (complexity, boundary-crossing, inclusion of diverse perspectives, cultural transcendence, and transformative reflection) and propose a guiding model for its implementation in school science. This model reinforces convergence with the Janus framework by insisting that tackling complex problems requires the blurring of disciplinary boundaries and the coherent articulation of academic and community-based knowledge.

The "A" in STEAM is consistently represented through visual or plastic arts, music, design, or performing arts; however, studies that address literary contributions from the perspective of children's literature didactics and reading promotion are virtually nonexistent. Even when taxonomies of artistic integration are offered, the discussion usually focuses on avoiding the instrumentalization and devaluation of "the arts" (Sanz-Camarero et al., 2023), without acknowledging reading, text analysis, or literary creation as distinct and legitimate domains. In this sense, the Global Science Opera (GSO), a recurring paradigm of the integration of art and science, examines the creative process of opera primarily from a performative and musical point of view; the literary dimension of the libretto, in fact, is not problematized as an object of literary instruction or as an area of competence in its own right.

In this context, the present study pursues a dual aim: (1) to design and validate the TALES-STEAM scale, intended to measure teachers' attitudes towards the integration of literature within STEAM projects, and (2) to evaluate the impact of an online program focused on the articulation of oral storytelling, informational literature, mathematical comics, narrative robotics, and picturebooks in integrated teaching contexts at these educational levels through a pretest-posttest design with early childhood and primary school teachers. The objective is to determine whether the instructional intervention significantly enhances the curricular, integrative, and creative relevance of transdisciplinary STEAM-based teaching through the classroom intervention.

2. Literature review

2.1 Educational benefits and enabling conditions

To further explore the systemic implications of integrated teaching, Perales and Aróstegui (2024) examine the shift from the STEM to the STEAM paradigm, highlighting not only its educational benefits but also its social and economic repercussions. Their findings, based on experiences in the United Kingdom, the United States, and within the Global Science Opera itself, show that a STEAM curriculum enhances creativity, critical thinking, and the development of social skills essential for the global economy, provided it is supported by robust teacher training and coherent education policies that prioritize disciplinary interconnectedness.

In this line, Costantino (2017) argues that transdisciplinary practice in art and design should not be reduced to merely "adding" the A to STEM, but rather must reframe the creative inquiry processes that underlie all disciplines. Her reviews of STEAM projects demonstrate that combining art and science methods expands students' ability to formulate and solve problems holistically, fosters innovation, and allows for a more nuanced understanding of the phenomena being studied. Similarly, Hunter-Doniger (2021) shows that when the interdependence of disciplines in STEAM learning is structured as a space for play, autonomy, and artistic exploration, early childhood students experience growth in their creative abilities, sustained curiosity toward scientific and technological knowledge, and deeper levels of engagement.

Guyotte et al. (2014), for their part, conceptualise STEAM education as a situated social practice that incorporates art and design into engineering, with the aim of enabling students to develop broader perspectives on problem-solving and create solutions with greater cultural and community impact. This perspective, based on improving conceptual understanding and developing a positive attitudes towards learning, supports the idea that competitiveness and innovation depend on educational environments where problem-solving creativity can flourish within transdisciplinary spaces. From this standpoint, Markauskaite et al. (2024) conceptualize this type of learning as a dynamic and multiscalar phenomenon. Their approach extends the previous model by emphasizing the infrastructures, temporalities, and reciprocities that sustain interdisciplinary collaboration, calling for the design of learning environments that promote productive participation and civic responsibility.

2.2 Obstacles and styles of arts integration

The role of the arts in the context of integrated education is at the centre of the analysis by Sanz-Camarero et al. (2023). After a comprehensive critical literature review, these authors identify four main obstacles (instrumentalization, devaluation, insufficient teacher training, and evaluative neglect) and describe five styles of integration, ranging from subordinate to authentically artistic. Their defense of the epistemological autonomy of the arts reinforces the need to design evaluative frameworks that recognize artistic practices and prevent the reproduction of traditional disciplinary hierarchies.

In this vein, Helvacı's (2020) review of doctoral dissertations on the STEAM approach in Turkey reveals a disciplinary imbalance: although research output has grown in recent years, most studies continue to focus on science and mathematics, while the visual arts remain underrepresented. This finding confirms Sanz-Camarero et al.'s (2023) warning about the marginalization of the arts and underscores the urgency of research that is able to restore their epistemic role, and thus avoid the aesthetic instrumentalization of integration.

However, the transdisciplinary integration of the STEAM approach within the domain of social studies, has developed unevenly. The meta-analysis of 109 studies (2010–2018) conducted by Lim and Kwon (2020) reports a steady increase in scholarly output in this area, largely dominated by quantitative approaches that prioritize the analysis of students' affective variables. In their assessment, they caution that these efforts remain grounded in limited interdisciplinary models and call for the development of a theoretical and curricular framework aimed at fostering creative and critical convergence.

2.3 STEAM in early childhood and primary education

The 2017–2023 review by Su et al. (2024) identifies that STEAM initiatives in early childhood education, predominantly developed through qualitative and mixed-methods designs, are grounded in curricular frameworks, foster technology-enhanced learning, and report improvements in knowledge, skills, and attitudes. However, challenges remain concerning pedagogical content knowledge, teachers' attitudes, and the availability of guidelines and resources, areas that underscore the need for teacher training and sufficient institutional scaffolding to ensure optimal implementation (Su et al., 2024).

Similarly, in the early years of primary education, teachers express positive perceptions and strong confidence in facilitating inquiry-based activities (particularly in mathematics and science), while they acknowledge time and resource constraints and lower confidence in engineering content. These patterns reinforce the relevance of targeted teacher training and school-level conditions (spaces, materials, and support) to sustain integrated approaches (Nikolopoulou & Tsimperidis, 2023).

3. Method

3.1 Participants

The sample consisted of 2,136 early childhood and primary education teachers (Table 1) who participated in an online continuing education course on transdisciplinary approaches to the didactics of children's literature and reading promotion (Table 2). Participants were selected through a mixed non-probability sample: convenience sampling, taking advantage of accessibility to the teaching population; and purposive or judgmental sample, based on each teacher's suitability in relation to the objectives of the study. This combination allowed the feasibility of the fieldwork without compromising the alignment of the sample with the research aims.

3.2 Instrument

The TALES-STEAM scale (Textual and Literary Engagement in STEAM Projects Scale), designed ad hoc, was administered for this study. The construction of the items followed methodological guidelines aimed at ensuring the formal coherence of the instrument. In accordance with the recommendations of Hernández-Sampieri and Mendoza (2018), each statement was formulated on a basis of single, well-defined logical idea. To enhance conceptual clarity and reduce the cognitive load placed on participants when answering, each item was limited to a maximum of twenty words, as advised in methodological literature. Likewise, to allow for a more nuanced assessment of the degree of agreement expressed by teachers and to elicit consistent perceptions (Gil Pascual, 2011), a five-point Likert-type response scale was used, with response categories for all items ranging from 1 (strongly disagree) to 5 (strongly agree).

To avoid a possible bias due to acquiescence, one item (Item 4) was phrased in the reverse direction, following Gil Pascual's (2011) recommendations. This strategy helps identify automated response patterns and supports the accurate interpretation of the data. In the analysis phase, this item was recoded as a necessary methodological step to maintain the internal consistency of the scale, ensure the reliability of the instrument, and control for frequent response bias. The five items, each of which adheres to the recommended length and focused on exploring teachers' attitudes toward the integration of literature in interdisciplinary teaching projects, are presented below (Table 3).

3.2.1 Construct validity

To confirm the factorial structure of the scale, the suitability of the instrument was assessed. A single latent factor hypothesis, defined by five observed indicators, was tested. The main objective was to determine the degree of association between these indicators and the underlying construct, based on model fit indices. For this purpose, a confirmatory factor analysis (CFA) was conducted within the framework of structural equation modelling based on the covariance matrix.

As shown in Table 4, the values of the RMSEA (Root Mean Square Error of Approximation) and SRMR (Standardized Root Mean Square Residual) are within the recommended thresholds (≤ .08), while the incremental indices, CFI (Comparative Fit Index) and TLI (Tucker–Lewis Index),

reach optimal levels (≥ .90). The parsimony statistic ($X^2(5) = 7.945$, $p > .05$), together with the remaining absolute and comparative fit indices, indicates a good overall model fit. In addition, the upper bound of the 90% confidence interval for the RMSEA does not exceed the .08 threshold, further supporting evidence of the model's satisfactory fit (Figure 1).

The obtained factor loadings approach or exceed the acceptable threshold of ≥ 0.40, demonstrating a strong relationship between each indicator and its corresponding factor. Additionally, the differences among the factor loadings resulted in a low overall standard deviation (SD = 0.08), suggesting a homogeneous and balanced contribution of the indicators to the factor estimation. Finally, the statistical significance ($p < .001$ in all cases) further supports the validity of the model. It can thus be concluded that the indicators contribute meaningfully and consistently to the measurement of teachers' learning perceptions regarding the effective contributions of literature within the integrated STEAM teaching model.

Table 1. Comparative table (Early Childhood/Preschool and Primary Education) for Spain, Portugal, Italy, Mexico, Chile, and Ecuador: Official stage names and typical age ranges

Country	Stage	Typical age range	Duration	Notes
Spain	Early Childhood Education	0–6	6 years	Two cycles: 0–3 (not compulsory), 3–6 (free in publicly funded schools).
	Primary Education	6–12	6 years	Compulsory
Portugal	Preschool Education	3–6	3 years	Not compulsory; prepares children for entry into basic education.
	Basic Education - First Cycle (equivalent to Primary Education)	6–10	4 years	Compulsory; mandatory entry at age 6 (special rules for children born between 16 Sept–31 Dec).
Italia	School of Childhood (Scuola dell'Infanzia)	3–6	3 years	Not compulsory; part of the integrated 0–6 system.
	Primary School (Scuola Primaria)	6–11	5 years	Compulsory
Mexico	Preschool Education	3–5	3 years	Three grades; entry at age 3 (SEP regulation).
	Primary Education	6–12	6 years	Compulsory; entry at age 6 (SEP regulation).
Chile	Early Childhood Education	0–6	6 years	Levels: nursery (0–2), middle (2–4), transition (4–6). Kindergarten (5–6) is compulsory.
	Basic Education (Primary Education)	6–13	8 years	Compulsory (Grades 1–8)
Ecuador	Initial Education (Sublevels 1 and 2)	0–5	5 years	Initial 1 (0–3), Initial 2 (3–5)
	General Basic Education (EGB) - Primary Segment (Preparatory, Elementary, and Middle)	5–11	7 years	Preparatory (5), Elementary (6–8), Middle (9–11). Full EGB lasts 10 years (ages 5–14).

Note. In most countries, the cut-off date is set according to the calendar year (e.g., reaching the required age before December 31), although occasional exceptions may apply.

Table 2. Sociodemographic characteristics

Variable	Category	f_i (p_i)
Gender	Female	1003 (47)
	Male	1089 (51)
	OI	44 (2.1)
Age	AG1	726 (34)
	AG2	811 (38)
	AG3	599 (28)
Country of origin	Spain	768 (36)
	Portugal and Italy	704 (33)
	Mexico, Chile, adn Ecuador	664 (31.1)
Teaching experience (years)	1-5	1210 (56.6)
	6-11	655 (3.7)
	≥ 12	271 (9.1)
Previous experience in STEAM or integrated approaches (years)	≤ 3	1425 (66.7)
	4-8	516 (24.1)
	≥ 9	195 (9.1)

Note. OI: Other gender identities. AG1 = 26-32 years old. AG2 = 33-39 years old. AG3 = 40-46 years old. fi = absolute frequency. pi = relative frequency (percentage).

Table 3. TALES-STEAM scale

Number	Item	Source
1	Merging oral storytelling with engineering challenges enhances students' creativity and reading comprehension.	Pagano et al. (2024)
2	Exploring scientific concepts through literary texts stimulates critical observation of natural phenomena.	Cardullo and Burton (2025)
3	Digital comics based on mathematical problems improve reading motivation and logical reasoning.	Chu and Toh (2020)
4	Integrating narrative robotics makes it harder for my students to focus on the literary aesthetics of texts.	Andrée et al., (2024)
5	STEAM projects based on picturebooks foster inclusion and collaborative work in Early Childhood and Primary Education.	Wade et al. (2023)

Table 4. Absolute fit (RMSEA and SRMR) and comparative fit (CFI and TLI)

			RMSEA 90% CI		
CFI	TLI	SRMR	RMSEA	Lower	Upper
0.974	0.948	0.033	0.043	0.021	0.077

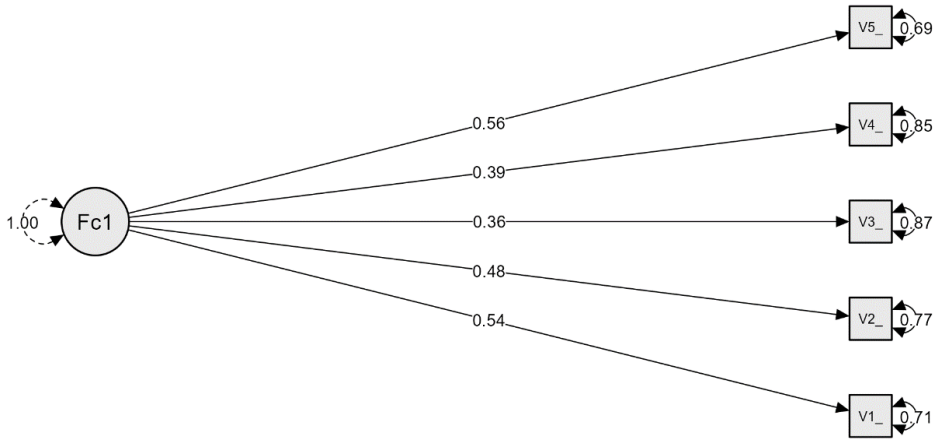

Figure 1. Path diagram of the final model

3.2.2 Reliability as internal consistency

The internal consistency reliability of the instrument's items was assessed using Cronbach's alpha (α) and McDonald's omega (ω) coefficients. The results indicate an adequate level of reliability for the scale (> .70) (Table 5).

3.3 Design and procedure

3.3.1 Design

The study employed a pre-experimental one-group design with pretest–posttest measurements (O_1 X O_2). According to Campbell and Stanley (1995), this design is situated among quasi-experiments when there is no random assignment or comparison group. Following the classic typology of McMillan and Schumacher (2005), it is classified as a one-group pretest–posttest design, in which each participant serves as their own control.

Although this design is appropriate in educational contexts where classroom reorganization would not be feasible, it has specific threats to internal validity. Among the best known are history, maturation, pretest reactivity, instrumentation, and the Hawthorne effect. To mitigate these, the study limited the intervention to five weeks, selected a homogeneous cohort in terms of age and educational level, separated the pretest and posttest by four weeks and used counterbalanced item matrices (Pérez et al., 2012), and standardized the administration of instruments through a written protocol. Consequently, the potential bias due to teachers' awareness of being observed (Hawthorne effect) was controlled by integrating the intervention and the two assessments without presenting the experience as a stand-alone experiment, as recommended in the literature. To minimize the practice effect, the questionnaire was administered in two identical versions (matrices A and B) containing the same items but arranged in a 5×5 Latin square. Version A was used for the pretest and version B for the posttest, so that each item changed its position in the sequence, thereby disrupting response–memory associations (i.e., positional recall). This counterbalancing preserved content equivalence and reduced the reactivity typically associated with repeated testing, without increasing participants' cognitive load (Navarro, 2017). In this way, each item shifted from its original position (1–5) to a different one (e.g., 3–2). This represents an incomplete counterbalancing approach, which is recommended to attenuate the practice effect when not all five rows of the square are used (Table 6).

As far as external validity is concerned, both components were taken into account. For population validity, the entire cohort of enrolled participants was included (n = 2,136), self-selection bias and facilitated generalization of the results to groups with similar characteristics. Ecological validity was strengthened by conducting the intervention within the virtual classroom environment, using the usual resources, pacing, and assessment systems. This ensured that the experience did not involve any technological or contextual novelties that could artificially amplify the effects of the treatment.

Table 5. Internal consistency coefficients

Pretest						Posttest					
	95 % CI			*95 % CI*			*95 % CI*			*95 % CI*	
ω	*Lower*	*Upper*	α	*Lower*	*Upper*	ω	*Lower*	*Upper*	α	*Lower*	*Upper*
.950	0.946	0.953	.912	0.908	0.917	.927	0.922	0.932	.938	0.935	0.942

Table 6. Item ordering using a 5 × 5 latin square

Version A (pretest)	Version B (posttest)
Item 1. Merging oral storytelling with engineering challenges enhances students' creativity and reading comprehension.	Item 3. Digital comics based on mathematical problems improve reading motivation and logical reasoning.
Item 2. Exploring scientific concepts through literary texts stimulates critical observation of natural phenomena.	Item 4. Integrating narrative robotics makes it harder for my students to focus on the literary aesthetics of texts.
Item 3. Digital comics based on mathematical problems improve reading motivation and logical reasoning.	Item 5. STEAM projects based on picturebooks foster inclusion and collaborative work in Early Childhood and Primary Education.
Item 4. Integrating narrative robotics makes it harder for my students to focus on the literary aesthetics of texts.	Item 1. Merging oral storytelling with engineering challenges enhances students' creativity and reading comprehension.
Item 5. STEAM projects based on picturebooks foster inclusion and collaborative work in Early Childhood and Primary Education.	Item 2. Exploring scientific concepts through literary texts stimulates critical observation of natural phenomena.

3.3.2 Procedure

A five-week (25-hour) professional development course on STEAM for literary education in early childhood and primary education was developed for in-service teachers and led by the research team of the present study. Each week consisted of 90 minutes of theoretical lecture, 120 minutes of design laboratory, and 30 minutes of critical reflection supported by the latest international scientific literature.

In Week 1, modelled the integration of oral storytelling with technical challenges: Using cumulative tales, teachers tackled a structured challenge that followed the ask–imagine–plan–create–improve cycle. This strategy is supported by evidence showing that storytelling in conjuction with engineering design enhances creativity and the verbalization of engineering concepts in early childhood (Pagano et al., 2024). Week 2 focused on scientific inquiry through informational and poetic literary texts. Following a dialogic reading session, participants developed investigative questions for implementation, aiming to foster critical observation of natural phenomena, in line with the Equity-Oriented STEM Literacy Framework, which positions picturebooks as gateways to science (Cardullo & Burton, 2025). In Week 3, participants designed interactive digital comics based on contextualized mathematical problems. The session followed the TSCT structure (Theme–Storyline–Character–Text), drawing on evidence about the potential of comics to enhance students' reading motivation and logical reasoning (Chu & Toh, 2020).

Week 4 focused on prototyping stories using educational robotics (Tell–Draw–Code). The session explored how technical execution may divert attention from the literary aesthetics of a text, a theme that aligns with studies describing the tension between functionality and aesthetic experience in school robotics programming (Andrée et al., 2024). Finally, Week 5 involved the creation of cooperative STEAM projects based on picturebooks selected using the Equity-Oriented STEM Literacy Framework and planned according to the principles of Universal Design for Learning. Research shows that such practices foster inclusion and active participation of all students, with and without disabilities (Wade et al., 2023). The final session included a micro-teaching activity in which each teacher implemented their project in a 20-minute lesson (Table 7).

The TALES-STEAM scale was administered in three equivalent linguistic versions (Spanish, Portuguese, and Italian), with measurements taken in December (pretest) and January (posttest) of the years 2024 and 2025, with the aim of estimating the changes within subjects between the two time points. Given the multilingual nature of the scale, careful attention was paid to the quality standards of the scale (validity, reliability, and objectivity) and to the comparability of the measurements across versions, in accordance with the general guidelines for the rigorous development and administration of questionnaires and scales within the quantitative research pathway (Hernández-Sampieri & Mendoza, 2018). Accordingly, TALES-STEAM was applied in linguistically equivalent versions and according to a fixed schedule, to ensure measurement conditions consistent with the pretest–posttest design and with recognized psychometric criteria (McMillan & Schumacher, 2005).

The study was designed and conducted in accordance with the ethical principles recognized in the literature on educational research. The research team ensured professional competence, integrity, and social responsibility. The dignity and diversity of participants was protected through informed consent, which included specific information about the aims of the study, the procedures, and the potential risks before obtaining participants' voluntary agreement. To safeguard the confidentiality and anonymity of participants, individual data were coded and reported only in aggregate form. Lastly, the principle of non-maleficence and beneficence was adhered by carefully weighing potential risks against educational benefits and ensuring that no the absence of any physical or psychological harm. Accordingly, the study fully complied with the ethical standards of the American Educational Research Association.

Table 7. Main stages of the intervention (contents and competencies)

Stage (week/session)	Main Focus / Activity	Core contents and tasks	Competencies developed
Week 1	Oral storytelling and engineering challenges (ask–imagine–plan–create–improve cycle)	Didactic modeling with cumulative tales and guided resolution of an engineering challenge, supported by evidence on storytelling and engineering design (Pagano et al., 2024).	Creativity; design/engineering thinking; oral communication and verbalization of engineering concepts; collaborative work; iteration and improvement.
Week 2	Scientific inquiry through informational and poetic literary texts	Dialogic reading; generation of investigable classroom questions; critical observation of natural phenomena within the equity-oriented STEM literacy framework (Cardullo & Burton, 2025).	Scientific literacy; questioning and inquiry; critical reading; systematic observation; equity perspective in STEM.
Week 3	Interactive digital comics for contextualized mathematical problems (TSCT: Theme–Storyline–Character–Text)	Design of multimodal narratives to represent and solve problems; grounded in evidence on reading motivation and logical reasoning through comics (Chu & Toh, 2020).	Logical–mathematical reasoning; reading and multimodal literacy; written and visual communication; basic digital competence; problem contextualization.
Week 4	Tell–Draw–Code: prototyping narratives with educational robotics	Development of programmable narrative prototypes; analysis of the functionality–aesthetic experience tension in school robotics programming (Andrée et al., 2024).	Initial computational thinking; problem solving; prototyping and debugging; aesthetic sensitivity and judgment; metacognition on trade-offs.
Week 5	Cooperative STEAM projects with picture books (Equity-Oriented STEM Literacy Framework + UDL)	Selection of picture books; didactic planning with Universal Design for Learning principles; design of inclusive activities (Wade et al., 2023).	Inclusive didactic design (UDL); collaboration; participation and accessibility; project planning; leadership and team management.
Closing session	Micro-teaching	Each teacher implements a micro-teaching session using the products developed.	Transfer to practice; teaching communication; formative assessment; evidence-based critical reflection.

3.4 Data analysis

Descriptive (medians and ranges) and inferential analyses were carried out on the data obtained. After verifying the violation of the normality assumption, both at the factorial level and for each indicator, using the Kolmogorov–Smirnov test (K–S) ($p < .001$), the Wilcoxon signed-rank test was applied. Additionally, the effect size was estimated using the rank-biserial correlation coefficient (*rrb*), which ranges from –1 to +1; values close to 1 indicate a complete shift in ranks, that is, a maximum effect. In the social sciences, an effect size of .50 is considered large.

Finally, to determine the probability of a correct rejection of the null hypothesis if it is in fact false in the population, and thus to assess the reliability of the p-values obtained, the statistical power was calculated. This step was intended to confirm whether the statistical decisions to reject the null hypothesis were sufficiently supported by evidence.

4. Results

In line with the directional hypothesis (Measurement 2 > Measurement 1), all six Wilcoxon signed-rank tests for related samples yielded high Z statistics ($–36 \leq Z \leq –40$; $p < .001$), indicating a clear shift in ranks in favor of the post-test (Table 8).

The effect size was ranged between .96 and 1. Given that $rrb = 1$ indicates a complete absence of overlap between the distributions, the observed improvements in teachers' perceptions are particularly significant. Moreover, the probability of Type II error decreased to the order of 10-255, placing the empirical power (1–β) at approximately 100% (> .80), thus implying a virtually null probability of failing to detect a real effect. Consequently, there is strong evidence that the training program produced improvements of considerable magnitude across all indicators and in the overall factor score, marking a shift from disagreement (no responses remained in the initial disagreement positions) ($M_{e\ pre} \approx 2.2$) to widespread agreement with the item statements ($M_{e\ post} = 4$, R = [1, 4]).

Each of the five instructional modules, delivered during the five-week program, provided immersed participants with hands-on experiences that directly corresponded with the assessed items and the overall factor, resulting in near-maximum attitudinal gains (Table 9). Specifically,

the instructional treatment of storytelling combined with engineering operational processes, and participation in creative problem-solving cycles, resulted in a complete shift from initial disagreement to full agreement regarding the relevance of this strategy, as reflected in a perfect effect size (*rrb* = 1). The same pattern was observed in the module on literary and scientific education: the use of informational picturebooks as drivers of scientific inquiry completely shifted the response ranks, demonstrating that literary reading can serve as an effective gateway to scientific thinking. In trun, the design of digital mathematical comics, significantly increased both the motivation and the perceived accessibility of mathematics, resulting in almost no overlap between the pre- and post-test distributions (*rrb* ≈ .99). Meanwhile, narrative robotics, the only negatively worded item, transformed initial aesthetic concerns into near-unanimous acceptance (*rrb* ≈ .96), indicating that situated practice can neutralize preconceived notions about the alleged opposition between technology and literature.

Finally, working with picturebooks within the framework of Universal Design for Learning and an equity-oriented STEM literacy model reinforced the belief that STEAM-based proposals are capable of fostering inclusive and collaborative learning, once again producing a perfect effect (*rrb* = 1). The convergence of these findings confirms that the teacher training intervention uniformly shifted participants' attitudes and supports the feasibility of integrating literary narratives into STEAM projects aimed at enhancing creativity, scientific inquiry, mathematical reasoning, and educational inclusion.

Table 8. Descriptive statistics and pre–post test results

Instruction module	Measurement 1	Measurement 2	Z	*p*	*rrb*	1-β
	Me (R)	*Me (R)*				
I1 (storytelling and engineering)	2 (3)	4 (1)	-40.002	< .001	1	.99
I2 (literature and science)	2 (3)	4 (3)	-40.030	< .001	1	.99
I3 (mathematical comics)	2 (1)	4 (4)	-38.724	< .001	.99	.99
I4 (narrative robotics)*	3 (4)	4 (1)	-36.077	< .001	.96	.99
I5 (STEAM and picturebooks)	2 (2)	4 (3)	-39.823	< .001	1	.99
Factor	2.20 (2.60)	4 (2.40)	-40.030	< .001	1	.99

Note. *rrb* = rank-biserial correlation.
* Reversed item; recoded prior to analysis.

Table 9. Evidence of attitudinal change derived from teachers' training experience

Module	Teachers' training experience	Evidence of attitudinal change
Storytelling and engineering	Cumulative storytelling followed by a "Ask–Imagine–Plan–Create–Improve" challenge using simple construction materials.	*rrb* = 1; shift from skepticism to conviction regarding the creative and reading potential of this approach.
Literature and science	Dialogic reading of informational picturebooks, used as a basis for formulating research questions and short experiments.	*rrb* = 1; clear reinforcement of critical observation of phenomena and curricular value of literary informational texts.
Mathematical comics	Design of interactive digital comics following the TSCT sequence (Theme–Storyline–Character–Text), integrating narrative and logical reasoning.	*rrb* ≈ .99; significant increase in motivation and perceived accessibility of mathematics.
Narrative robotics	Tell–Draw–Code prototyping of animated stories with robots, followed by a debate on aesthetics vs. functionality.	*rrb* ≈ .96; disappearance of initial concern about technology dominating the literary space.
STEAM and picturebooks	Development of projects based on Universal Design for Learning (UDL) and the Equity-Oriented STEM Literacy framework using picturebooks.	*rrb* = 1; strengthened perception of STEAM proposals' inclusive and collaborative learning potential.

5. Discusion and conclusion

The results obtained are consistent with those of the longitudinal study by Hughes et al. (2022), whose results show improvements in science achievement (particularly among emergent bilingual students) even in contexts with moderate instructional fidelity, following the implementation of teaching sequences based first on STEAM activities and subsequently on STEM approaches. The reduction of linguistic and affective barriers, as well as the early integration of artistic components as an equity-driven strategy to foster participation, significantly reinforce the inclusive nature of the STEAM approach.

Similarly, the findings of the present study align with those reported by Penner (2019), in which the design, implementation, and evaluation of social studies teaching units through a STEAM lens resulted in greater student engagement and increased sociocultural revelance of integrated content instruction. Penner's conclusions, like those drawn in this study, confirm that the sustainability of such integration depends on both curriculum design and ongoing instructional support. In this regard, the STEAM approach indeed requires preserving the identity of the arts, formalizing transdisciplinary pedagogies, and strengthening teacher training and assessment.

The convergence of these findings with those presented by Andrée et al. (2024) lies in the central role of the aesthetic–emotional dimension. These authors describe cycles of frustration and satisfaction in the programming of robots by adolescents and highlight the role of teacher in transforming frustration into "productive struggle." Our data complement this view: when teachers themselves engage in such aesthetic experiences, their willingness to provide emotional support to students reaches the theoretical maximum ($rrb = 1$). This suggests that effective support stems from deeply rooted prior sensitization.

Cardullo and Burton (2025), for their part, show that picturebooks assessed with the Equity-Oriented STEM Literacy Framework have low levels of identity representation and empathy. Although experiential training provides teachers with the conviction and strategies needed to implement STEAM practices that are sensitive to emotional aesthetics, the contrast with their review reveals structural deficiencies in the resources available. However, the present study indicates that the participating teachers are able to bridge this gap by selecting (or even creating) materials that reflect cultural diversity and foster the empathy that those authors found lacking.

The mathematical comic module, based on the TSCT framework proposed by Chu and Toh (2020), resulted in an almost complete shift in pre–post ranks ($rrb \approx .99$). The proximity between text and image, the humor, and the sympathetic characters helped reduce cognitive load and math anxiety, while the process of the comic creation process enabled teachers to anticipate and correct misconceptions, thus neutralizing the main concern noted by the authors regarding the need for strong pedagogical scaffolding.

Our data reveal a complete dispositional shift among teachers ($rrb \approx 1$), positioning them as active protagonists in the narratives and thus creating the necessary condition for the digital storytelling strategy to subsequently generate the expected cognitive benefits in students. This finding complements the observations of Pagano et al. (2024), who demonstrated that digital storytelling in action enhances children's engineering discourse and improves memory retention, despite minimal changes in parental technical talk. Similarly, our intervention, by allowing teachers to experience first-hand the four stages of the Universal Design for Learning (UDL) framework proposed by Wade et al. (2023), eliminated all pre–post distribution overlap and provided the necessary magnitude of impact. This demonstrates that lived experience ensures both the fidelity and sustainability of inclusive STEAM practices.

The body of evidence supports the thesis that teacher training grounded in aesthetic and narrative experiences, along with Universal Design for Learning (UDL) principles, is sufficient to change attitudes and ensure genuinely inclusive STEAM practices. As Pagano et al. (2024) document in detail, improvements in children's learning depend on the presence of previously sensitized teachers, while the promise of equity demands an expansion of the repertoire of teaching materials, as Cardullo and Burton (2025) point out.

It can therefore be affirmed that the viability of the STEAM approach lies in its capacity to balance the identity of the arts (including literature), provide pedagogical foundations for transdisciplinarity, and strive for disciplinary–didactic equity. The authentic integration of the arts not only enriches science and technology learning but also promotes educational justice and civic capacity to face the complex challenges of the present. The findings of this study thus support the effectiveness of teacher training programs in which the integrated didactics of literature can facilitate the articulation of inclusive, creative, and evidence-based practices in the early years of schooling.

These results contribute to a growing theoretical body that justifies the adoption of STEAM frameworks capable of transcending the mere juxtaposition of disciplines. There is growing consensus that the authentic integration of disciplines (particularly those related to the arts and literature) is beneficial for scientific-technological teaching and learning processes, for supporting students' holistic development, and for promoting innovation in response to emerging social and economic demands. Within this framework, the arts, and more specifically, the narratives associated with literary education, stand out as a foundational structural element for fostering creativity, critical thinking, and emotional engagement. Nevertheless, additional empirical evidence is required to validate the proposed conceptual models and to support the design of educational policies that ensure teacher preparation capable of sustaining transdisciplinary, integrated teaching approaches in the classroom.

6. Limitation and future research direction

Although the choice of a one-group pretest–posttest design was guided by pedagogical feasibility, the rigorous application of methodological controls boosted the rigor and inferential capacity of the study without compromising its relevance within an authentic professional setting. Despite these controls, the potential threats to internal validity must be considered in light of the use of non-probability sampling, including both purposive and convenience-based sampling. This approach introduces self-selection bias, limits generalizability to other educational levels or contexts, and increases vulnerability to social desirability bias. External validity is also limited, given that the intervention was brief and entirely online, with no longitudinal follow-up or comparison with face-to-face or hybrid modalities. Furthermore, although the TALES-STEAM scale demonstrated a robust factorial structure, its measurement invariance across groups was not assessed. This absence highlights the need to replicate the construct across countries, educational stages, and/or teacher genders before applying it in comparative relational studies based on participants' sociodemographic characteristics.

In this regard, five priority directions for future research are proposed. The causal interpretation of the results is constrained by the single-group pretest–posttest design used: without a control group, it is not possible to conclusively attribute the observed changes to the intervention, as classical threats to internal validity remain (e.g., history, maturation, instrumentation, or testing effects). Consequently, future studies should prioritize experimental or quasi-experimental designs with an equivalent control group and, where feasible, random assignment, in order to isolate the net effect of the program and strengthen causal inference.

Second, multivariate longitudinal tracking (repeated measurements over time/panel designs) should examine the stability, sustainability, and trajectory (fidelity, dosage, reach) of teachers' attitudes and, more importantly, changes in classroom practices and student outcomes (learning, creativity, and inclusion) to determine the long-term persistence and actual transfer of the intervention. Indeed, such follow-up should be complemented with implementation indicators (fidelity, dosage, and reach), as well as with behavioral and observational evidence on how teachers transfer the training into classroom practice (planning, didactic strategies, authentic assessments), together with student outcomes. This would involve triangulating multiple sources, including teachers, external observations, and classroom products. The combination of a control group and longitudinal evaluation would thus enhance both the internal and external validity of the study and provide stronger evidence on the effective transfer of training to teaching performance (Hernández-Sampieri & Mendoza, 2018).

Third, the TALES-STEAM scale should be expanded and internationally validated through factorial invariance studies (with CFI $\geq$ .95) and culturally adapted to other languages, with the aim of solidifying its comparative utility. Fourth, practice-centered mixed-methods research should be employed, triangulating questionnaires, classroom observations, teacher portfolios, and focus groups to explain how the convergence of art (literature) and science is navigated in authentic educational settings. Finally, a fifth direction involves comparing the relative effectiveness of face-to-face, hybrid, and fully online modalities, controlling for the degree of interaction and pedagogical scaffolding. This analysis would help determine which training conditions most effectively maximize STEAM integration.

Authors' contributions

Carlos Pérez-González: Conceptualization, Methodology, Resources, Data Curation, Visualization, Supervision, Writing-Review & Editing; Delfín Ortega-Sánchez: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing- Original Draft, Writing-Review & Editing, Project administration, Funding acquisition.

Conflict of interest

The authors have not reported any potential conflicts of interest in relation to this article.

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Ethical approval statement

The research was conducted in accordance with the October 2024 revision of the World Medical Association's Declaration of Helsinki, the EU General Data Protection Regulation (Regulation [EU] 2016/679), and the Spanish Organic Law 3/2018 on the Protection of Personal Data and Guarantee of Digital Rights. It ensured full respect for the dignity, privacy, and integrity of participants, as well as

the technical and legal security of their data. The protocol specified the exclusive participation of teachers over the age of 18 working in Early Childhood and Primary schools. Participation involved voluntarily completing an online questionnaire and did not entail any clinical procedures or the collection of biological samples. All databases were pseudonymized prior to analysis and securely stored on restricted institutional servers.

Informed consent statement

All participants, adult professionals, gave digital informed consent after reviewing a document detailing the study's aims, methodology, risks, and data use. Consent was voluntary, pseudonymized, and documented electronically. No incentives were offered, identities remained protected, and results may be published anonymously. No vulnerable populations were involved, so no additional authorizations were required.

Data availability statement

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and confidentiality agreements with the participants. However, they may be made available by the corresponding author upon reasonable request, provided that the purpose is justified and appropriate measures are taken to safeguard the privacy and anonymity of the individuals involved.

Declaration of generative artificial intelligence tools

The authors hereby declare that, throughout the conduct of this research, no generative artificial intelligence tools were employed at any stage of the study, including its design, data collection, data analysis, or the drafting of the manuscript.

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