Part 12 / Strand 12

Equity, Diversity And Identity In Science Education

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Socio-political, sociocultural, multicultural, multilingual, multi-modal, intersectional, racial/ethnic, equity, critical, feminist, and gender studies, as well as special needs in science education. Proposals that include theories, methods, and practices related to ways-of-being and ways-of-knowing in science education and through an array of onto-epistemological perspectives, ideas, theoretical, and methodological approaches build on and perhaps exceed identity in inter-, multi- and transdisciplinary ways. Inviting critical examination of identities as multiple and situated in various systems of power and privilege to afford complex understandings of educational opportunities related to access and achievement.

Sub-themes:

1) Addressing Gender and Racial Equity in Science Education
2) Multicultural and Multilingual Approaches in Science Teaching
3) Inclusive Practices for Students with Special Needs in Science
4) Intersectionality and Identity in Science Education
5) Critical Pedagogy and Social Justice in Science Education

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Strand 12: Equity, Diversity And Identity In Science Education

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Equity, diversity and identity are central to science education, shaping who is recognized as a legitimate participant in science, whose knowledge is valued, and who can imagine scientific futures. Research on science identity, recognition and Science Capital shows that participation is mediated not only by attainment or interest, but also by social relations, institutional cultures and wider systemic inequalities (Archer et al., 2015; Carlone & Johnson, 2007; Hughes et al., 2021; Danielsson et al., 2023; Dou & Cian, 2022). At the same time, expanding work on science identities has highlighted the importance of recognizing the complex, dynamic and socially situated nature of identity formation across contexts and over time (MacLeod & Avraamidou, 2025), foregrounding how identities are continuously negotiated within educational systems and broader sociocultural structures. An identity-focused perspective therefore invites science educators in Europe and across the world to examine how curricula, pedagogies, assessments and learning environments can (re)produce exclusion, but also how they can open more just and meaningful forms of participation (Avraamidou, 2020).

The ESERA 2025 proceedings in Strand 12 (Equity, Diversity and Identity in Science Education) explore contemporary issues in science and STEM education across diverse contexts, disciplines, and educational levels. Covering Indigenous knowledge systems, STEM, physics, science education research, and teacher education, the works address learners from middle elementary to higher education, as well as pre-service teachers, in-service teachers, and teacher educators. Together, the proceedings highlight science education as a culturally and socially embedded practice and emphasize the need for inclusive, context sensitive approaches that connect learners' experiences with scientific knowledge. The works reflect a broad international scope across multiple continents, including authors affiliated with institutions in Europe with Austria (1), Denmark (1), Germany (7), Greece (1), the Netherlands (1), Spain (2), Switzerland (1), and the United Kingdom (1), Asia with Israel (1), Singapore (1), and Taiwan (1), North America with the United States (1), and South America with Brazil (4).

The contributions in this strand address science and STEM education through three closely connected perspectives: 1) STEM and science identity formation, 2) equity and intersectionality, and 3) sociocultural influences. Across the papers, identity emerges as a dynamic process shaped by subject experiences, gender, Science Capital, and broader epistemological positions, while persistent inequities highlight how access, participation, and belonging are unevenly distributed. Learning is shown to be deeply embedded in sociocultural contexts, including family practices, language use, and Indigenous knowledge systems, which often remain underrecognized in formal science and STEM education. These perspectives converge in a shared concern with transforming educational practices, as studies on inquiry and teaching highlight the need to move beyond deficit views and address systemic and structural barriers. Together, the three themes point to a common pattern: participation in science is co-constructed through the interplay of identity, culture, and educational structures, calling for more inclusive, context-sensitive approaches to science education. However, they also display the diversification of perspectives on Equity, Diversity and Identity in Science Education.

STEM/Science Identity Formation and Trajectories

These contributions collectively frame science and STEM identities as contextually situated, evolving and unevenly supported across educational settings. Rather than treating participation as a matter of stable preference or ability, they show how learners negotiate subject-specific identifications, broader STEM self-concepts, environmental orientations, digital practices, and ideas about science in relation to school biography, gender, Science Capital and cultural knowledge systems (Bochert et al., 574; Manassero-Mas & Vázquez-Alonso, 1601; Birner et al., 716; Lisa-Marie Christ et al., 659; Bub et al., 830). Across the submissions, identity formation appears as a dynamic process shaped by institutional structures and epistemic norms: students may move towards or away from physics, chemistry or STEM more broadly as they encounter particular classroom experiences, disciplinary images and recognition opportunities. Several papers also point to the need for more inclusive and longitudinal approaches, both methodologically and pedagogically, including validated identity measures, narrative and interview-based work, and decolonial models that challenge the marginalization of Indigenous knowledge in science education (Raupp & Vanuchi, 901).

Equity, Diversity, Inclusion, and Intersectionality

These contributions collectively examine how inequality and inclusion in science education are produced through intersecting social, institutional, spatial and epistemic conditions. Rather than treating disadvantage as a single-axis problem, they show how race, gender, class, geography, disability, sexuality, gender identity and Science Capital shape learners' participation, recognition and sense of belonging in STEM. Submissions highlight the need for more intersectional and context-sensitive analyses, including work on how inequality is represented in science education research, how teacher educators and pre-service teachers understand gender equality, and how students' STEM motivations differ across social and geographic contexts (Pontes Silva & Franco dos Santos, 84; García-Ruiz et al., 40; Duek et al., 512; Silva, Teixeira, & Santos, 474).

Across the studies, inclusion is framed not only as a matter of access, but as a question of embodied participation, institutional responsiveness and everyday classroom practice. Contributions on physical ability, open inquiry, transgender students' experiences, and trans trajectories in chemical engineering show that barriers often arise from taken-for-granted norms about bodies, methods, identities and belonging, rather than from learners' deficits (Müller et al., 551; Abels et al., 1749; Cordeiro Lopes Fonte & Mendes da Silva, 239; Marosi et al., 784). Others caution that ostensibly inclusive spaces, such as out-of-school STEM laboratories, may reproduce gendered hierarchies through implicit pedagogical assumptions and differential forms of address (Gross & Abels, 194). Taken together, these submissions suggest that meaningful inclusion requires coordinated work across curriculum, pedagogy, teacher education, institutional culture and policy, particularly because teachers may support inclusive principles while still feeling underprepared to enact them in practice (Pannullo et al., 1751).

Sociocultural and Community Influences on STEM Learning

These contributions foreground sociocultural, linguistic and familial resources as central to science learning, challenging narrow views of what counts as legitimate scientific knowledge and participation. Across multicultural, multilingual and family contexts, they show that learners' sense-making is shaped by culturally embedded classification practices, translanguaging and everyday experiences that often sit outside formal school science. Indigenous Tao learners' biological classifications, for example, combine increasing taxonomic precision with ecological and cultural knowledge, challenging deficit views of Indigenous learners (Ge et al., 617).

Similarly, translanguaging among English learners appears as a collaborative resource for scientific reasoning and meaning making rather than a barrier to instruction (Barron et al., 788). Family activities also generate rich forms of Science Capital, but these sensory and meaningful experiences are not always recognized by schools (Nielsen et al., 1428). Together, the submissions argue for science education that connects disciplinary learning with students' cultural, linguistic and everyday lives.

The contributions in this strand offer rich and multifaceted insights into science identity, equity, diversity, and in particular the sociocultural dimensions of learning. Further, they point directly and indirectly to areas that remain less developed within current research and/or its communication in the proceedings of ESERA Strand 12. Much of the work continues to focus on how learners navigate participation within existing structures of science education, while fewer contributions explicitly interrogate how those structures themselves define the boundaries of legitimate knowledge, identity, and participation. Questions of epistemic justice, whose knowledge systems shape science education, how scientific norms are historically and culturally constituted, and how dominant epistemologies might be re-imagined, remain comparatively invisible. While intersectional and sociocultural perspectives are increasingly present, there are potentials and openings to more fully engage with science education as part of broader socio-political and historical formations, including colonial and global knowledge hierarchies that continue to shape what counts as science. Moving forward, we suggest the value of expanding science identity research beyond questions of access and recognition towards inquiries that also consider transformation and possible futures: not only how diverse learners come to see themselves as scientists, but how science education itself might be reconfigured when multiple ways of knowing, being, and valuing are taken as constitutive rather than supplementary, transgressing narrow and often deficit-oriented and neoliberal ideas of equity and diversity towards collaborative, collective, and community-oriented social and environmental justice.

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Design And Validation Of An Instrument For Analysing Gender Perspectives In STEM Teaching Practices: The WOUMAP Questionnaire

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In the changing world in which we find ourselves, there is a need to form a citizenry with a background in STEM (Science, Technology, Engineering, and Mathematics) related areas, who develop skills and competencies needed to make reasoned, well-founded decisions about problems that have not yet arisen. However, despite the emphasis on promoting curricular integrated STEM education, a gender gap persists, with women underrepresented in STEM fields. This imbalance, which has significant implications for equity and progress, limits innovation and social development, perpetuates labour inequality, and generates biased technological solutions by excluding diverse perspectives, resulting in less female representation that hinders equity and progress. It begins to manifest itself in Early Childhood Education, being therefore essential to prepare teachers at different educational levels in this regard, by understanding their initial perceptions of teaching science and technology from a gender perspective and delving into the stereotypes they hold based on their previous experiences. Consequently, this study describes the validation by experts of a structured questionnaire designed to examine teacher trainers' and pre-service teachers' perceptions concerning promoting gender equality in STEM areas. The validation was carried out through a panel of experts in science education, guaranteeing the relevance and reliability of the instrument, composed of 15 items distributed in four main categories related to perception and awareness of gender equality in STEM, practices and initiatives for the promotion of equity, identification and impact of female references in STEM and experiences and improvement proposals. Implementing the validated questionnaire will contribute to understanding current practices in STEM education, providing a comprehensive view of how teachers address the gender perspective in their teaching, their knowledge of leading women in the field, and the strategies they consider to promote gender equality.

Keywords: Pre-service teachers, Gender Awareness, STEM education

Theoretical Framework

International organisations have increasingly prioritised educational equity within STEM (Science, Technology, Engineering and Mathematics) disciplines, with gender-responsive pedagogy emerging as a critical policy concern (European Commission, 2020; OECD, 2022), aiming to deconstruct gender-normative assumptions in developing inclusive STEM education systems. However, there is a persistent STEM gender-bias strongly influenced by internalised gender stereotypes, social expectations, and a lack of scientific references (Hughes et al., 2020), that culminates in an imbalance in shaping professional trajectories, with overrepresentation of women in health-related and well-being areas, as opposed to underrepresentation in the STEM areas (World Economic Forum, 2023).

Research has continuously demonstrated that such disparity originates from the early stages of compulsory education (Brussino and McBrient, 2022), with female students developing a gender-based self-perception and competency-related doubts that affect their motivation, expectations,

intellectual aptitudes, and ultimately, their education and professional career choices towards strong social orientation careers (Cimpian et al., 2020; Evagorou et al., 2024).

Within this scenario, schools and educational actors emerged as key agents in the socialisation process of youth, developing an active role in disrupting gender stereotypes reproduction, as defined within the objectives of the STEM Alliance for Female Talent (Grañeras et al., 2022), which proposes goals such as making women visible in scientific-technological fields. This emphasis on the school's role should make educators, researchers, and policymakers feel the importance of their work in challenging gender stereotypes (Brussino and McBrient, 2022).

Multiple publications demonstrate that exposure to inspiring role models is crucial for fostering student commitment to STEM disciplines, an effect that is especially pronounced among women exposed to role models of the same gender. However, this representation is far from being adequately gender inclusive (González-Pérez et al. 2020). The need for more gender-inclusive role models is urgent, and it is crucial that pre-service teachers develop an adequate understanding of science and technology to challenge the stereotypes that persist in curricula and within the teaching community.

Aims And Research Questions

Considering the relevance of the exposure to women role models in STEM fields throughout the different education stages, we understand that it is necessary to research and analyse the perception that pre-service teachers and their teacher trainers of the degrees of Early Childhood Education, Primary Education and the scientific-technical specialities of the Master in Education have about the visibility of women in STEM areas. We hypothesise that the teacher's reflection on the gender gap in STEM areas will increase knowledge across all educational strata, fostering a concept of inclusive science, and an appreciation of female talent from an early age. Consequently, we aimed to design a questionnaire to address the following research question:

- How do we design and validate an instrument that evaluates teacher trainers' and pre-service teachers' perceptions and practices about promoting gender equality in STEM disciplines?

Methodology

Questionnaire Design

We designed the WOUMAP questionnaire following a thorough review of the relevant literature and discussions with the co-authors of this research. The first draft consisted of 15 items, which combined open-ended and 5-point Likert-type scale questions. The items were organised into four main categories: perception and awareness of gender equality in STEM (items I1, I2, I4 and I9), practices and initiatives for the promotion of equity (items I5-I9), identification and impact of female references in STEM (items I10-I15) and experiences and improvement proposals (items I3 and I11). Given our target participants, we elaborated two equivalent versions of the questionnaire, one for teacher trainers and another for pre-service teachers.

Validation Process

We proceeded with instrument validation using a digital form in *Google Forms*. Since participation in the validation process required the identification of experts, thereby implying the processing of personal data, we followed the guidelines on the Protection of Personal Data and Guarantee of Digital Rights and obtained with the approval of the Ethics Committee of the University of Málaga (reference no. 96-2023-H).

The form briefly introduced the objectives and context of the research, establishing the guidelines for completing the review. The first block included some demographic questions to characterise the expert. Next, the second block presented the 15 items, along with an explanation of the associated research objective. For review, we asked the panel to indicate the degree of adequacy of each item to the corresponding objective on a four-point Likert-type scale (1: very low, 2: low, 3: high and 4: very high), as well as the justification of the item's degree of adequacy chosen and possible comments and suggestions for improvement to the item.

Data Analysis

We carried out the analysis in accordance with the nature of the data collected with the validation questionnaire. Hence, we used the R-based software JAMOVI (version 2.3.21) to analyse the quantitative data, examining the distribution of scores for each question and providing the frequency percentages, the mean (*M*) and standard deviation (*SD*) as interpretive values. We also calculated the Content Validity Index (CVI) for each item (I-CVI) and for the scale as a whole (S-CVI), as well as the exact binomial test (*p*), which represents the probability of obtaining the observed level of agreement or higher by chance. The I-CVI was calculated as the number of experts who gave a rating with a high degree of agreement (values of 3 and 4 on the 4-point Likert scale) divided by the total number of panel members, considering acceptable values equal or greater than 0.80 and as statistically significant results, coefficient p values less than 0.05. The S-CVI was calculated as the average, calculated as the sum of all the I-CVI of the scale divided by the number of items (S-CVI/Ave), with a threshold of 0.90 or higher being considered excellent.

At the same time, we assessed the consistency and reliability of the ratings given by each evaluator on the panel by calculating the Fleiss' *kappa* statistic, which analyses the agreement between the evaluations of the different people on the panel and, unlike the CVI, considers the agreement that is produced by chance (Fleiss et al., 2003). As in the calculation of the CVI, given that the interest was in distinguishing between the degree of general agreement and disagreement, the analysis was simplified by dichotomising the data, treating values of 3 and 4 as "agreement" and values of 1 and 2 as "disagreement".

On the other hand, the comments recorded as qualitative data were pooled for evaluation of modifications or deletions to the valued item.

Findings

The S-CVI/Ave for the entire questionnaire was 0.94 in the teacher trainers' version. The I-CVI scores ranged from 0.78 to 1.00 (Table 1). Except for I2, the I-CVI scores ranged between 0.89 and 1.00 (Table 1), and 8 of the 15 items reached the maximum level, with statistically significant *p*-values in all cases ($p < 0.05$). Item I2, which had the lowest threshold (0.78), was carefully reviewed, modified, or eliminated in accordance with the panel's comments. In addition, the Fleiss' *kappa* statistic was calculated, obtaining a value of $K = 0.89$ (standard error = 0.04, 95% CI = 0.82 - 0.96, $p < 0.01$), which represents a degree of substantial agreement of the instrument (values between 0.81 and 1.00) (Fleiss et al., 2003). We observed similar results for the pre-service teachers' version, with an S-CVI/Ave of 0.95 and the same I-CVI scores distribution. Only item I3 presented an unacceptable value (0.78), which was also reviewed. Fleiss' *kappa* statistic value was $K = 0.91$ (standard error = 0.08, 95% CI = 0.75 – 1.00, $p < 0.01$).

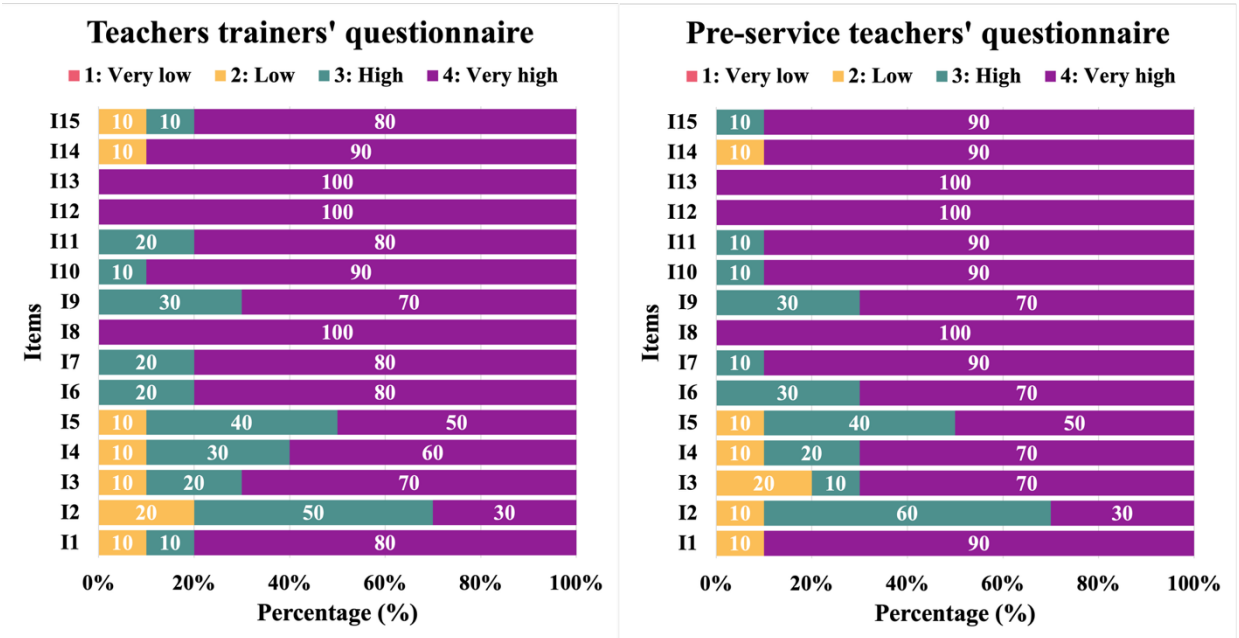
Figure 1 shows the results of the percentage of frequency obtained for items I1-I15 on teacher trainers' and pre-service teachers' versions. We observed a favourable assessment in all cases, with the sum of "high" and "very high" percentages exceeding 80% and mean values above 3.1 across all items. As indicated, I2 and I3 in the teachers' and students' questionnaires, respectively, which had the lowest mean and I-CVI values, were revised based on the qualitative assessment.

Table 1. Code, Content Validity Index (I-CVI), Mean (M), and Standard Deviation (SD) for each Item.

	Teacher trainers' version				Pre-service teachers' version			
Item	**I-VCI**	***p***	***M***	***SD***	**I-VCI**	***p***	***M***	***SD***
I1	0.89	0.01	3.70	0.67	0.89	0.02	3.80	0.63
I2	0.78	0.06	3.10	0.74	0.89	0.02	3.20	0.63
I3	0.89	0.01	3.60	0.70	0.78	0.04	3.50	0.85
I4	0.89	0.01	3.50	0.71	0.89	0.02	3.60	0.70
I5	0.89	0.01	3.40	0.70	0.89	0.02	3.40	0.70
I6	1.00	0.00	3.80	0.42	1.00	0.00	3.70	0.48
I7	1.00	0.00	3.80	0.42	1.00	0.00	3.90	0.32
I8	1.00	0.00	4.00	0.00	1.00	0.00	4.00	0.00
I9	1.00	0.00	3.70	0.48	1.00	0.00	3.70	0.48
I10	1.00	0.00	3.90	0.32	1.00	0.00	3.90	0.32
I11	1.00	0.00	3.80	0.42	1.00	0.00	3.90	0.32
I12	1.00	0.00	4.00	0.00	1.00	0.00	4.00	0.00
I13	1.00	0.00	4.00	0.00	1.00	0.00	4.00	0.00
I14	0.89	0.01	3.80	0.63	0.89	0.02	3.80	0.63
I15	0.89	0.01	3.70	0.67	1.00	0.00	3.90	0.32

I-CVI: Item content validity index; *p:* exact binomial test

Figure 1. Results of the Quantitative Validation on the Items I1-I15 for Teacher Trainers' and Pre-service Teachers' Questionnaire.



Thus, the final validated questionnaire consisted of 15 items, including questions on a 5-point Likert scale and open-ended responses, with summarised and general statements for the teacher trainers' and pre-service teachers' versions shown in Figure 2.

Conclusions And Implications

This work presents an *ad hoc* research instrument designed for teacher trainers and pre-service teachers in Early Childhood Education, Primary Education, and the scientific-technical areas of Secondary Education. The WOUMAP questionnaire would allow us to investigate these teachers' perceptions about the visibility of women in STEM areas and the gender gap they identify in their teaching practice.

Figure 2. Simplified Statements of the WOUMAP Questionnaire Items.

PERCEPTION AND AWARENESS OF GENDER EQUALITY IN STEM	EXPERIENCES AND IMPROVEMENT PROPOSALS
I1. To what extent do you think there are stereotypes and barriers that can hinder the interest of students in STEM careers (related to science, technology, engineering and mathematics? What do you consider those stereotypes and barriers to be? **I2.** To what degree do you think dedication to a career in STEM areas is compatible with personal balance and/or familiar balance? **I4.** To what degree do you consider that the gender perspective is adequately represented in the training of STEM areas? **I9.** To what extent do you think women are adequately represented in STEM fields?	**I3.** Could you describe if you have experienced support, empowerment or an increase in confidence during your development in teaching-learning in STEM areas? If so, what has this support been like, from whom, and how do you think it can or has had an impact on your professional career? **I11.** What actions or changes would you propose to increase the presence and visibility of leading women in STEM education?
PRACTICES AND INITIATIVE FOR THE PROMOTION OF EQUITY	**FEMALE REFERENCES IN STEM: IDENTIFICATION AND IMPACT**
I5. In the subjects of the degree or master's degree that you are teaching/ studying, to what degree is a gender perspective incorporated or is gender equality explicitly promoted in the teaching of STEM subjects? **I6.** In the subjects of the degree or master's degree that you teach/study what type of activities are carried out to promote the visibility of women in STEM disciplines (Activities aimed at emphasizing the achievements of women in my area/Mentoring programs/Inclusive curriculum/Others) **I7.** What type of initiatives or programs aimed at promoting the visibility of women in STEM disciplines do you know of? **I8.** Indicate how frequently the following actions are shown or discussed in the subjects of the degree or master's degree that you teach/study: • Science/Engineering as a human product built jointly by men and women • Poor representation of women in science/engineering • Current and relevant women close to science/engineering • Contributions from women relevant to science/engineering • Social and personal context of women relevant to science/engineering • Scientists/engineers invited to give a talk on the subject • Reflection that it is not necessary to have extraordinary abilities to dedicate yourself to science/engineering • Physical and geographic diversity of people who do science/engineering	**I10.** Could you mention three qualities or characteristics that you consider essential for a female scientist and/or engineer to become a reference or role model in these disciplines? **I12.** Make a list of three women scientists or engineers you know, identifying any particular discovery or contribution to their field. **I13.** How did you find out about these three women? **I14.** To what extent has knowledge about any of the women you have referenced influenced your interest in STEM areas? **I15.** Describe how that influence has been on your professional career.

After a rigorous validation process by a panel of experts in Science Education, statistics were calculated to assess the validity of the content (CVI) and the agreement among the panel's evaluations (Fleiss' *kappa*), yielding satisfactory results in both cases. These results, supported by the analysis of the qualitative responses provided by the evaluators concerning each item analysed, have generated a final questionnaire comprised of 15 items of combined typology (Likert scale and open response), offering an efficient tool to deepen the vision and commitment that teacher trainers and pre-service teachers have with respect to the practice of inclusive teaching, and thus being able to identify successful strategies for addressing the gender perspective at all levels of education.

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The Debate on the Race-Gender-Class Triad at The Main Science Education Research Event in Brazil, from 1997 to 2023

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The history of science education in Brazil is permeated by domination and exploitation based on class, race, and gender. Thus, aiming to present an analysis of how the race-gender-class triad has been debated in science education in Brazil, we conducted a text search in the proceedings of the main science education research event in the country, the National Science Education Meeting (ENPEC), and analysed the theoretical frameworks underlying the articulation between these three categories in the works found. The debate involving race-gender-class in this field of research still treats the elements of this triad separately, as if they were independent of one another and not as part of the Brazilian socio-historical structure. This result reveals a deficiency in the way the Brazilian context of science education is treated in academia, an issue that must be overcome so that we can develop a fully emancipatory science education.

Keywords: race, gender, social justice

Introduction

Comprehending the historical development of science education in Brazil must involve understanding racism, class struggle and gender issues in the country, which permeate the entire history of Latin America. That is because it was the unit colonialism-capitalism-racism that structured all the development of Brazilian society (Santos, 2024), including science education. As Delizoicov (2004) points out, it is necessary to do the "historical recovery of science teaching" (p. 148) in Brazil, in a broad and multidisciplinary way.

Before entering science education history, it is important to remember the racist history of science, which used its social prestige to justify the inferiorisation and exploitation of black people, through craniology and phrenology, for example (Santos, 2024). Science, as a social product, has also been utilized to discriminate against women and, in some areas, still presents sexist views of the "feminine", associating it with hysteria, weakness and inability to use logic and reason, as it was in the beginning of hysteria history (Schmitz, 2021).

According to Santos and Galletti (2023), science education in Brazil began in the 16th century with Jesuit education developed from a scholastic perspective with the purpose of catechizing, indoctrinating and acculturating the native peoples of the "New World". In the 19th century, intending to educate the bourgeoisie children of the Brazilian landowning oligarchy, scientific education gained new nuances and a place of importance (Santos & Galletti, 2023). However, it was only from 1950 onwards, following a global trend, that scientific education became institutionalized and was officially included in the country's educational legislation, albeit of a professionalizing nature, seeking to respond to historical demands for industrialization and the enhancement of study and research centers (Santos & Galletti, 2023). Since the 1970s, during the military dictatorship in Brazil, questions about the neutrality of science, technological determinism, and scientific production risks arose and discussions have included not only what or how to teach, but also the subjects (who) and the purposes (for what). In this sense, since the political reopening and the efforts of organized political movements, issues of class, race, and gender have occupied the research and practice agenda in science education.

Thus, this paper's objective is to present an analysis of how the race-gender-class triad has been debated in science education in Brazil. We intend to answer the following question: how has the debate on the race-gender-class triad been treated in the field of science education in Brazil? We hope the answer can help us identify how these three categories are present in this area of education, how they are articulated, and how they indicate paths for developing a fully emancipatory education.

Theoretical Frame Of Reference

Considering that Brazilian science education was developed based on a society that excludes people who do not fit the universal subject model, the white man (Souza, 2020), it is necessary to understand the categories of race, class and gender as a unit in science education research. Addressing this triad requires a complex analysis, which comprehends the implications of these three elements together and, in this case, within the specificities of the concrete Brazilian reality. According to Kosik (1976), concrete reality takes in consideration what is beyond appearance, beyond the superficial and the immediate, a reality dependent on its socio-historical processes.

The dissociation of the three categories is reflected in science teaching, from the incipient representation of black women as members of the scientific class in textbooks (Silvério & Verrangia, 2021; Skumra et al., 2020) to the apparent difficulty (or resistance) that science teachers might have in complying with current educational legislation, including the teaching of Afro-Brazilian and Indigenous history and culture (*Lei [Law] 10.639*, 2003; *Lei [Law] 11.645*, 2008) in their pedagogical activities.

In this sense, we turn to Lélia Gonzalez (1984), who, when dealing with race, class and gender in Brazil, uses the dialectic between consciousness and memory. For the author, making a social analysis based solely on the class struggle, excluding gender and race, is the same as insisting on forgetting these categories and it is the same as denying the subject condition to black women.

It is important to mention that, differently from other perspectives that seek to establish intersections based on identity or other individual and group experiences in a society marked by different types of violence, Gonzalez (2020) articulates race, gender and class based on the social division of labor. A prominent intellectual during an internationalist period of the Brazilian Black Movement and with socialist interlocutors (Domingues, 2024), Gonzalez understands that the classic division of labor, broadly discussed in Marxist tradition, reproduces itself in the Latin-American and Caribbean context as a racial and gendered division of labor. From the centrality of the work category, the education role for the hegemonic reproduction of the productive model is questioned. Thus, the question remains: what is the education for the Brazilian working class constrained by dependency (Bambirra, 2013), by racism (Moura, 1983) and by misogyny (González, 2020; Saffioti, 1978)? Or, as Santos (2024) states, “what is the scientific education for the Brazilian working class today, considering its contradictions and the historicity of its material conformation, in a way of: potentializing the working class resistant forms, organizations and intellectuality; guaranteeing the solid general basic education in attention to the historical and contextual particularities of black people; adjusting itself to the objective contexts of the margins, peripheries and neglected peoples” (p. 12).

The memory erasure that Gonzalez (1984) refers to, also called *memoricide*, demeans non-white people and denies the influence of gender on social inequalities (Costa, 2005), contributing to the reaffirmation of the white man as a universal subject (Souza, 2020). Another author, Nancy Fraser (1997), would categorize these social inequalities as cultural injustice, which must be corrected by recognition policies. A second category of inequalities created by Fraser (1997) is socioeconomic injustice, which must be corrected by redistribution policies. Fraser (1997) also

admits reconciling these two types of policies – recognition and distribution – might be challenging, considering that sometimes they seem to represent opposite interests: individuality and community, respectively. Thus, initiatives that involve these two kinds of policies such as i) the publication of *Lei [Law] 10.639* (2003), which includes in the official curriculum of the Brazilian Education Network the mandatory teaching of the theme "Afro-Brazilian History and Culture"; ii) government actions and the strengthening of public policies for women (Ministério das Mulheres [Ministry of Women], 2023), as a result of the articulations of feminist movements (Costa, 2005), present themselves as a reaction to this memoricide.

Hence, assuming race-gender-class as a thematic and political unit in science teaching can contribute to critical scientific education, adapted to the concrete Brazilian reality. It was from this scenario that we conducted the research described in the following section and proposed an analysis of how the field of science education has conducted the debate on the race-gender-class triad.

In this perspective, we highlight some practical and epistemological consequences arising from the adoption of this unity within the context of science education:

- Recognition of the inseparability of race, gender, education and work categories in the historical processes analysis, safeguarded the particularities and contradictions (unity in diversity), promoting the inclusion/exclusion of scientific and historical themes, debates and contents, thus producing conditions for thematization and problematization of the reality engaged in the anti-racist and anti-sexist struggles, and in the class struggle itself.
- Search for unifying or overcoming exclusive or profoundly particularized approaches, in order to broaden the perception of phenomena and of reality itself, focused on reading society's historical and concrete movement and its effects in the scope of natural sciences production and education.
- Highlight the potential of educational processes, especially, of natural sciences education, in undertaking emancipatory projects with analytic, critical and interruption-transformation capacity.
- All the elements dialectally link themselves to the political dimension of science education which highlights and assumes the historical disputes in terms of contents, methods and axiological aspects of the educational phenomenon.

Methodology

To answer the question posed in the introduction section (how has the debate on the race-gender-class triad been treated in the field of science education in Brazil?), we conducted a text search in all available[1] proceedings of the National Meeting of Research in Science Education (Encontro Nacional de Pesquisa em Educação em Ciências - ENPEC), since 1997, totaling 13 editions. The search terms were: "race" ["*raça*"], "rac", "ethn" ["*etn*"], "negr", "class" ["*classe*"], "gender" ["*gênero*"], "sex"[2]. The papers that presented a connection with at least one of the elements of the aforementioned triad, expressed in their title, abstract and/or keywords[3], were counted in table 1 below.

[1] The proceedings of the II ENPEC, from 1999, were not available on the website https://abrapec.com/enpec-edicoes-anteriores/ and it was not possible to obtain them until the conclusion of this work.

[2] The word search was in Portuguese, because this is the main language at Enpec's proceedings. Also, incomplete words were used to encompass similar terms and those that were not related to the research were excluded.

[3] In most of the available proceedings, it was only possible to use the search tool considering the title of the papers. In these cases, we did not count the search terms that may appear in the abstracts and keywords.

Analysis and Discussion

Table 1 shows that, until the eighth event (2011), there were at most two papers that addressed race or class in their titles. A similar situation occurred with the gender category, but until the seventh event (2009). The number of papers with the race category in the title soared from 1 in 2011 to 5 in 2013. This increase may be related to the spirit of the times, since in the previous year, 2012, *Lei [Law] 12.711* (2012) was enacted, establishing the reservation of places in federal higher education institutions, such as universities, for students from public schools, as well as for black, brown and indigenous people.

Table 1. Number of ENPEC works that mention race, class and/or gender.

ENPEC edition	Race	Class	Gender	Triad
1997	0	1	0	0
1999	-	-	-	-
2001	1	0	1	0
2003	0	0	0	0
2005	2	2	3	1
2007	2	0	3	0
2009	0	1	2	0
2011	1	1	7	0
2013	5	0	13	0
2015	5	1	8	0
2017	6	1	15	0
2019	11	0	30	0
2021	6	0	14	0
2023	15	0	19	0

Subsequently, we read the only paper that presented the three elements (Cabral & Bazzo, 2005) to analyse how this debate was carried out.

The gender category, despite having oscillated in the number of appearances at each event, has maintained its constant presence since 2005. What is noteworthy is that this category has always been more present in ENPEC proceedings than the other two. Although we observed papers that mentioned race and gender, in our textual search, only one cited the three categories – race, gender and class – in its abstract. A possible issue in our research design, that we identified *a posteriori*, was not including search terms as "afr*", "woman*" or "women*" [*mulher**], "girl*" ["*menina**"] and others that, even in a peripheral way, could present an articulated debate involving gender.

This paper (Cabral & Bazzo, 2005), despite considering the race-gender-class triad, does not actually address it. In the introduction section, the authors present statistical data on the gender of researchers in different areas of science and technology (ST) to characterize the background of the investigated group:

> In the field of science and technology education, I conduct a qualitative investigation of socio-historical and epistemological aspects of a group of female professors and

> researchers in engineering and computer science at the Technological Center of the Federal University of Santa Catarina [*Centro Tecnológico da Universidade Federal de Santa Catarina*] (CTC-UFSC). Their accounts, collected as life stories, have revealed a trajectory often marked by inequalities and discrimination in the academic field in which they work, the adoption of strategies to overcome these hostilities, and the work efforts made beyond the efforts of their male colleagues (CABRAL, 2005).
>
> A greater presence of women in this area – I suggest in my work – is strengthened by transformations that involve awareness-raising processes, towards a critical awareness of scientific and technological practice and of gender.
>
> ...
>
> At CTC-UFSC, the average number of female professors and/or researchers is only 15%. Life stories of the investigated group confirm the existence of discrimination and micro-inequalities in the area, requiring them, among other strategies, an "extra effort" in attitude and work, and the delay or renunciation of personal desires. At times distanced/drifted away from research, they shift their interests solely to teaching.[4] (Cabral & Bazzo, 2005, pp. 2-3)

However, there is no mention of ethnic-racial data of researchers, which could contribute to a more qualified discussion about gender and race in the analysed field. As in relation to class, there is no consideration about its implications in work activities in ST, for example. Race and class are mentioned in the abstract referring to the non-neutrality of ST: "The science and technology way under de neutrality myth repelled gender issues, as well as race and social class, for example." (Cabral & Bazzo, 2005, p. 1). Along the paper, the authors write about class to explain the non-neutrality of ST, but there is no in-depth discussion.

> Cerezo and Luján (2001), when discussing the need for a new social contract for science, state that this challenge requires consideration of the cultural, ethical-political, economic, and academic dimensions, as well as the risks with which societies coexist.
>
> According to these authors, these risks would be associated with the "universalization of technology and its negative consequences for the abolition of national, social class, or generational barriers" (Ibid., 2001). In contemporary society, both goods and risks would be distributed – it would be a "society of risk". (Cabral & Bazzo, 2005, p. 3)

As in relation to race, it only appears again in a quote of another author, along with gender, also referring to the non-neutrality of ST. There is a predominance of the gender category and almost no articulation of it with the other two categories, they are not addressed as a triad. Beyond identifying representations, presences or absences of gender, race and class, the main issue we identify is the lack of an articulated analysis of how these dimensions are fundamental to read Brazil's historical problems, along with dependencies, territory and imperialism issues.

In general, although there is acknowledgement of the historical predominance of white men in the field of science to the detriment of black and indigenous people and women in general (Conselho Nacional de Desenvolvimento Científico e Tecnológico [CNPq], 2024), especially in studies on ethnic-racial relations and gender issues, little importance is given to the connection between race, gender and class in science education research. This scenario indicates that the view of white men as universal subjects and the limited space for black and indigenous people, especially women, still exert great influence in the field of science education.

[4] Translated from the original text in Portuguese.

Although socially relevant topics such as race and gender are present in science education research, the lack of articulation between them both and class may indicate a difficulty in recognizing that racism, sexism, and class exploitation are part of the same social structure in which science education is inserted. Finally, resistance to the class debate may be related to the elitist, historically based nature that still permeates science education and academia, neglecting historical research and the deeper problems of our society that require investigative shifts from the micro to the macro and vice versa.

It is worth mentioning a Brazilian author who theorizes about class and race, Clóvis Moura (1983), and states that these two categories are connected dialectically, as components of a productive unity: race and class orient work relations in Brazil (as well as in other countries with a history stained by slavery and segregation based on race). Thus, addressing class and race separately is a way of turning concrete reality invisible. Addressing class-race-gender issues more deeply is important to promote justice in science education, because this way, we can propose remedies, proper to our field, for both socioeconomic and cultural injustices that affect our students and the whole community. As Fraser (1997) states, there is a difficulty in connecting recognition to redistribution, but if we invest in one (often recognition) without the other (often redistribution), injustice will persist.

Conclusion

Affirmative action policies established in legislations such as *Lei 10,639* (2003), *Lei 11,645* (2008) and *Lei 12,711* (2012), as well as government initiatives in gender area, were and are important for the development of an emancipatory scientific education. However, the discussion of the race-gender-class triad, necessary for overcoming social inequalities, is still timid in the field of science education research.

The low number of papers addressing this triad at the main science education research event in Brazil demonstrates a significant gap in academic production and social appreciation of this topic by the community that thinks about science teaching in the country, which struggles with so many inequalities, including both cultural and socioeconomic injustices. Therefore, the results of this research point to the need for studies that address the concrete problems of this field, with the aim of promoting contextualized scientific knowledge, that thinks about scientific practice and questions the history of science, especially in Brazil.

If we want to develop a truly equitable science education, we must first acknowledge its racist, sexist and class-based history. The necessary communication between education, sociology and economic politics poses a challenge to science education researchers, a challenge we have decided to accept and we expect other researchers to do the same. Understanding the constant contradictions in the development of our field of work and study, we can overcome them through other proposals, truly emancipatory, developing policies of recognition and redistribution specific for science education.

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Addressing Girls In Out-Of-School STEM Labs

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Out-of-school labs have been implemented to inspire and inform youth about STEM, to broaden participation, and to counteract the growing lack of STEM professionals. Despite their potential to address persistent inequities in STEM, recent research has shown that pedagogical approaches rather maintain than reduce gendered hierarchies. How girls are addressed in STEM partly depends on the educators and their workshop-related actions, which is affected by their teaching expertise and personal characteristics, such as related values, implicit beliefs or orientations. This study was conducted in cooperation with an out-of-school lab in northern Germany, that faces a decreasing number of girls attending workshops in their spare time. This challenge has led to the following research question: How are girls (not) addressed by the out-of-school STEM lab educators? To answer this question, episodic interviews with N=7 staff members were conducted to gain insights into impressions, experiences and observations during their workshop-related actions. To reconstruct the educators' (possible) gender-related orientations, which result in their workshop-related actions, five interviews were analysed so far using Documentary Method. Relevant topics emerge from the formulating interpretation: organisational design of the workshops, girls' and boys' behaviour and the educators' expertise. Through the reflective interpretation, different reconstructed modi operandi as narrated practices of action could be assigned to three areas: standardisation of a male-connoted STEM culture, gender-differentiated workshop-actions and attribution. By giving an in-depth insight into several orientations about girls in STEM behind the modi operandi, this study outlines the need for out-of-school research being redirected to the role of educators and their gender beliefs.

Keywords: Out-of-School Learning Environments, Science Education, Gender Issues

Theoretical Background

For years, STEM subjects have been accused of gender blindness and structures that continue promoting gender stereotypical education and career choices (Onnen, 2015; Stich, 2024). Traditional gender roles, stereotypes or the lack of role models can be identified as barriers for young women to pursue a career in STEM (European Commission, 2024). The variety of out-of-school STEM labs have the potential to overcome these barriers by making STEM subjects experienceable in an environment without traditional gender role models and the pressure to perform (Baar & Schönknecht, 2018). However, pedagogical approaches, which were originally implemented to provide access to STEM education *for all*, rather maintain than reduce gender-specific hierarchies (Archer et al., 2021).

Within the context of out-of-school STEM learning, researchers have strongly focused on the need to change young people's motivation, identity, or interest regarding STEM through lab interventions (Archer et al., 2021). However, recent findings have shown that research should rather focus on changing the (teaching) offers instead of learners to fulfil its potential for widening participation as well as disrupting gender hierarchies in STEM (Archer et al., 2021; Rodéhn, 2019; Silfver, 2018).

Numerous studies have shown that schoolteachers' performance is partly influenced by their explicit knowledge, pedagogical orientations and subjective values (Elsen, 2020; Hand et al., 2017; Helmke, 2017). This includes implicit knowledge, such as gender-related orientation patterns, which are reflected in their teaching actions, including body language, facial expressions or voice (Elsen, 2020). While there is a broad database on teachers' gender-stereotypical influence in schools (overview in Elsen, 2020), there are hardly results available about educators

in STEM learning contexts outside school (Archer et al., 2021; Rodéhn, 2019; Silfver, 2018). Especially in labs without a link to an educational institution, educators hold a wide range of credentials from formal teaching certificates to no educational practice (Tran, 2008). Research-based findings and developments from the school sector can therefore not simply be transferred here. In addition, it is questionable whether the educators are experienced or qualified in dealing with gender in STEM at all. Hence, it is "necessary to start exploring issues pertaining to educators [and] (…) their understanding of gender" (Rodéhn 2019, p. 163f).

Aim Of The Study

Current research findings show the necessity of adapting the offer on site to promote the participation of young people in STEM and to reduce gender hierarchies (Archer et al., 2021; Rodéhn, 2019; Silfver, 2018). Educators' implicit orientations in out-of-school STEM labs are crucial, because they shape their workshop-related actions. Aiming to investigate educators' implicit orientations about girls in STEM, this exploratory case study was conducted in cooperation with an out-of-school STEM lab in northern Germany without a connection to an educational institution. According to the educators, the number of girls participating in workshops in their spare time is steadily decreasing. This background leads to the following research question:

How are girls (not) addressed by out-of-school STEM lab educators?

Note: Although a gradual opening towards gender diversity in STEM can be observed, research results are still based on a binary gender perspective. These circumstances as well as the fact that the interviewees commonly referred to girls and boys as dichotomous gender characteristics lead to classifying results according to a binary gender definition, which does not represent the perspective of the authors.

Design & Methods

To answer the research question, episodic interviews (Flick, 2000) with full-time educators (N=5) and the management (N=2) in an out-of-school STEM lab were conducted. In contrast to narrative interviews, episodic interviews are characterised by the combination of two methodological approaches: narration and questioning (Flick, 2000, 2011). Accordingly, information about the educators' implicit orientations on girls in STEM are collected through narrative prompts regarding workshop-related situations as well as (feedback) questions based on the narratives that aim for subjective explanations, argumentations or definitions (Flick, 2000, 2011). Beyond obtaining this qualitative data, that method-internal triangulation is suitable for reducing the social desirability bias, which has an influence on responses referring to sensitive topic of "gender" (Wolter, 2022). The educators' professional qualifications differ widely (e.g., apprenticeship in carpentry, a degree in mechanical engineering with a specialisation in aerospace engineering or a doctorate in geology). Among the educators and the management, four people identified themselves as female, two as male and one as human. At the time of data collection, the interviewees were between 27 and 74 years old.

The episodic interviews were analysed by using Documentary Method according to Nohl (2010, 2017). This reconstructive analysing method is particularly suitable for gaining a profound insight into implicit, possibly gender related orientations, as the analysis focuses not only on the narrated practice of action (modi operandi), but also on how it was said as well as its context (Nohl, 2017; Rabe et al., 2023). For this purpose, the Documentary Method involves three core analytical steps: In the formulating interpretation, sections relevant to the research question are identified, thereby capturing the explicit content level of what was said in terms of topics. In the subsequent reflecting interpretation, underlying orientations about girls in STEM are elaborated behind the

narrated practice of action (Nohl, 2017). The third core element, the comparative sequence analysis, enables the contrast of relevant interview sections within and across cases to identify internal linguistic and/or (workshop-related) action logics or breaks. Regularly participating in research- and interpretation-colloquia serve to ensure the scientific quality of one's own interpretation and to continuously reflect on one's own location-boundness (Rabe et al., 2023).

Insight Into Preliminary Results

The analysis of five interviews, including the core steps described above, has been fully completed. The following relevant topics emerged from the formulating interpretation: organizational design of the workshops, the girls', boys' and educators' behaviour in the workshops as well as the educators' expertise.

During the reflective interpretation, a range of internal action logics could be reconstructed, which can be divided into three areas: standardization of a male-connoted STEM culture, gender-differentiated actions in the STEM workshops, and attribution. The educators' narrated action practices (modi operandi) show that they implicitly associate math, physics, computer science, and technology with masculinity. This is evident, for example, in the choice of workshop topics (programming car racing games) or the standardization of boys' (dominant) and girls' (cautious) behaviour. This implicit standardization results in specific gender-differentiated workshop actions, such as addressing girls by topics based on gender-specific stereotypes (natural cosmetics or jewellery soldering), encouraging girls ("you can do it"), working in gender-homogeneous groups, or concealing male-connoted STEM disciplines by avoiding "provocative" words (e.g., "graphs"). It was also mentioned that girls in the workshops need to be protected from dominant boys who devalued their work. Finally, all educators draw conclusions referring to the youth's interest based on the behaviour the educators observe: for example, the dominance of boys is attributed to a high level of interest, while the girls' restraint is implicitly assumed to indicate little or no interest.

The reconstructed logic behind the educators' modi operandi is based on their collectively shared belief that "STEM is male". This leads them to implicitly characterize girls as a target group that deviates from the norm in STEM, meaning that alternative approaches are needed to address them in STEM. These alternative approaches result in an implicit need for girls' own topics, own language, and own treatment in STEM workshops. Thus, in terms of their narrated practice actions, educators implicitly assume that addressing girls in STEM requires additional effort.

Discussion

The preliminary results clearly show that a variety of gender-specific orientations can be reconstructed, which make educators implicitly reproduce gender hierarchies and prevent girls from feeling a sense of belonging in STEM (Archer et al., 2021; Çolakoğlu, 2024). It is questionable why these orientations are so powerful, even though the decreasing participation of girls is regularly discussed within the team. Further studies are needed to investigate possible reasons. Educators implicitly believe that they are addressing girls by means of the gender-specific actions outlined above. However, their (explicit) narratives made clear that girls do not feel addressed, but rather that their feeling of "not belonging" is implicitly reinforced by the additional effort that was made (Çolakoğlu, 2024). With reference to Çolakoğlu (2024), working in gender-homogeneous groups initially seems to be a sensitive short-term solution to strengthen girls' sense of belonging against the backdrop of a male-dominated environment. In the long term, however, these groups are very exclusive in nature, reproducing gender and subject-related stereotypes and confirming implicit assumptions about the need to make extra effort for

addressing girls. Due to the lack of a sense of belonging, girls' participation in voluntary activities at the out-of-school STEM lab would probably remain low (Çolakoğlu, 2024).

Implications

As initial results from the project already indicated, there is not only an urgent need for action to minimise the impact of educators' implicit, gender-stereotypical orientations, but also to shift research's focus on the role of educators and their competencies regarding gender in STEM. Referring to the enormous diversity of out-of-school STEM settings in Germany, considerations about suitable interventions cannot (and should not) result in an overarching "recipe" for qualifying all out-of-school educators working in STEM labs. Even more, this study indicates providing support for educators to regularly reflect on their implicit, gender-stereotypical orientations. Additionally, it is conceivable to formulate corresponding competencies as recruitment requirements or to anchor the topic of gender in STEM as a fixed component of continuous professionalization opportunities for educators in out-of-school STEM labs.

Outlook

The Documentary Method will be further conducted to first analyse the last two interviews and secondly further contrast them with the (already) reconstructed modi operandi as well as those underlying orientation patterns. Additionally, episodic interviews with other STEM educators are planned to further contrast between the reconstructed gender-specific orientations, which result in the educators' workshop-related actions. A criteria-based selection of suitable STEM labs is already made.

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The Influence Of School Experiences In The Construction Of A Scientific Identity – A Case Study With Brazilian Transgender Persons

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This qualitative case study investigates the influence of school and science classroom experiences on the construction of a scientific identity among transgender individuals in Brazil. Drawing on Foucauldian theories of disciplinary power and on the concept of Science Capital, the research analysed the narratives of eight transgender participants collected via online questionnaires. The findings reveal a dichotomous influence: profoundly negative experiences — characterized by systemic bullying, discrimination, spatial precarity, and institutional neglect — actively dismantle Science Capital and divert individuals from scientific paths. Conversely, affirmative experiences, particularly through supportive and gender-sensitive science teachers who provide recognition and mentorship, can foster resilience, build Science Capital, and catalyse the pursuit of scientific careers, often as an act of social resistance. The study concludes that the school environment functions as a critical filter, either reinforcing exclusion or enabling inclusion. It underscores the pivotal role of educators and institutional policies in shaping trajectories and calls for urgent structural reforms—including teacher training, curriculum revision, anti-bullying programs, and affirmative actions in higher education—to transform educational spaces into equitable foundations for scientific identity development among transgender students.

Keywords: Equity in Education; Gender Equity; Science Identities

Introduction

Gender identity and sexuality play a crucial role in shaping social interactions and career choices, deeply tied to one's sense of belonging. In Western societies, the male/female binary is a foundational element of capitalist and colonial structures, dictating social roles and labor opportunities—particularly in peripheral regions such as Latin America, where heteronormative authority continues to subordinate women and gender-diverse minorities.

This structural inequality is starkly evident in Brazil, which records the world's highest rates of murders and suicides among transgender and non-binary people. Widespread transphobia permeates all spheres of life, including education and future professional prospects. Although transgender and non-binary individuals represent 2% of the population, they account for only 0.3% of university students, with most abandoning school between ages 14 and 18 (Observatory of LGBTI+ Deaths and Violence in Brazil, 2025).

Prejudice is especially severe for trans women, reflecting socio-historical processes that silence femininity (Junqueira, 2016). The formation of gender and sexual identities is intrinsically linked to power relations (Seffner, 2011), and transgender people face systematic human rights violations worldwide, intensified by their visibility and the inability to conceal their gender identity (Rodrigues, 2011).

Foucault (1988) studied power relations and how they manifest themselves in social institutions. He argues that modern society is structured around complex networks of power that exert control over the bodies and identities of individuals, exercised through norms, discourses and practices that define what is considered normal. In the context of transsexuality, Foucault's insight can be applied to understand how educational institutions perpetuate gender norms that marginalize

those who do not conform to binary gender expectations. Foucault suggests that power is not only repressive, but also productive, in that it creates categories of identity and regulates behaviours through mechanisms of discipline and surveillance.

For Foucault, school is one of the main institutions that contribute to the formation of subjectivities, using a series of disciplinary techniques to shape behaviours and identities. These techniques include constant surveillance, ongoing assessment and normalization, which together work to reinforce prevailing gender norms. Transgender individuals who challenge these norms often face discrimination and exclusion, which can have a significant impact on their educational experience and psychological well-being.

Furthermore, Foucault highlights the importance of discourse in constructing identities and maintaining power relations. Medical discourse, for example, has historically pathologized transsexuality, classifying it as a disorder or abnormality. At school, this pathologization can manifest itself through discriminatory practices and the lack of inclusive policies that recognize and respect the diversity of gender identities.

For transgender people, the need for authenticity in expressing their identity often collides with social and institutional expectations, generating conflicts that harm concentration, active participation and knowledge acquisition. Thus, addressing the school experiences of transgender people is crucial for the creation of a more democratic and inclusive environment at schools and to promote equity and social justice.

Besides, few studies have addressed the formation of scientific identity of transgender students. Recently, Datta (2024) reported the results of an investigation about how transgender people negotiate identity and community questions in Indian science institutions, showing that the lack of social capital strongly determines their professional trajectories. Archer and coworkers (2019) had already delt with the relations between gender and the development of scientific identity when analysing groups of British students at high school, showing that Science teachers tend to endorse their male students' discourses.

Thus, investigating school experiences of transgender people is crucial for the development of a more inclusive environment, where they can build confidence on their abilities to pursue a scientific career. Thus, the objective of this paper is to describe our research on the experiences of a group of transgender people in Science classes and how they influenced in their professional choices. Our research question can be pointed out as: how Science class experiences influence in the adhesion of Brazilian transgender people to a scientific identity/career?

Theoretical background

Historical analysis reveals that transgender phenomena and gender diversity are not modern constructs but have ancient roots. Furthermore, many non-Western societies have historically treated gender variance as a sacred or mystical experience, distinct from the rigid Western binary (Correa, 2020). In Brazil, evidence of trans existence dates to the 16th century, with figures who resisted imposed gender norms despite persecution and derogatory descriptions in colonial records (Mott, 2005). The 20th century witnessed both severe repression — such as the targeting of trans people during the Military Dictatorship under accusations of subversion — and gradual medical and legal recognition.

The pathologization of transgender identities has been progressively challenged; homosexuality was declassified as a mental disorder by the APA in 1973 (and fully removed from the DSM-III in 1980) and by the WHO in 1990, while transgender identity was initially categorized as Gender Identity Disorder in the DSM (1980), later renamed Gender Dysphoria (2013), and more recently

defined as gender incongruence in the ICD-11 (2018), moving away from a pathological framework (Coacci, 2020). This historical trajectory underscores the long-standing presence of trans identities and the shifting socio-medical discourses surrounding them.

Human sexuality transcends mere biological differences, enabling research to incorporate the social dimension of gender (Melo & Sobreira, 2018). A fundamental distinction lies between sex (biological attributes) and gender (a sociohistorical construct), a conceptual advance that challenges the historical conflation of the two, which naturalized behaviours and social roles based solely on biology (Jesus, 2012). Gender is thus understood as a normative construction that assigns characteristics as masculine or feminine (Oka & Laurenti, 2018). Central to this framework is gender identity—an individual's subjective sense of self, which may be cisgender (aligned with sex assigned at birth), transgender (non-aligned), or non-binary (Jesus, 2012). This must be distinguished from sexual orientation, which pertains to affective-sexual attraction toward certain genders (Siqueira & Klidzio, 2021), illustrating the broad spectrum of human relations (Jesus, 2012).

Drawing on Michel Foucault's seminal work, schools can be understood as quintessential disciplinary institutions that actively produce and regulate normative gender identities. Through mechanisms of constant surveillance, evaluation, and the normalization of behaviours, educational environments reinforce a rigid gender binarism (Foucault, 1987). This disciplinary power operates not merely through repression but productively, shaping subjects by defining what constitutes a "normal" boy or girl, thereby marginalizing those who deviate from these cisheteronormative expectations. The historical pathologization of transsexuality within medical discourse, as analysed by Foucault (1988), finds its parallel in school practices that, often through omission or discriminatory behaviour, treat transgender identities as anomalies to be corrected or silenced. This framework illuminates how institutional structures systematically enforce gender norms, rendering transgender students vulnerable to exclusion and psychological harm as they challenge the established binary order.

However, this Foucauldian analysis also reveals the potential for resistance and transformation within the educational field. If power is diffuse and productive, it also creates spaces for counter-discourses and practices. The very institution that disciplines can be reimagined as a site of emancipation (Frigotto, 2001). Moving beyond a pathologizing view requires recognizing transgender existence as a legitimate form of subjective experience and social being, as emphasized by theorists like Arán, Murta, and Lionço (2009) and Butler (2009). From this perspective, education transforms into a tool for challenging the norms it has historically upheld. This entails actively deconstructing the heteronormative matrix (Louro, 2013) and cisnormative pedagogies (Junqueira, 2016) embedded in curricula and daily interactions.

Therefore, the potential for schools to become inclusive spaces hinges on a deliberate shift from disciplinary normalization to the affirmation of diversity. This requires implementing concrete policies that protect and respect gender identity, coupled with continuous teacher training to foster sensitive and informed approaches. By critically engaging with and disrupting the power relations that sustain gender binarism, education can fulfil its emancipatory promise. It can become a space where diverse gender identities are not only recognized but valued, allowing all students, especially those from marginalized groups, to fully access knowledge and build their futures without having to renounce their authentic selves.

The construction of a scientific identity is deeply intertwined with issues of access, representation, and social validation. Drawing on the work of Archer and colleagues, the concept of "Science Capital" is crucial here; it posits that the aspiration to pursue science is not merely an individual choice but is significantly shaped by one's access to a composite of economic, social, and cultural

resources specifically related to science. This framework helps explain how systemic inequalities — such as those based on gender, class, and race — can limit the development of a scientific identity from an early age, as historically seen in the exclusion of women, particularly poor and Black women, from exact and natural sciences. For transgender individuals, these barriers are compounded by a profound lack of representation and institutional recognition, which directly impacts their sense of belonging and possibility within scientific fields.

This marginalization is mirrored and reinforced by a prominent academic void. As highlighted by Moura and Zibetti (2023), there is a severe scarcity of research focusing on the schooling of transgender people in Brazil. Their systematic review, which filtered thousands of records down to only 28 relevant studies, reveals a field that is incipient, fragmented, and geographically concentrated in the South and Southeast regions. This research gap is not neutral; it reflects and perpetuates the structural invisibility of trans experiences in educational policy and discourse. The lack of interdisciplinary studies, especially from fields like Psychology that could illuminate subjective and psychosocial dimensions, means the specific challenges transgender students face in forming a scientific identity remain largely unexamined and unaddressed, thereby allowing cycles of exclusion in science education to persist unchallenged.

Methodology

This study is characterized as an applied, qualitative research, configured as an exploratory case study (Yin, 2001). The qualitative approach was chosen as it aims to investigate how individuals perceive and attribute meaning to their experiences, ideas, and events (Câmara, 2013), allowing for an in-depth understanding of the participants lived educational trajectories. The case study design was appropriate for obtaining insights from the detailed experiences of a specific group within their real-life context (Creswell, 2010).

The research involved eight transgender individuals (including both trans men and trans women), aged between 19 and 36, from different Brazilian states (Rio de Janeiro, São Paulo, and Pernambuco). Participants were recruited virtually through a non-probabilistic sampling technique, where invitations were directed to individuals who self-identified as transgender in their Instagram biographies. To ensure privacy, comfort, and an environment conducive to authentic sharing, all data were collected anonymously, with no request for identifying information such as names.

Data collection was conducted via an online questionnaire on the Google Forms platform, enabling access to participants from various regions. The instrument contained both open and closed questions, structured into three thematic blocks: (i) sociodemographic data, (ii) school and academic experiences, and (iii) professional experiences in teaching (where applicable). The questionnaire covered topics such as experiences of respect or discrimination in school, relationships with science teachers, access to higher education, and perceptions of the work environment.

For data analysis, documentary analysis and content analysis were employed, following the principles proposed by Bardin (2016). The process followed three fundamental stages: pre-analysis, material exploration, and treatment of results. From the responses, four core analytical categories were established based on the recurrence of themes and the research objectives: 1) School Experiences (encompassing bullying, discrimination, and sense of belonging), 2) Relationship with Science Teachers, 3) Experiences in Higher Education, and 4) Professional Trajectory and Teaching. These categories guided the interpretive analysis, allowing the participants' narratives to be critically examined considering the theoretical framework on education, diversity, and the inclusion of transgender people.

Results And Discussion

Guided by the dual theoretical lenses of disciplinary power (Foucault) and Science Capital (Archer et al.), this section analyses participants' narratives to address the central research question: how do Science class experiences influence the adhesion of Brazilian transgender people to a scientific identity or career? The analysis examines these accounts as lived experiences where the theoretical mechanisms of normalization and exclusion materialize concretely, while also highlighting moments of affirmation and resistance that directly shaped their relationship with science. This approach allows us to understand how specific interactions in the science classroom impacted their sense of belonging, access to scientific resources, and ultimately, their trajectory toward or away from a scientific career.

The school environment emerged from the narratives as a primary site of disciplinary power, where violence and exclusion enforce gender binarism. All interviewees reported severe bullying, from verbal harassment to sexual abuse. Interviewee H recounted: "Physical education classes were terrifying... they made my life hell, assaulted me physically, mentally, sexually, turning me into the class joke." This multiform violence targets non-normative bodies, seeking to render them docile (Foucault, 1987), and initiates a cycle of psychological suffering that corrodes self-worth and belonging (Aran et al., 2008). Exclusion was perpetuated not only by peers but through institutional neglect. Interviewee D noted a dissonance: "The teachers listened to my proposals... but often my gender identity was not respected," reflecting a form of symbolic violence born from a lack of understanding and inclusive policies (Bronzo, 2010).

The consequences were directly academic and aspirational. The relentless bullying described by Interviewee H led to plummeting grades and the abandonment of her medical career aspirations after a cruel incident in Grade 9: "The damage was already done, they broke me." This trauma hit her nascent Science Capital (Archer et al., 2015), depleting the resources necessary to sustain scientific identity formation. This illustrates how exclusionary environments actively dismantle, rather than build, the professional trajectories of transgender students.

The Foucauldian analysis is further concretized in the issue of spatial control, such as the acute anxiety around bathroom use mentioned by Interviewee E. This fear is a manifestation of spatial discipline and surveillance (Foucault, 1987). Bathrooms, as rigidly gendered binary spaces, become sites of normalization and potential confrontation, placing transgender students in a state of spatial precarity. This daily practice reinforces binary norms, invalidates their identity, and consumes cognitive energy that could be directed toward learning, creating a tangible barrier to educational engagement and academic belonging.

While the school environment emerged as a pervasive system of disciplinary power that actively eroded belonging and dismantled Science Capital, the participants' narratives revealed that specific actors within this system could function as decisive counterweights. This dynamic between structural exclusion and potential affirmation brings into sharp focus the pivotal role of educators. The following analysis examines the agency of science teachers, exploring how their pedagogical stance — ranging from conscious inclusion to passive neglect — directly mediated the impact of the hostile school climate. Their actions crucially determined whether initial student interest in science was validated and nurtured into tangible Science Capital or whether it was extinguished by the broader culture of exclusion.

Within the often-hostile school environment, Science teachers emerged as pivotal figures capable of acting as counterweights to disciplinary exclusion, directly influencing the participants' relationship with scientific knowledge. Positive reports highlighted teachers who respected

gender identity and actively engaged students' interests. Interviewee H recalled, "I always liked sciences, especially natural sciences. My teachers were very open and treated me equally, which made me consider the area as a career option when I was younger." This respectful and equitable treatment, as Oka and Laurenti (2018) argue, is fundamental for creating an inclusive pedagogical practice that can foster sustained interest in science among marginalized groups. Similarly, Interviewee D received significant support from her teacher, who encouraged her participation in national science and biology olympiads. This active mentorship provided her with specific forms of Science Capital (Archer et al., 2015) — such as access to special knowledge (Olympiad preparation), institutional recognition, and a network of support — that validated her scientific competence and belonging.

However, these affirming experiences contrasted with a broader institutional failure. Four interviewees stated they received no encouragement from teachers or schools to pursue science. This widespread lack of formal support reveals a systemic gap where personal interest was not translated into concrete aspirational identity due to absent mentorship, career information, or validation of scientific potential.

The analysis of these contrasting experiences underscores the teacher's dual role as both a potential agent of inclusion and an unwitting accomplice to systemic neglect. The positive cases demonstrate that when educators consciously adopt a gender-sensitive approach, they do more than transmit content; they perform an act of identity affirmation. By treating a transgender student with equality and actively promoting their participation, these teachers directly combat the pathologizing discourse and social exclusion their students face elsewhere. They become facilitators of Science Capital accumulation, building the social and cultural resources necessary for scientific identity formation. Conversely, the more common absence of active encouragement, even amidst otherwise respectful treatment, reflects a pedagogical shortcoming.

The influence of science teachers proved to be a critical variable, either facilitating a connection to scientific knowledge or reinforcing a sense of alienation from it. However, the translation of this school-based Science Capital into sustained scientific trajectories hinges on the subsequent gateway of higher education. The journey into and through university represents a contested stage where earlier experiences of support or exclusion are recontextualized within new structures of power and recognition. It is marked by profound structural inequalities. As evidenced by the interviews, access is not guaranteed, with financial and social barriers acting as significant gatekeepers. Interviewee B’s situation, who "could not attend college due to a lack of financial resources and opportunities," exemplifies the social vulnerability described by Filgueiras (2004), where systematic marginalization deprives groups of essential resources like education. The empirical reality of these barriers underscores the theoretical point that exclusion is not merely incidental but a structured outcome, preventing many from even entering university space.

Once within academia, the experiences diverge sharply, revealing the university as a deeply contradictory space. For some, it becomes a transformative environment for self-knowledge and affirmation, what resonates with Bento's (2014) conception of the university as a conducive context for the dynamic and non-linear process of gender reinvention, offering the freedom to reconnect with one’s identity. Conversely, others confront persistent invisibility and new challenges. Interviewee C, despite some growth, felt "constantly invisible," while Interviewee H’s earlier engineering studies were marked by intense depression and isolation, leading to severe mental health struggles. This contrast illustrates the dual potential of the university: it can be a site of emancipation for some while perpetuating normative exclusion for others.

This duality exposes the university as an arena where both liberation and normative control are negotiated. The positive accounts of Interviewees E and F, who found in university an opportunity

to "liberate themselves in relation to their own body" and experience a "process of self-construction," align with Bento's (2014) view of academia as a space for personal emancipation from previous social restrictions. However, the "invisibility" reported by Interviewee C and the pathologizing marginalization discussed by Marreiros e Silva (2015) reveal how institutional spaces often maintain a binary gender logic that silences trans presences.

Ultimately, the empirical data compels a critical synthesis: the university is a microcosm of broader social tensions regarding gender. True transformation, as theorized by Bento (2014) and Perelson (2011), requires actively dismantling the normative frameworks that render trans identities secondary.

The ambivalent nature of higher education — as both a site of liberation and of continued normative exclusion — frames the ultimate stage in the pathway toward a scientific identity: the professional career. The analysis of the experiences described by the interviewees reveals how a scientific identity, when achieved, is often enacted as a form of social resistance. It directly answers how adverse school experiences can ultimately lead not only to withdrawal from science but also to a resilient, politically charged commitment to transforming scientific and educational spaces for future generations.

Six of the interviewees opted for a degree in Education. The choice to enter the teaching profession emerges from the interviews as a deliberate act of social resistance and transformation. Interviewee D's trajectory is paradigmatic; she explicitly pursued a teaching career "with the aim of deconstructing the stigma that transgender people are not socially or intellectually capable." This motivation is deeply rooted in her own positive schooling experience, where supportive science teachers encouraged her participation in competitions and emphasized pursuing higher education. Her decision to become a Biology teacher, therefore, transcends mere career choice, embodying what Frigotto (2006) conceptualizes as education mobilized for the construction of a more just society. By seeking to "destigmatize gender prejudice" through pedagogy, she positions teaching not as the neutral transmission of knowledge, but as a critical practice that challenges oppressive norms and aims to transform social reality. This aligns with the resistance movement described by Frigotto and Ciavatta (2012), where education becomes a tool to contest the very structures of discrimination.

The reported current work experiences of the trans educators reveal a professional environment that is both affirming and demanding of constant resilience. Empirically, the accounts are "profoundly positive and inspiring," with Interviewee C describing his teaching experience as "incredible" and feeling like a "potency inside the classroom." Similarly, Interviewee F shares being "incredibly respected" during teaching internships, particularly regarding discussions on gender and transness. These positive experiences reflect Perelson's (2011) notion of recognition, where professional respect becomes foundational for affirmed identities and suggests that educational spaces can indeed become sites of empowerment. However, this affirmation coexists with the need for persistent self-assertion. As Interviewee C notes, the requirement to constantly impose himself to avoid delegitimization highlights the ongoing structural prejudice that necessitates a resilient and proactive stance. Thus, while their teaching practice is transformative for themselves and potentially for their students, it is continuously enacted within a context that still requires them to navigate and resist marginalizing forces.

In synthesis, the professional trajectories of these interviewees exemplify teaching as a transformative practice in a dual sense. First, it serves as a personal and political vehicle for resisting stigma and reclaiming social legitimacy, as theorized by Frigotto. Second, their active presence in classrooms performs a transformative social function, potentially altering the educational environment for future generations. The empirical data demonstrates that their

pedagogy is intrinsically linked to a project of social change. Their generally positive workplace experiences indicate progress, yet the undercurrent of needed resilience confirms that their transformative work occurs not in a void of acceptance, but through continuous engagement with and resistance to persistent normative structures.

Conclusions

This study concludes that experiences in science classes and school environments are decisive in shaping the scientific identity and career trajectories of transgender individuals. The empirical data reveals a sharp dichotomy: profoundly negative experiences, marked by discrimination, abuse, and exclusion, can cause deep trauma and divert individuals from scientific paths, as exemplified by Interviewee H who abandoned a medical career after feeling she "would never be accepted." Conversely, positive and inclusive experiences, centered on respectful and encouraging relationships with teachers, can foster a strong scientific identity and resilience. The testimony of Interviewee D, who received "consistent support from her teachers" leading her to become a Biology teacher, underscores how affirmative pedagogical relationships can empower trans students to pursue and thrive in scientific careers.

In direct answer to the research question — how Science class experiences influence the adhesion of Brazilian transgender people to a scientific identity/career — the findings demonstrate that these experiences function as a critical filter. They can either act as a mechanism of exclusion, reinforcing societal stigma and severing the connection between trans students and scientific fields, or as a catalyst for inclusion, providing the recognition and support necessary to build a scientific identity and a trajectory of resistance through education.

Based on these conclusions, urgent and multidimensional actions are recommended. At the policy level, this includes revising educational policies to incorporate specific guidelines for gender equity and the protection of transgender students. Institutionally, mandatory pre- and in-service teacher training on gender diversity and inclusive pedagogies is essential. Within Science education, a reformulation of curricula is needed to critically address concepts of sex and gender, thereby incorporating human diversity and deconstructing cisnormative biases. Schools must implement robust anti-bullying programs and establish integrated psychological and social support networks. Furthermore, to address barriers in higher education, affirmative actions for transgender access and permanence must be promoted. This study acknowledges its primary limitation as a qualitative case study with a small sample. Future research should expand on these insights through larger-scale, quantitative or mixed-method studies with more diverse demographic samples, as well as longitudinal designs that follow the educational and professional trajectories of trans individuals over time.

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Science Capital Of Brazilian Students From The Periphery Of Rio De Janeiro: Correlations Between Gender, Ethnicity And Parents' Educational Level

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Science Capital, introduced by Archer and coworkers, is based on Bourdieu's concept of capital and how students' cultural, social and economic capitals influence the formation of a scientific identity and future career engagement. Higher Science Capital is linked to families with strong ties to science, with gender and ethnicity also playing a role. A key outcome of their research was a questionnaire assessing three dimensions—scientific cultural capital, science-related behaviours, and scientific social capital—generating a score from 0 to 105, classified as low, medium, or high. Since 2018, our group has been studying the Science Capital of public school students, who represent over 80% of Brazilian students mainly from lower-income backgrounds, with the aim of investigating the factors that promote inequalities in engagement with science. In this context, public schools both reflect social inequalities and provide opportunities for equity and social justice. Our research involved 936 high school students (ages 14-20) from six public schools in the metropolitan region of Rio de Janeiro, using a Portuguese-adapted Science Capital questionnaire. Results indicated a predominance of medium Science Capital levels, with the mother's educational level being the primary influencing factor. More male students were in the medium level, while gender non-normative students had a higher proportion in the high level. These findings emphasize the role of gender in Science identity formation and the need for policies promoting gender equity in education to ensure more inclusive access to scientific careers in Brazilian public schools.

Keywords: Educational equity, Equity in Science, Science Identities

Introduction

Science Capital is a concept developed by Archer and coworkers (2015) based on the Bourdieusian concept of capital and taking into consideration the school educational field. The concept was developed from their participation in the ASPIRES project (King's College, 2013), aimed to reflect the reduction in the interest of following scientific careers by young people.

The authors suggest that the legitimization of resources related to science is an important form of contemporary capital as they play a significant role in producing social relations of advantages and disadvantages, not only due to their high symbolic and exchange value in contemporary society, but also because science is conceived, in various international contexts, as a national priority within government policies (Archer et al, 2015). Thus, as we live in a society that continuously uses science and values it as important, the authors aimed to add new contributions to Bourdieu's theory of capital, specifically regarding scientific matters, which could contribute to a more democratic society.

After the initial study, other researchers have used this approach to evaluate the Science Capital in different countries, such as Finland (Kaakinen et al., 2023) and Singapore (Teo et al., 2018). In Brazil, our group has been developing research on the Science Capital of students since 2018, with a major interest in investigating the factors that influence the choice of a scientific career by female students from low income, peripheral neighbourhoods (Silva, Teixeira & Silva, 2023). Our investigation with ten students from five public schools from the Metropolitan region of Rio de Janeiro has shown that participating in science projects was the only way they could interact

with science professionals and science-related professions. We could also observe that those students had their mothers as professional inspirations and, so, they have a crucial role in their future professional choices. The girls that foresaw Science as a professional possibility pointed out that social media, TV shows and their teachers played a pivotal role in this choice. As a result of this research, we developed an e-book with orientations for teachers who wish to promote the development of the Science Capital of their students.

Our research group has recently published a paper (Mileo Jr & Silva, 2025) describing the results of research on the scientific aspirations of two groups of Brazilian students from different educational systems, using data collected with Archer's Science Capital questionnaire. The first group, composed of students from a Federal public school, displayed higher levels of cultural and social capitals than those of the other, composed by students of public schools ruled by the State of Rio de Janeiro local government. These results are reflected in a greater adherence of the former group to a scientific identity. Scientific aspirations are strongly influenced by social inequities within the groups and thus educational policies related to Science education are necessary to promote equity and social justice among these schools.

The research described in this paper deals with an investigation of students from six schools located in the metropolitan region of Rio de Janeiro, the second largest city of Brazil, aiming to answer the following questions: how the students at the analysed public schools are distributed in the three levels of Science Capital? In which extension can the sociodemographic data of these students explain this distribution? Are there relationships between our data and those found by Archer and coworkers (Archer et al., 2015)?

Theoretical Background

According to Archer (Archer et al, 2015), Science Capital is not a different kind of capital, but a way of grouping aspects of the social, cultural and economic capitals that are more related to creation and value exchanges that leads to a higher participation or adhesion to a scientific identity or career. The concept is related to the theory of social reproduction (Bourdieu, 1983) and, consequently, the values attributed to what is established as scientific capital are a function of the social context (field), and the strategies for obtaining this capital are directly linked to individuals' nonconscious perception of their position within this context (*habitus*). Thus, Archer synthesizes the relationship between the values and logics that shape students' engagement with science. In her view, Science Capital is a function of all the ways students relate to scientific knowledge, which can be understood through the following main dimensions: scientific literacy; attitudes and values related to science; scientific behaviours outside of school; and contact with people who work in science (Godec et al., 2017).

Considering these dimensions, the first results of Archer group's research showed that a higher Science Capital was associated with students who belong to a family with higher social and cultural capital associated with science. Other factors that influence the levels of Science Capital are gender and ethnicity, with higher levels being more likely to be found among white male students from high cultural capital families, in which at least one member has a Science related career. On the other hand, female students and black students suffer numerous experiences throughout their lives that lead them to believe that Science is not for them at all (see also Archer et al., 2019).

From measuring Science Capital, it becomes possible to develop diagnostic processes regarding students' relationships with elements of the different dimensions and to propose guidelines to increase their engagement with science. One of the key achievements of Archer research was the development of a questionnaire that can be used to quantitatively measure Science Capital

(Archer et al, 2015). The questions are divided in three dimensions (scientific forms of cultural capital, behaviours and practices related to science, scientific forms of social capital) from which 14 specific items were used to calculate the Science Capital, that can vary from 0 to 105. These values can be ranked in three different levels: low (0-34.5), medium (35-69.5) and high (above 70).

Methodology

We are particularly interested in the levels of Science Capital of young people studying at public schools, since they are frequented by more than 80% of the Brazilian students, especially those from the lowest economic income fraction of the society. This makes the public schools a scenario for the reproduction of the social inequities of Brazilian society, as well as a field to provide experiences that can promote equity and social justice. Understanding the distribution of the students in the three Science Capital levels and its relationship with their sociodemographic data may open opportunities to develop activities which can potentially enhance their social and cultural capital related to science.

The research was then conducted with 936 high school students from six public schools from the metropolitan region of Rio de Janeiro, Brazil. All of these schools are in peripheric, low-income districts and with limited financial support from the local government, which restricts the pedagogical opportunities available to teachers to overcome educational inequities. There is an important index of school evasion during the first year of High School, when boys are required to find an occupation to improve their family income. On the other hand, girls can leave school or reduce their time of dedication to their studies to take care of domestic affairs or due to an early pregnancy.

The students, ranging from 14 to 20 years old, answered a version of the Science Capital questionnaire (Archer et al. 2015) translated to Portuguese, with minor adaptations necessary to adjust the questions to the cultural and institutional realities of the schools. The answers were collected and treated using Excel. One-factor ANOVA tests were performed at $p < 0.01$. The answers were submitted to Cronbach's alpha test, which verified the internal consistency of the data collected (Table 1). After that, the Science Capital was calculated following Archer's methodology, and the students were grouped in the three levels (low, medium and high Science Capital) as described before. Then, correlations between these levels and the sociodemographic data collected in the same survey were drawn to find how these factors are associated with the construction of the students' Science Capital.

Table 1. Cronbach's alpha for the subdimensions of the Science Capital questionnaire.

Component	Cronbach's alpha*
Future science job affinity (aspirations)	0.66
Valuing science and scientists	0.69
Family attitudes (including attitudes to science)	0.74
Utility of science qualifications	0.76
'Informal' science activities	0.63
Science media engagement	0.75
Valuing museums/ museum experiences	0.79
Science teachers and lessons	0.77
Self-efficacy in science	0.66

* Cronbach's alpha values above 0.6 were considered satisfactory (Wartha & Santana, 2020).

Results And Discussion

Sociodemographic (gender, ethnicity and parents schooling) data of the analysed population are resumed in Table 2. It was composed equitably by male and female students. Most of them declared to be Black, which is consistent with Brazilian demographic (Brasil, 2025) data and with the fact that most of the lowest income families are composed of this ethnic group as a consequence of the strong marks of African slavery and the way its abolition was unfairly conducted in Brazil.

Table 2. Sociodemographic data of the students.

	Gender			Ethnicity		
	Male	Female	Other*	White	Black	Other*
n (%)	447 (47.8)	443 (47.3)	46 (4.9)	220 (23.5)	630 (67.3)	86 (9.2)

* Other response/Preferred to not answer

The percentual distribution of the students in the three levels of Science Capital is depicted in Table 3, together with data related to their family's cultural capital. Most of them are in the medium stratum and less than 1% was ranked with high Science Capital, while Archer's initial study pointed to a percentage of 5% at this level among British students.

Table 3. Science Capital and Parents' Educational Level (n = 936).

	Low (%)	Medium (%)	High (%)
Science Capital	45.7	53.5	0.7
Mother left the school before 16 y.o.	23.8	27.7	0
Mother frequented a university	7.2	13	28.6
Father left the school before 16 y.o.	25.2	28.3	28.6
Father frequented a university	6.3	12.4	14.3

The data highlights that the mother's educational level is a more significant predictor for achieving a high Science Capital score than the father's educational level, which exhibits a weaker influence. Feijó, França, and Pinho Neto (2022) studied the influence of mothers on the academic performance of Brazilian high school students. Using a national government database on student scores in the ENEM (the national university entrance exam), the authors found that a mother's level of education has a greater impact on her children's academic performance than the father's level of education — an effect that is stronger among daughters, particularly when the mother holds a university degree. This influence was independent of the traditional channels of educational transmission — the identifiable means through which higher parental education typically improves children's school performance, such as higher family income, fewer children, better household infrastructure, and the ability to choose higher-quality schools. The authors suggest that these effects may be related to the transmission of cultural values, parental involvement, and the communication of maternal expectations and future aspirations regarding their children's educational achievement.

Our results corroborate the findings of Feijó, França and Pinho Neto (2022) and can be related to the social role usually attributed to mothers as the parent responsible for taking care of their children's educational development and to encourage them to complete their studies. Another important fact is that, in Brazil, more than 50% of the families are headed by the mothers, which highlights their role in the constitution of their children's Science Capital. In addition, it is important to highlight the homogeneity in the rates of parents who left school before the age of

16 across all levels of Science Capital, which points to the critical issue of school dropout among men—especially Black men—as previously reported by Ratusniak (2024).

Table 4 describes how the different genders are distributed among the three Science Capital levels. There are no significantly differences between the means of male and female students at $p < 0.01$ (low level: 24.9 (male), 25.1 (female); $F(10.988) = 0.087$; medium level: 45.5 (male), 45.3 (female); $F(10.963) = 0.039$). It was not possible to perform the statistical analysis at the high Science Capital level due to the small number of students at this stratum.

Table 4. Science Capital and gender (n = 936).

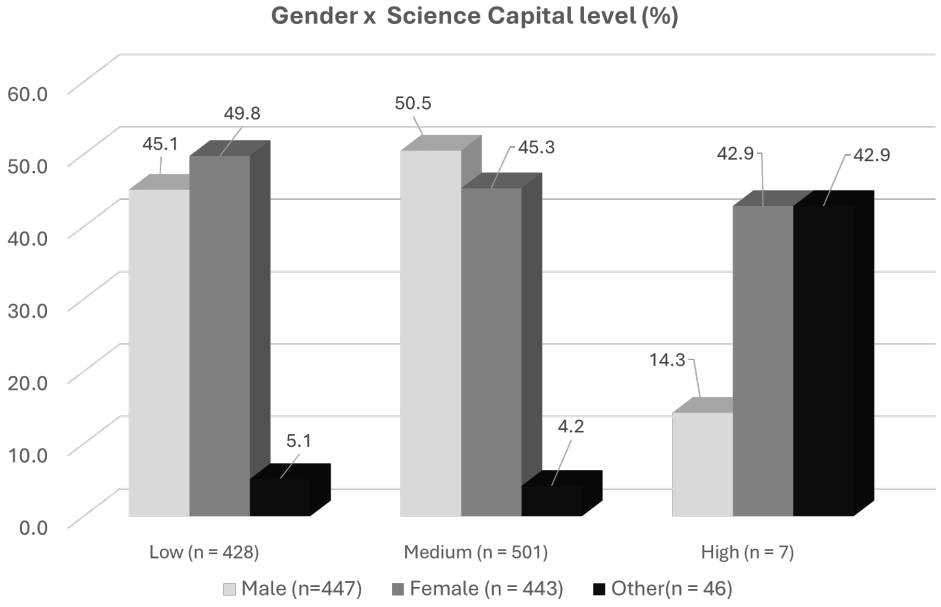
	Low (%)	Medium (%)	High (%)
Male	43.2	56.6	0.2
Female	48.1	51.2	0.2
Other*	47.8	45.7	6.5

* Other response/Preferred to not answer

It is noteworthy that a higher percentage of students with high levels of Science Capital did not identify themselves as male or female. However, further studies are needed to explore this finding, particularly given the small number of respondents in this group.

We have also analysed gender distribution in each Science Capital level (Figure 1). The result reinforces the small, non-statistically significant differences between the gender distribution at low and medium levels of Science Capital.

Figure 1. Distribution of the population by gender in each Science Capital level.



The influence of ethnicity on the Science Capital scores were also analysed and the results are described at Table 5.

Table 5. Science Capital and Ethnicity (n = 936).

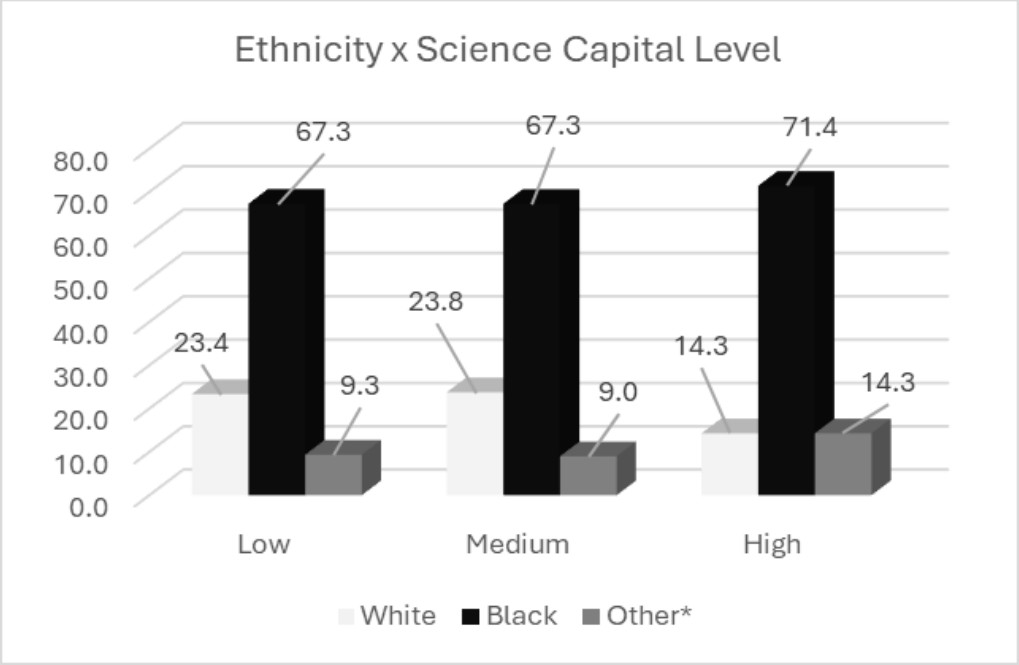
	Low (%)	Medium (%)	High (%)
White	45.5	54.1	0.5
Black	45.7	53.5	0.8
Other*	46.5	52.3	1.2

* Other response/Preferred to not answer

The data show similar distributions of White and Black students at the low and medium levels. At the low level, the means are not significantly different at $p < 0.01$ (25.3 (White), 25.0 (Black);

F(10.995) = 0.118) and the same is observed at the medium level at $p < 0.01$ (46.9 (White), 45.1 (Black); F(10.970) = 4.734). These data contrast with those obtained by Archer and colleagues (2015), in which ethnicity played an important role, a difference that may be associated with the different sample sizes of students in each ethnic group. On the other hand, we can infer the influence of low socioeconomic status, which, in these regions, does not differ greatly between these groups. These results are reinforced by the results depicted in Figure 2, showing that the ethnic distribution in each Science Capital level is similar to the ethnic distribution of the research population, as shown in Table 2.

Figure 2. Distribution of the population by ethnicity in each Science Capital level.



* Other response/Preferred to not answer

Conclusions

This study investigated the distribution of Science Capital among 936 high school students from public schools in the periphery of Rio de Janeiro and its correlation with sociodemographic variables. The results align with the international literature in one key aspect: the majority of students (53.5%) were concentrated at the medium level of Science Capital. However, our findings also reveal distinctive characteristics of the Brazilian context studied.

The most prominent factor associated with higher Science Capital was the mother's educational level, corroborating national research on the outsized influence of mothers on academic trajectories (Feijó et al., 2022). This underscores the crucial role of maternal cultural capital and involvement in fostering a scientific identity, especially in a social context where mothers are frequently the heads of households and primary educational guides.

Regarding gender, no statistically significant difference was found between the mean scores of male and female students. The higher percentage of gender non-normative students in the *high* Science Capital category demands deeper qualitative investigation to understand the specific trajectories and strategies of this group. Contrary to findings from Archer et al. (2015), ethnicity has not shown to be a statistically significant differentiating factor in this sample, suggesting that in these specific peripheral school contexts, with a high proportion of Black students, socioeconomic may override ethnic and gender distinctions in the formation of Science Capital.

These conclusions carry important implications for educational policy and practice: they reinforce the need for socioeconomic equity policies in science education, as this is strongly associated with gender and ethnicity in Brazil. Furthermore, they point to the potential of school-based interventions, such as science projects, to act as compensatory mechanisms for low familial Science Capital, particularly by connecting students with science professionals and career visions.

A primary limitation of this study is the extremely low percentage (0.7%) of students classified with high Science Capital, which restricts robust statistical analysis for this group. Future research should employ mixed methods, combining quantitative surveys with in-depth interviews and ethnographic observations. This approach would allow for a richer understanding of how Science Capital is mobilized, negotiated, and potentially resisted by students within their families and school environments, guiding the development of more effective and contextualized pedagogical actions.

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Inclusive Movement: Rethinking Physical Engagement In Science Classrooms

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Science education includes many physical learning activities designed to support learning. Students inevitably move when they participate in laboratory experiments, excursions, or if they are animated to move in a certain way that is supposed to promote learning. However, most research focuses on normative physical bodies and interpersonal relationships and thus unintentionally or implicitly excludes many students who are unwilling to perform certain actions as they may feel uncomfortable doing so. For instance, one may be an introvert and/or afraid of being observed. Some learners may have body-related trauma that makes them deeply distressed with certain activities, and others might simply be less athletic or less confident in taking up space than their peers. Finally, some bodies may be prohibited from performing certain actions due to physical disabilities. In this exploratory seminar, we invite researchers and educators who design physical activities of any form for students. Together, we explored what we need to know about students, and their bodies, for the design process, and what we can offer to students who might not be comfortable with the designed activity without isolating them.

Keywords: Embodiment, Inclusive Education, Science Education

Introduction

Physical engagement such as movement, gesture, and interaction is an integral part of science education. Students perform lab activities, they learn on excursions outside the classroom, or educators animate them to move in a way that promotes learning (e.g. Choudhary et al., 2019). Many scholars understand learning today as situated, active, and context-dependent (Nathan, 2021; Wilson & Clark, 2001), meaning that how students move and interact will affect learning.

Concurrently, science education aims to promote inclusion. Inclusion here denotes the "process of addressing and responding to the diversity of needs of all learners through increasing participation [...] and reducing exclusion within and from education" (UNESCO, 2005, p. 13). While studying the general effectiveness of interventions for the average student is crucial, scholars further ask for who under what conditions interventions may fail or even be harmful.

This seminar explored how scholars and educators may design physical activity inclusively. Specifically, we asked for whom a certain activity might create more stress as well as with whose bodies this activity is aligned and with whose not. For example, asking students to act as atoms and run faster when the temperature is higher is aligned with the bodies of students who can run (well), enjoy it, and feel comfortable about being perceived by others as well as interacting with them. We thereby build on work by Vickery and colleagues (2024) who found that students were aware of how their own and other students' bodies differ from a normative body and how this may affect learning experiences that involve physical activity.

In the following, we first pose the problem that this seminar aimed to address. Second, we provide a set of illustrative examples of empirical studies, which specifically target physical activity. Finally, we present the objectives and results of the seminar.

Learning And Physical Engagement

Conceptual Framework

Traditionally, separating body and mind was the common way to approach learning and educational practices. Fundamental learning theories like cognitivism by Piaget and behaviourism by Skinner overlooked their interconnectedness (Shapiro & Stolz, 2019). Later, Dewey suggested that students learn by interacting with the world (Dewey, 1986). Likewise, embodied cognition theories suggest that (inter)action influences cognition; therefore, meaning-making, problem-solving, and other cognitive activities are influenced by the learner's interactions with the world (Wilson, 2002).

In science education specifically, experimentation activities are a prominent example where students investigate phenomena by manipulating objects or materials while moving in a specific way (Hardahl et al., 2019). Furthermore, research shows that physical movement enhances science learning under the right conditions: for example, moving according to a predicted asteroid trajectory improved understanding of gravity and planetary motion (Lindgren et al., 2016), mixed-reality environments aided retention of centripetal force concepts (Johnson-Glenberg et al., 2016), and dance increased engagement with the periodic table (Solomon et al., 2022).

However, not all students are equally capable of or comfortable with physical and social activity (Spiel, 2021). Vickery and colleagues (2024) recently analysed fifth-grade students' reflections on their embodied modelling experiences. They found that the students saw tension between their non-normative bodies (e.g. physical dis/ability, or athleticism) and the normative expectations (e.g. moving around). The authors thereby pointed towards questions that we targeted in this seminar: for which participants might a certain activity create additional stress, with whose bodies is this activity aligned and with whose they are not? Are there other options for the latter?

Illustrative Examples: Interventions And Concerns Related To Physical And Social Engagement

Currently, research involving deliberate engagement of students' bodily movements primarily focuses on the effect of the interventions on learning and motivation, while students' willingness or concerns are seldom mentioned. In the following, we illustrate how such interventions might potentially intimidate or disadvantage certain groups of students by examining four studies, which involve social dynamics, educational technology, or direct embodiment. Importantly, note that we do not intend to criticize the study designs but to shed light on overlooked practical implications.

First, immersive tools and interactive platforms, while engaging, can pose challenges related to students' sensorimotor abilities. For example, in a study where students learned chemical concepts by using a haptic device providing force feedback (Müller et al., 2024), successfully navigating the device and interacting with virtual molecules was critical to learning. Furthermore, anecdotally, not all students experienced the force feedback from the haptic system equally. These differences might have had an impact on the effectiveness of the embodied activity. Similarly, in another study where students learned about derivatives in a VR environment, results showed that students with higher bodily awareness benefited more from the activity (Chatain et al., 2024). This discovery points to the need of designing for interactions that accommodate diverse bodily abilities.

Second, the social pressure inherent in classroom settings might put students into dilemmas when participating in embodied activities. For example, in the Energy Theater study (Scherr et al.,

2013), each student was “a unit of energy” and was required to use hand signs or move with their peers to a certain region to indicate the energy flow. In these activities, students may feel that their explicit movements are being observed by the group. They may then hesitate to participate in such learning activities due to a lack of confidence in their movements yet feel unable to opt out for fear of disrupting the group dynamic or being perceived as uncooperative. Therefore, educators and researchers might need to seek students’ consent in advance and implement facilitation strategies that acknowledge and address these social pressures.

Finally, direct embodiment helps students form a bodily representation of the concept but can also implicitly establish normative body shapes. For example, in a study where students learned about robot anatomy, teachers prompted them to dance alongside robots and think about the similarities between human and robot body structures (Zhang et al., 2024). This activity may be uncomfortable for some students, as it involves comparing their bodies to a normative ideal, represented by the robot’s form. We conjecture that students with physical disabilities might feel excluded. Other students who perceive their bodies as bigger, smaller, or simply different than the normative expectation may also feel self-conscious under constant comparison. Thus, these differences between the expected norm (in the case of this study represented by the robots) and the students' bodies need to be framed in a supportive and sensitive way.

Objectives

Immediate Outcomes

The primary aim of this exploratory seminar was for participants of this seminar to leave with heightened awareness of which parts of certain activities might create additional stress for which students and whose bodies certain activities are aligned with and whose are not. Furthermore, the participants should get ideas for alternative solutions for these students.

Together, we reflected on current design choices in science education that engage students' physical bodies and explore potential design guidelines to facilitate these choices. For example, how may we design alternative versions of an educational activity to include students with different bodies without alienating them? How can we build a trusting environment for students to be physically active? This seminar aimed to critically discuss such questions in the context of science education.

We created a short summary from two data sources. First, from group discussions, we gathered the physical mind maps that the groups created. Second, we took detailed notes during the whole-group discussion. From this, we identified three recurring themes:

First, a frequently suggested idea was designing **alternative options** inclusively for students who are unable or prefer not to participate in a certain activity. We can either co-design and negotiate alternative options with the students, or instructors can offer equally meaningful and important options (e.g., assigning the role of the observer but reframing it as an important part of an experiment).

Second, we discussed how to design **space and material** inclusively. We can avoid exclusion by communicating a certain activity ahead of time and thereby allowing students to prepare, e.g., by choosing appropriate/comfortable clothing. Furthermore, the use of manipulatives could replace body-based activities (e.g., using a fake hand instead of a physical one). Generally, creating a safe space (i.e., the physical learning space) in which students can also explore activities out of their comfort zone is important. However, we need to elaborate more on what a safe space fully entails and how to create it.

Finally, some participants stressed the importance of fostering a positive **attitude** towards new experiences. Specifically, we should encourage students to try activities that they may initially not be comfortable with. In other words, it is necessary to foster an open mindset towards new experiences. In this context, we can even further teach students how to deal with discomfort to a certain extent.

Expected Long-Term Outcomes

Since we were aware that a 45-minute session is not sufficient to conceive complete design guidelines, we facilitated the formation of research relationships among participants to further discuss science education research in the context of inclusive movement. We have since continued the discussion virtually with interested participants. Currently, as a group, we developed a leading question: what actions can teachers take to ensure inclusive scientific experimentation and how does this depend on context? We are preparing more contributions to the scientific discussion on inclusive science education by building on the outcomes of this seminar. This is a first step towards a more inclusive movement in science education, starting with a highly prominent form of movement – experimentation. Interested scholars and practitioners are invited to contact any of the authors.

Conclusion

This exploratory seminar highlighted the importance of inclusive alternatives, thoughtfully designed spaces and materials, and fostering an open mindset that supports students in engaging with new and potentially uncomfortable learning experiences. We hope that participants have left this exploratory seminar with heightened awareness of the diversity of human bodies in classrooms and empirical studies, and how they might stand in tension with the normative expectations of certain activities. We invite interested participants, graduate students, educators, and researchers to join our newly formed group by contacting any of the authors.

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Validation Of A Professional Science Identity Scale For Higher Education Students Of Chemistry

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Although wide-spread internationally, science identity is just recently gaining importance in higher education in Germany as a possible factor impacting retention rates in science study programmes. Since German language instruments for surveying higher education students' science identity are lacking, this study validated a scale for use in chemistry-related programmes. Areas of science identity negotiations were drawn from science identity theory following Carlone and Johnson (2007) and Hazari et al. (2010). From a review of existing English language scales, a science identity scale with references to science identity theory and professional aspirations was chosen and translated. Hypotheses concerning validity were formulated and tested. Evidence of face validity and content validity was collected by means of discussion with science education experts and in qualitative think alouds with Bachelor students in chemistry-related courses. A quantitative survey of Bachelor students in chemistry and primary science was used to examine convergent and differential evidence of validity. The study generated evidence for the validity of the scale for use with higher education students in chemistry-related programmes. In future studies with German-speaking students, the scale can be used as an indicator of professional science identity and its utility as a predictor of retention and completion of chemistry-related higher education courses can be examined.

Keywords: identity negotiation, measurement instrument

Introduction

Both numbers of enrolment in chemistry programmes and successful completions have been declining over the last decade (GDCh, 2024). While attrition and drop-out from higher education and their interplay with study-related variables have been studied extensively in the German context (e.g. Fischer et al., 2020), science identity has not yet been considered a possible predictor in chemistry. Even though developing a science identity is important for professional aspirations of science learners (Archer et al., 2015) and success in higher education (Carlone & Johnson, 2007), science identity is rarely studied in higher education in Germany (Borchert & Schwedler, 2024; Danielsson et al., 2023; Günter et al., 2023; Schmid, 2023).

Identity is often described as "[b]eing recognized as a certain 'kind of person' in a given context" (Gee, 2000, p. 99). These recognition processes are based on shared, normative expectations about what constitutes that kind of person (cf. virtual social identity, Goffman, 1963). Areas of negotiation of those identity norms in science are competence, performance, recognition and interest (Carlone & Johnson, 2007; Hazari et al., 2010). A science identity scale should therefore be able capture identity negotiations along these norms.

There are several English language measurement instruments for science identity, some focusing on specific subjects, e.g. chemistry (Wolfe, 2013; Hosbein & Barbera, 2020) or physics (Hazari et al., 2010; Wulff, 2019). Often a single-item indicator of seeing oneself or being seen as a science person is used, together with related scales for the areas of science identity negotiation (Archer et al., 2015; Hazari et al., 2010; Hosbein & Barbera, 2020; Schmid, 2023). Shorter scales combine the areas of negotiation (e.g. Wolfe, 2013), survey belonging to the community of scientists (Byars-Winston et al., 2016) or professional aspirations (Lockhart et al., 2022; Williams et al., 2018). However, there are no short instruments in German for professional science identity

in higher education. This study therefore validated a German translation of the scale by Williams et al. (2018) for use in chemistry-related courses.

Research Questions And Hypotheses

The science identity scale by Williams et al. (2018) addresses the areas of negotiation of science identity norms and professional aspirations by relating science identity to a professional future self. This focus is of interest to our intended use of the scale with higher education students as a predictor for attainment or drop-out (Beaujean, et al., 2025).

Validation of the German translation followed the research question: To what extent can the translated scale be used as an indicator of professional science identity (PSI) when administered to Bachelor students in chemistry-related study programmes with the aim to assess interindividual differences in the extent of PSI?

The validation process (Hartig et al., 2020) was guided by the following hypotheses:

H1: The score on the PSI scale is linked to the areas of science identity negotiation.

H2: Differences in scores on the PSI scale can in part be traced back to difference in the enrolment in a study programme.

Methodology

Translation And Think Aloud

The science identity scale by Williams et al. (2018; cf. Supplement 2) was chosen for translation to German. Its nine items each consist of a statement about the participants and their relation to science (e.g. Item 1: “I am the kind of person who can succeed in science”; German translation: “Ich bin so eine Person, die in den Naturwissenschaften erfolgreich sein kann”). Experts in chemistry education assessed whether the translation was idiomatic and consistent with the aims of the scale.

After revision of the translation, five Bachelor students in chemistry-related study programmes answered the items and commented on the scale in a think aloud study (Kansizoglu, 2024). Qualitative content analysis (Kuckartz & Rädiker, 2023) was used to analyse transcriptions of the audio recordings. The areas of science identity negotiation, “Competence”, “Performance”, “Recognition” and “Interest” (Carlone & Johnson, 2007; Hazari et al., 2010) were used as deductive categories for coding. The remaining data was coded inductively as fitting in with science (“Fit”) and job and career negotiations (“Aspirations”).

Collection Of Quantitative Data

In an online survey, the scale was administered to students in two chemistry-related Bachelor programmes (Chemistry and Primary School Science) during the summer terms of 2024 and 2025 at a German full university. The survey also contained established German language scales on interest in chemistry, chemistry self-efficacy and chemistry self-concept (van Vorst, 2013; cf. Schmid, 2023) for comparison to areas of science identity negotiations. All instruments were scored on a 4-point rating scale. Demographic data comprised age, gender identity, study programme, semester, academic generation, grade of school-leaving certificate and course profiles for chemistry.

Analysis Of Quantitative Data

Internal structure of the PSI scale was determined using exploratory factor analysis (EFA) with principal axis factoring and promax rotation (Weiber & Sarstedt, 2021). Parallel analysis was run

to determine factor structure (Weiber & Sarstedt, 2021) and reliability was calculated using Cronbach's Alpha.

In order to examine evidence for convergent validity (H1), the mean score on the PID scale was correlated with the mean scores on the scales for interest, self-efficacy and self-concept using Pearson correlation coefficient.

Differential evidence (Kline, 2016; H2) was examined by testing mean scores of PSI for differences between study programmes with the two groups of chemistry students and primary teacher students. The latter group studies general concepts of chemistry among other natural and social sciences in their education courses but does not participate in courses such as physical or organic chemistry. Therefore, lower scores on the PSI scale were expected for the primary science students than for the chemistry students. Since Shapiro-Wilk test indicated that data in the chemistry group were not normally distributed, differences were tested using Mann-Whitney U test.

Description Of Sample

The sample consisted of 133 participants. 36 were chemistry students and 97 primary teacher students. On average, the students were 22 years old and in their third semester. 94 students identified as women, 36 as men and 3 reported a non-binary gender identification. 71 students were first generation academics, 61 were at least second-generation academics.

Mean grade of school-leaving certificate ("Abitur", the grading system ranges from 1.0 (highest) to 4.0 (lowest passing grade)) was 2.2 ± 0.57. Regarding the course profiles for their school-leaving certificate, 23 students had studied advanced level chemistry, 46 basic level chemistry and 62 students had had no chemistry classes.

Results

Evidence Of Content Validity (H1)

In the think aloud study the students reported on their thoughts when reading and answering the PSI items. Evidence was found for all four areas of science identity negotiations. There were 16 codings addressing aspects of competence and 5 codings about performance in science. In 8 codings, recognition as a science person was expressed and 11 codings reported on student interest in science. The remaining data was coded inductively. There were 30 codings in which the students negotiated fitting in with science biographically and currently, while 21 codings dealt with their future job and career aspirations of becoming a science professional.

EFA with parallel analysis indicated an 8-item scale with one-factorial structure. Following EFA, item 9 was eliminated from the scale. Cronbach's Alpha of the 8-item scale was 0.895, indicating high reliability.

Convergent (H1) And Differential (H2) Evidence

Mean PSI score was found to correlate significantly and with a large effect size with interest in chemistry ($r = 0.667$; $p = .000$) and chemical self-concept ($r = 0.561$; $p = .000$) and with a medium effect size with chemical self-efficacy ($r = 0.423$; $p = .000$).

Chemistry students (MD = 3.6; IQR = 0.7; $n = 36$) scored higher on the PSI scale than primary teacher students (MD = 2.9; IQR = 0.6; $n = 97$) with a large effect size ($U = 555.550$; $p < .001$; $r = 0.52$).

Discussion And Conclusion

The study provides evidence of validity and reliability of the PSI scale for use with students in chemistry-related study programmes. Both hypotheses were supported by data analysis. Think aloud data further underpins that participants negotiate their identities against the norms of science identity and a professional self in science when answering the items.

Chemistry students score higher on the PSI scale than students of primary school science, indicating that the scale can distinguish students in degree programmes with varying importance of chemistry.

As sample sizes of the sub-groups differed, more data from students of chemistry need to be collected and confirmatory factor analysis needs to be run to assess factor structure in order to complete the validation process.

The PSI scale can be used as an indicator of professional science identity negotiations in higher education students. Its utility as a predictor of retention and completion of higher education chemistry programmes can be examined.

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Examining Cultural Influences On The Development Of Classification Among Indigenous Students

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In multicultural science education, classification is often treated as a neutral cognitive skill aligned with scientific taxonomy, while culturally embedded ways of organizing knowledge receive limited attention. Grounded in epistemological pluralism, a worldview perspective, and developmental psychology, this study examines how classification develops among Indigenous Tao learners and how cultural and experiential factors shape classification practices across age groups. Participants included Tao middle and upper elementary students and community elders. They completed a two-phase classification task involving living organisms, followed by semi-structured interviews. Data were analysed using an iterative coding scheme integrating theoretically informed categories with participants' sorting rationales and verbal explanations. Three interrelated patterns were identified. First, developmental shifts were observed in students' classification criteria, with upper elementary students demonstrating more stable use of biologically defined attributes and greater linguistic precision than younger students. Second, cultural influences on classification increased with age: elders consistently emphasized relational and ecological criteria grounded in lived experience, such as habitat and food chains, reflecting culturally embedded ways of knowing rather than less advanced reasoning. Third, instances of misunderstanding decreased over development and were primarily associated with early linguistic and conceptual instability, rather than cultural differences. These findings challenge deficit-oriented interpretations of Indigenous learners' scientific reasoning and reconceptualize classification as a developmental and culturally mediated practice. The study highlights the interaction of cognitive development, language, and worldview in shaping classification, and underscores the value of integrating Indigenous ecological knowledge within more inclusive approaches to science education.

Keywords: classification, developmental psychology, indigenous knowledge, epistemological pluralism, world view

Introduction

The Indigenous Tao people are a minority Austronesian group who migrated from Taiwan to the Philippines and later returned to a small island due to famine. Their culture, particularly fish taxonomy and dietary practices, differs significantly from scientific classification systems. However, this traditional knowledge is increasingly endangered, as modernization continues to replace indigenous ways of living. In formal schooling contexts, scientific taxonomy is often prioritized, while culturally embedded classification systems receive limited attention.

Previous empirical research in indigenous science education has demonstrated that learners' understanding of nature is not shaped solely by formal schooling, but is deeply intertwined with language practices, lived ecological experience, and culturally embedded knowledge systems. Evidence from longitudinal research involving Tao learners across age groups suggests that reasoning about living organisms consistently reflects relational and experience-based orientations, particularly in contexts where ecological interaction forms part of everyday life (Ge, 2022; Ge, 2023). At the same time, both local culture and school education play crucial roles in shaping students' understanding of scientific classification (Aikenhead & Jegede, 1999). In response to concerns about cultural erosion, the Taiwanese Ministry of Education has recently promoted culturally responsive curricula aimed at revitalizing indigenous knowledge. However,

how such cultural restoration efforts interact with formal science education remains insufficiently understood, raising important questions about how these frameworks coexist—or potentially conflict—in shaping students' learning experiences.

Classification is a fundamental and essential component of the Taiwanese elementary science curriculum at both middle and upper levels. Recent scholarship has emphasized that classification systems, like ethical judgments in science, are culturally mediated rather than universal, reflecting historically and socially situated ways of knowing (Castagno et al., 2023). From a worldview perspective, classification can be understood as reflecting underlying cognitive and cultural frameworks that organize how learners make sense of nature, rather than as an isolated cognitive skill detached from experience (Aikenhead, 2001). Although a small number of studies have explored how indigenous traditions and ways of thinking influence pupils' learning of taxonomy (Fu, 2004; Ge, 2023; Lee, Yen, & Aikenhead, 2012), classification as a developmental and culturally situated practice remains underexplored. In particular, empirical research examining how cultural influences shape the development of classification among Tao children is still limited. Greater attention to this issue may offer valuable insights for both science education research and policy initiatives within the Ministry of Education.

Research Questions

Accordingly, this study aims to explore the development of classification among Tao children across middle and upper elementary school levels, while also examining the extent to which cultural influences shape their classification processes. To address these aims, the study was guided by the following research questions:

1. How do Tao children at different elementary school levels classify living organisms in a sorting task?
2. What developmental shifts can be identified in Tao children's classification criteria across middle and upper elementary school levels?
3. How do cultural and ecological experiences influence Tao children's classification reasoning?

By situating classification within a worldview-oriented and epistemologically plural framework, this study seeks to contribute to a more nuanced understanding of how indigenous knowledge and formal science education interact in shaping children's scientific reasoning.

Theoretical Framework

In contemporary multicultural contexts, epistemological pluralism has increasingly been advocated as a way to challenge the exclusive representation of scientific knowledge in science education (Cobern & Loving, 2001; Sjöström, 2025). Grounded in theories from cultural anthropology and developmental psychology, this study examines the mechanisms underlying classification reasoning. From a worldview perspective, classification is not merely a technical or cognitive activity but reflects an organized framework of assumptions about reality. According to worldview theory (Kearney, 1984), people's ways of classifying the natural world are shaped not only by internal cognitive coherence, but also by ongoing interactions with, and adaptations to, their surrounding environments.

From a developmental psychology perspective (Bjorklund, 1995; Inhelder & Piaget, 1964; Vygotsky, 1962), although different theoretical traditions employ varying terminologies to describe cognitive developmental stages, they share the assumption that cognitive development unfolds over time. Early classification tends to rely on arbitrary or perceptual groupings, followed by organization based on relationships or associations, and eventually by categorization based on

shared attributes. While Inhelder and Piaget (1964) emphasized a relatively sequential progression aligned with cognitive maturation, Bjorklund (1995) and Vygotsky (1962) proposed more flexible developmental models that allow for variability across contexts and individuals. Importantly, Vygotsky (1962) argued that the development of classification is closely intertwined with language use, social interaction, and cultural participation, highlighting classification as a socioculturally mediated process rather than a purely logical operation.

Cultural influences on classification have been empirically demonstrated in cross-cultural psychology. For example, Ji, Zhang, and Nisbett (2004) found that Chinese participants tended to categorize objects based on relationships, whereas Western participants more frequently relied on shared attributes, suggesting that classification strategies are shaped by culturally patterned modes of reasoning and environmental affordances. More recent scholarship has extended this perspective by questioning the assumption that scientific knowledge—and the ethical judgments embedded within it—is epistemically neutral or culturally universal. Instead, ethics and knowledge practices are increasingly understood as culturally mediated, shaped by histories, epistemologies, and community practices (Castagno et al., 2023). From this viewpoint, tensions between Indigenous traditions and scientific knowledge are not merely ideological differences, but reflect encounters between distinct epistemological systems. Similarly, science learning has been conceptualized as relational, value-laden, and culturally situated, with knowledge produced through relationships among people, environments, histories, and purposes (Sjöström, 2025).

Research Method And Design

To investigate Tao children's classification patterns, this study employed a task adapted from Ji, Zhang, and Nisbett (2004). The task consisted of six sets of photo cards, each representing three common living organisms found on the island.

Phase I: Categorization Task

In the first phase, participants were asked to group two out of the three organisms together and explain the reasoning behind their choice. For example, if a participant grouped a pig and a monkey together while excluding a tree, stating that "both are animals," the response was coded as "characteristics" under the theme of "biological attributes" (as illustrated in Figure 1). Conversely, if a participant grouped a monkey and a tree together because "the monkey lives in the tree," the response was coded as "habitat" under the theme of "biological relations."

Phase II: Free Sorting Task

In the second phase, participants were instructed to freely sort all six sets of living organisms into groups based on their own criteria. To minimize linguistic influence, the selected organisms did not share any suffixes, affixes, or word roots in the Tao language.

Semi-Structured Interviews

In addition to the categorization task, participants took part in a semi-structured interview to assess their understanding of classification. At the beginning of the interview, they were asked whether they recognized the concept of classification. After completing the task, they were asked to reflect on whether their grouping decisions represented a form of classification

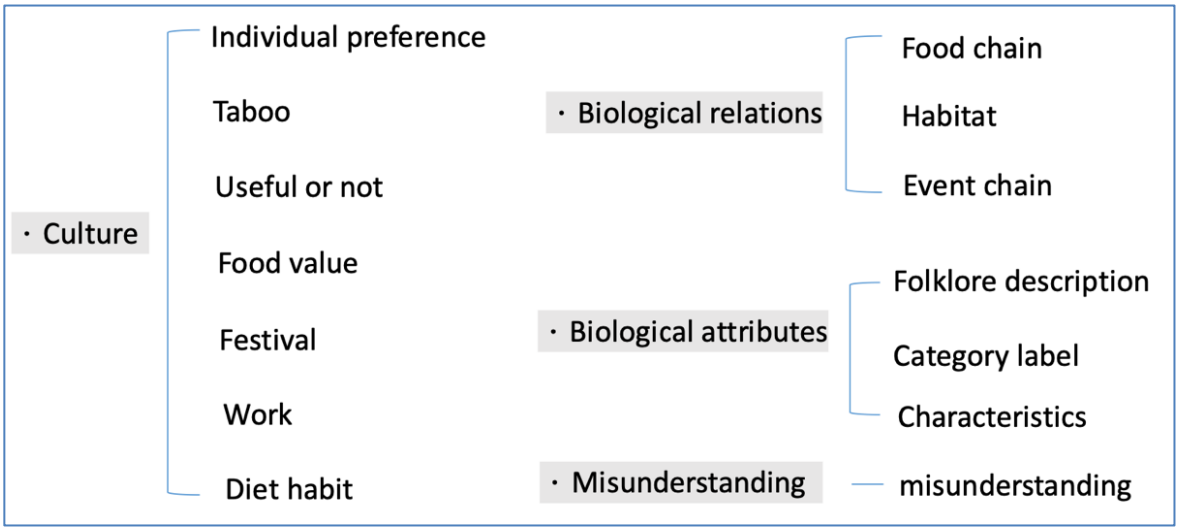
Data Analysis

Data analysis was guided by the study’s theoretical framework and research questions, drawing on perspectives from worldview theory and developmental psychology. The analysis aimed to examine how participants’ classification practices reflected both developmental patterns and culturally situated ways of reasoning. Rather than treating classification as a single outcome, the

analysis focused on the criteria and rationales participants used when grouping living organisms, as these were understood to index underlying cognitive, linguistic, and cultural orientations.

Participants' sorting decisions and verbal explanations were analysed iteratively. Initial coding focused on identifying the primary criteria used in classification, such as biological attributes and biological relations. These preliminary categories were informed by prior research on classification development and cross-cultural reasoning, providing an initial analytic lens for examining participants' responses. Comparisons were then conducted across middle elementary, upper elementary, and senior participants to identify developmental shifts and variations associated with age and lived ecological experience.

Figure 1. Coding scheme of classification criteria with 4 themes and 14 codes.



The coding scheme presented in Figure 1 was developed through an iterative process integrating theoretical perspectives and empirical data. As analysis progressed, participants' verbal explanations were closely examined to capture how classification criteria were articulated in practice. This process led to the refinement and expansion of coding categories, including the identification of culturally embedded reasoning, such as references to ecological practices, subsistence activities, and everyday experiences. Instances in which participants' explanations reflected ambiguous or inconsistent use of classification concepts were coded separately as misunderstandings, allowing analytic distinction between alternative epistemic orientations and conceptual confusion.

Consistent with a sociocultural perspective, participants' verbal explanations were treated as essential analytic data rather than supplementary comments. Attention was given to how language use, experiential references, and culturally grounded knowledge informed classification reasoning. Through this combined analytic process, the final coding scheme represents a synthesis of theoretical expectations and empirical regularities, providing a structured yet context-sensitive framework for interpreting classification as a developmental and culturally mediated practice within indigenous science learning contexts.

Participants

The study recruited both Tao elementary students and seniors as participants. Among the students, those in grades 3 and 4 were categorized as the middle school level group, while those in grades 5 and 6 were classified as the upper school level group. Table 1 presents the basic demographic information of the participants. Most of the senior participants had received a junior school education, while two had earned a bachelor's degree.

According to Table 1, the result that many students defined classification as waste sorting is related to Taiwanese waste management. Waste sorting has to be done before garbage disposal.

The data of seniors was drawn on previous study as reference so that the definition of classification and identification if their work is a kind of classification were not available in Table 1. Data analysis is based on the interview transcription and criteria of categorization. A coding scheme of 4 themes and 14 codes, shown as Figure 1, is developed for further comparison and analysis.

Table 1. Basic information about participants.

	number	gender	define classification	Is the work classification?
Middle elementary students	23	7 females 16 males	65% (n=15) waste sorting 13% (n=3) organize things 22% (n=5) sorting by common attributes	All confirmed
Upper elementary students	16	6 females 10 males	6% (n=1) unknown 44% (n=7) waste sorting 50% (n=8) sorting by common attributes	All confirmed
Seniors	24	12 females 12 males		

Findings And Discussion

The findings are presented with respect to three interrelated themes: developmental shifts in classification criteria, the increasing salience of cultural influences with age, and the reduction of conceptual misunderstanding over development.

I - Developmental Shift In Classification Criteria

Students' classification performances revealed clear developmental patterns that align with, but also extend, perspectives from developmental psychology. As shown in Table 2, upper elementary students were more likely to classify living organisms based on biological attributes (61.5%) than middle elementary students (49.4%) in Phase I. This pattern is consistent with developmental accounts suggesting that increasing cognitive maturity supports more stable use of attribute-based categorization. At the same time, the frequent misuse of terminology among middle-level students—for example, using "living things" to refer specifically to "animals"—indicates that younger students' classification reasoning is closely intertwined with ongoing language development. Classification at this stage appears to rely not only on perceptual features, but also on emerging linguistic resources that constrain how biological categories are expressed and differentiated.

In contrast to students' predominant reliance on biological attributes, seniors consistently classified organisms based on biological relations, such as habitat, food chains, and ecological interactions, across both Phase I and Phase II (Tables 2 and 3). Interview data revealed that many seniors explicitly drew on lived experiences of survival on the island, including fishing practices and long-term interactions with local organisms, when explaining their sorting decisions. Rather than indicating a less advanced form of classification, this relational pattern reflects an experience-driven mode of reasoning grounded in sustained engagement with the external environment. From a worldview perspective, seniors' classifications can be understood as the outcome of accumulated ecological knowledge, in which relationships among organisms are more salient than abstract categorical boundaries. This finding challenges a strictly linear interpretation of classification development and supports sociocultural models that emphasize variability in developmental trajectories shaped by experience and environmental adaptation.

Results from Phase II further illuminate the interaction between development, language, and classification. When participants were provided with a wider range of biological vocabulary, such as reptile categories, upper-level students demonstrated improved linguistic precision in their explanations. However, the overall reliance on biological attributes remained relatively consistent between middle and upper elementary students (Table 3). This suggests that while language development enhances students' ability to articulate classification decisions, it does not necessarily shift their underlying classification orientation. Developmental change in classification thus involves not only cognitive maturation, but also the expanding availability of linguistic and experiential resources that shape how classification criteria are selected and justified.

Table 2. Criteria of classification-the themes appear in Phase I.

Theme	Middle level students	Upper level students	Seniors
Culture	4.0%	6.3%	23.1%
Biological relations	25.0%	31.3%	63.9%
Biological attributes	49.4%	61.5%	9.5%
Misunderstanding	21.6%	1.0%	3.4%

Table 3. Criteria of classification -the themes appear in Phase II.

themes	Middle level students	Upper level students	Seniors
Culture	5.0%	11.2%	24.5%
Biological relations	31.5%	32.2%	55.0%
Biological attributes	50.8%	50.0%	19.9%
Misunderstanding	12.6%	6.6%	0.7%

Importantly, evidence beyond the sorting tasks further supports this interpretation. Interview data from a parallel longitudinal project (MOST 111–MY2) revealed convergent reasoning patterns, in which Tao participants across age groups consistently framed living organisms through relational, ecological, and culturally embedded explanations. This cross-task consistency indicates that the observed classification patterns reflect relatively stable epistemic orientations rather than task-specific strategies. Taken together, these findings suggest that differences between students' attribute-based classifications and seniors' relational classifications are best understood not as developmental deficits, but as distinct ways of organizing biological knowledge shaped by language development, lived experience, and culturally grounded worldviews.

II-Cultural Influence Increases With Age

Beyond developmental shifts in classification criteria, the findings indicate that cultural influences on classification become increasingly salient with age. As shown in Tables 2 and 3, seniors demonstrated the highest proportion of culturally grounded classification, frequently drawing on traditional ecological knowledge, subsistence practices, and culturally meaningful relationships among living organisms. In contrast, cultural references were comparatively rare among middle and upper elementary students, whose classifications were more strongly anchored in biologically defined attributes. This age-related pattern suggests that cultural knowledge does not merely coexist with scientific classification but progressively shapes how classification criteria are selected and prioritized over time.

From a worldview perspective, this pattern aligns with Kearney's (1984) assertion that classification systems reflect organized cognitive frameworks shaped through ongoing

interaction between individuals and their environments. Seniors' reliance on cultural reasoning indicates that classification is not simply a cognitive operation applied to biological entities, but a practice embedded within socio-cultural histories and lived ecological experiences. Cultural knowledge in this context functions as an interpretive framework that foregrounds relationships, purposes, and ecological interdependence, rather than abstract taxonomic boundaries.

These findings also resonate with research in cultural psychology demonstrating systematic differences in categorization strategies across cultural contexts. Ji, Zhang, and Nisbett (2004), for example, found that individuals from East Asian cultural backgrounds tend to emphasize relational classification, whereas Western participants more often rely on categorical attributes. The Tao seniors' classification practices extend this line of research by illustrating how relational and culturally embedded reasoning is not only culturally patterned, but also developmentally reinforced through long-term participation in local ecological and social practices. Taken together, the results suggest that indigenous classification systems represent integrated ways of knowing that connect biological understanding with cultural meaning, rather than deviations from scientific classification norms.

III-Reduction In Misunderstanding Over Development

In addition to developmental shifts and increasing cultural influence, the findings reveal a clear reduction in misunderstanding across age groups. As shown in Tables 2 and 3, instances coded as misunderstanding were more prevalent among middle elementary students and decreased substantially among upper elementary students and seniors. This pattern suggests that conceptual confusion in classification is not a stable characteristic of indigenous learners' reasoning, but rather a transitional phenomenon associated with early stages of cognitive and linguistic development.

Closer examination of students' explanations indicates that misunderstandings among younger participants often stemmed from limited linguistic resources and incomplete differentiation of biological categories, rather than from culturally grounded ways of knowing. For example, the use of overly general terms or inconsistent category labels reflected difficulties in articulating classification criteria, rather than alternative epistemic orientations. As students gained greater linguistic precision and conceptual stability, such ambiguities diminished, even as cultural or relational reasoning did not necessarily increase in the same way. This distinction is analytically important, as it underscores the need to differentiate between misunderstanding as conceptual instability and culturally embedded reasoning as a coherent way of organizing knowledge.

From a sociocultural and worldview perspective, the reduction of misunderstanding over development further supports the interpretation that indigenous learners' classification practices are shaped by expanding linguistic, cognitive, and experiential resources. Seniors' near absence of misunderstanding, alongside their strong reliance on relational and ecological criteria, indicates that culturally grounded classification is not a less developed form of scientific reasoning, but a stabilized epistemic orientation supported by extensive lived experience. Taken together, these findings suggest that effective science education in indigenous contexts should not aim to replace cultural ways of knowing, but to support learners in developing the linguistic and conceptual resources needed to navigate and articulate multiple classification frameworks.

Conclusion

This study examined the development of classification among Tao learners across middle and upper elementary school levels, with particular attention to how developmental, linguistic, and cultural factors shape classification practices. By integrating perspectives from developmental psychology, worldview theory, and epistemological pluralism, the findings offer a nuanced

account of classification as a culturally mediated and developmentally situated practice rather than a purely technical cognitive skill.

Across the findings, three interrelated patterns emerged. First, developmental shifts in classification criteria revealed that students increasingly relied on biologically defined attributes as cognitive and linguistic resources expanded, while seniors predominantly emphasized relational and ecological criteria grounded in lived experience. These patterns align with developmental theories yet also extend them by demonstrating that relational classification among elders reflects stabilized ecological knowledge rather than a less advanced stage of reasoning. Second, cultural influences on classification became more salient with age, as seniors' classifications drew extensively on traditional ecological knowledge and culturally meaningful relationships among organisms. From a worldview perspective, these findings highlight how classification functions as an epistemic practice shaped by sustained interaction with specific environments and cultural histories. Third, the reduction of misunderstanding over development underscores the importance of distinguishing conceptual instability associated with early language development from culturally embedded ways of knowing. As linguistic precision and experiential grounding increased, misunderstandings diminished, while culturally grounded classification orientations remained coherent and stable.

Taken together, these findings challenge deficit-oriented interpretations of indigenous learners' scientific reasoning and instead support a view of classification as a practice that emerges through the dynamic interplay of cognitive development, language use, and cultural participation. For science education, particularly in multicultural and indigenous contexts, this study suggests the value of pedagogical approaches that do not seek to replace indigenous ways of knowing, but rather support learners in navigating and articulating multiple classification frameworks. By recognizing relational and ecological reasoning as legitimate forms of scientific sense-making, science education can move toward more inclusive and contextually responsive practices.

Limitations And Future Research

Several limitations of this study should be acknowledged. First, the classification tasks employed in this research focused on living organisms within a specific ecological and cultural context. While this design was intentional and theoretically grounded, the findings may not be directly generalizable to other indigenous groups or scientific domains without further investigation. Second, although the study incorporated multiple data sources, including sorting tasks and interviews, the analysis relied primarily on qualitative coding of participants' explanations. Future research could complement this approach with longitudinal designs or mixed-method analyses to examine how classification practices evolve over time within individuals.

Future research could also explore how instructional interventions explicitly designed to bridge indigenous and scientific classification systems influence students' reasoning and language use. Comparative studies across different indigenous communities would further illuminate how diverse ecological contexts shape classification practices and worldview orientations. Finally, extending this line of inquiry to classroom-based interactions could provide deeper insight into how teachers and students negotiate multiple epistemic frameworks during science learning. Such research would contribute to ongoing efforts in science education to develop culturally responsive pedagogies that respect epistemological diversity while supporting students' scientific understanding.

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Positioning Towards Science From An Identity Perspective: Results Of An Interview Study With Pupils In Their Initial Science Lessons

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The identity perspective is one way to better understand educational choices. Against this background, pupils' perceived approaches to science and their first institutionalised encounters with science, for example in subject lessons, can provide initial indications of their educational decisions throughout their educational careers. The aim of this research project is to gain a better understanding of how grammar school pupils perceive and position themselves in relation to science and science lessons, particularly in physics and chemistry during their first two years of science education. Guided and narrative-based individual interviews were conducted in two German federal states and 15 different grammar schools. The interview study comprises two waves of data collection, with all learners having experienced at least one school year of physics lessons at the time of the first interview. In a first step we focus our analysis on understanding which aspects students use to position themselves in relation to science and physics in their first interview. The qualitative content analysis of 30 interviews led to the development of a category system with four main categories: personal characteristics, school biography, science (subjects) and physics (lessons). The analysis reveals that students primarily position themselves on the basis of the science lessons they have experienced. The four main categories also correspond to core areas of students' (science) identity development.

Keywords: Early Science Education, Qualitative Research, Science Identities

Introduction

According to international science education research, educational choices, such as the decision to engage with or distance oneself from science, or the experience of feeling included in or excluded from scientific communities, can be understood in relation to identity (Archer et al., 2010; Carlone & Johnson, 2007). A preliminary understanding of identity can be drawn from socio-psychological and sociological perspectives: identity formation involves both self-knowledge and self-image, as well as the perceptions and ideas developed through interactions with others (Morf, 2023; Shanahan, 2009). Therefore, identity construction can be seen as a negotiation process influenced by an individual's social context and embedded within broader societal frameworks (Regan & DeWitt, 2015).

Theoretical Background

In the research project IdentMINT the construct of identity is employed as a multi-perspective framework to analyse students' engagement with and positioning towards science. Our identity framework focuses on students as whole persons, rather than isolating individual educational constructs (Avraamidou, 2020; Rabe & Krey, 2018), thereby placing their self-perception and relevance systems at the center of the inquiry.

Numerous studies have explored science identities and found that gender, ethnicity, and socio-economic background significantly influence educational trajectories (e.g., Archer & DeWitt, 2015; Hazari et al., 2022; Holmegaard et al., 2014; Kessels et al., 2006). However, there remains a research gap regarding how introductory physics and chemistry education shapes identity negotiation (Rabe & Krey, 2018). This is especially important given that, in many countries, including Germany, institutional encounters with science coincide with adolescence, a critical

phase of identity development. A developing physics identity may conflict with other identities, such as a students' gender identity (Brickhouse et al., 2000).

Positioning is regarded as a relational construct and constitutes an integral part of human communication and understanding (e.g. through actions, speech acts or social interaction). It assigns a relational position to both persons and objects in social space, either explicitly or implicitly (Davies & Harré, 1990; Harré & Van Langenhove, 1991). In the research project IdentMINT, positionings are reconstructed from linguistic expressions, i.e. statements made by learners about an object, and are regarded as indicators of identities. This understanding aligns with Harré and Van Langenhove (1991), who emphasise that narratives in which people talk about themselves differ according to how the individuals wish to present themselves.

Research Interest

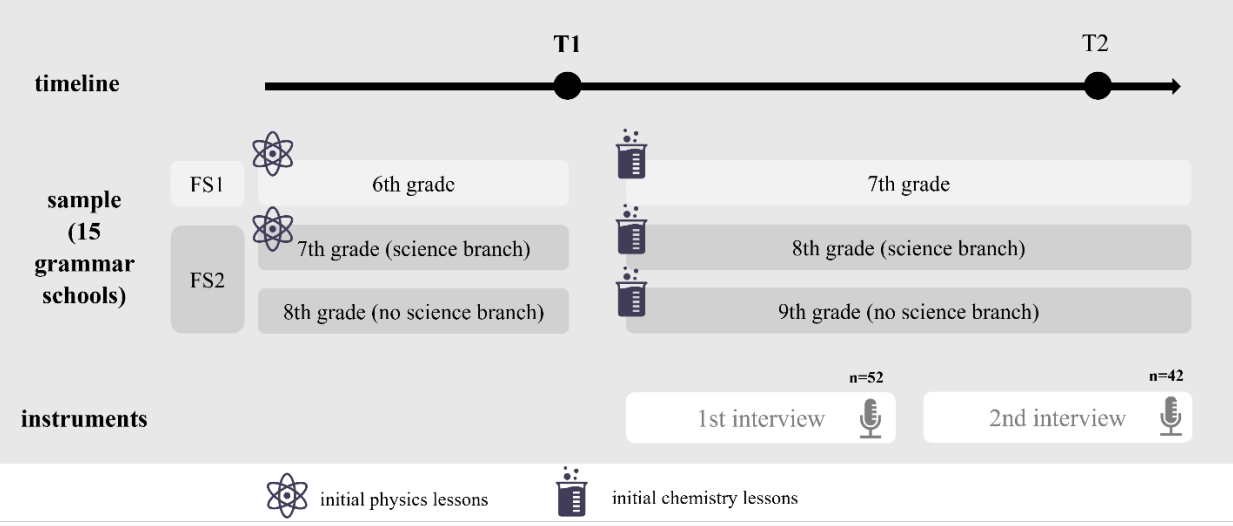
In Germany, science education is based on subject-specific lessons like physics, chemistry and biology, rather than an integrated subject "science". The goal of IdentMINT is to deepen our understanding of how grammar school students perceive and relate to science, particularly in physics and chemistry, during the initial years of their formal science education. The central research question is: How do young learners position themselves towards science, particularly physics and chemistry, when talking about it?

Study Design And Interview Sample

The research project employs a mixed-methods approach, combining the interview study presented in this article with a longitudinal questionnaire survey.

Narratives, in which students shed light on their own experiences, offer valuable opportunities for identity formation (Lucius-Hoene & Deppermann, 2002). Accordingly, guided, narrative-based individual interviews were conducted with students from fifteen different grammar schools across two federal states of Germany (FS1: Saxony Anhalt, FS2: Bavaria). The interview study comprises two data collection points (T1 and T2). By T1, all participants had completed at least one year of physics education and by T2, they had additionally completed one year of chemistry (see Figure 1). However, the present article reports only findings from interviews conducted at T1.

Figure 1. Overview of the longitudinal interview study design.



The interview sample was selected to be as heterogeneous as possible with respect to gender, ethnic background and migration history, interest in science, and Science Capital. The relevant school authorities have approved the data collection from an ethical and legal perspective. The sole requirement for participation was voluntary consent, authorized by the participants' legal

guardians. At T1, the sample comprised 52 students from grades 6 and 7 (FS1) or 7 to 9 (FS2), 42 of whom also participated at T2.

Data Analysis And Findings

To answer the research question, the interviews were analysed using qualitative content analysis (Kuckartz, 2018). The category system was developed on the basis of a reduced sub-sample of 30 learners, selected to ensure broad coverage of the aforementioned characteristics. The category development followed a combined deductive-inductive approach: initial categories were derived deductively from the interview guideline and the theoretical and empirical literature in the field. The categories were subsequently refined and specified inductively based on the interview transcripts. Throughout the analysis process, intercoder agreement is regularly assessed; so far, a 'substantial' level of agreement has been achieved with k_n= 0.73 (Brennan & Prediger, 1981). The developed category system will be applied to the remaining 22 interview transcripts and revised if necessary. Below, we will provide an illustrative insight into the category system, including selected illustrative examples.

Insight Into The Category System

As a first result, we identified four main categories, along with their respective subcategories, which highlight key aspects that students use to position themselves in relation to science:

- *Personal Characteristics* (e.g., self-attributed qualities, hobbies, career aspirations, role models, health-related aspects)
- *School Biography* (e.g., favourite subjects, influential people at school, transition from elementary to grammar school, school choice, selection of subject focus)
- *Science (Subjects)* (e.g., associations with science (subjects), general interest in science, extracurricular engagement with science, science-related activities at home)
- *Physics (Lessons)* (e.g., engagement with physics (lessons), comparisons with other subjects, attribution of ability, significant others in relation to physics (lessons), gender stereotypes in physics, factors leading to rejection)

Revealing information about oneself – such as discussing hobbies or career aspirations – can involve an explicit or implicit act of positioning in relation to science. Statements that provide such information have been assigned to the *Personal Characteristics* category.

Similarly, discussion of one's own school biography was identified as a form of positioning. Narratives about favourite subjects or the choice of grammar school often reflect positionings towards science that were therefore assigned to the *School Biography* category.

It is also noticeable that the learners tend to express themselves in a more vague and distant manner when referring to science in general compared to physics, chemistry, and biology. In their narratives, they predominantly draw on experiences from subject-specific lessons. To illustrate these subject-specific modes of positioning, we present examples from the following subcategories of *Physics (Lessons)* category:

- *Physics in Comparison with Other Subjects*,
- *Significant Others in Relation to Physics and Belonging*, and
- *Attribution of Ability*.

One common form of positioning is comparing physics with other subjects. Students typically identify a characteristic of physics and relate this characteristic to themselves. The following

excerpt from the interview with Ajala (pseudonyms are used) illustrates such a comparison, in this case between the subject of physics and German:

> "Physics also has its grammar, or something like that. In other words, [also in physics] there are things you must be able to do or know ways how you should approach it. In German, however, one can talk […]. German also has a gut feeling. You can answer something with a gut feeling, but in science it's just facts and you must be able to justify them and so on." (Ajala, grade 8; Pos. 167)

A second subcategory captures forms of positioning through significant others and a sense of belonging. Students position themselves in relation to physics by referring to people associated with this subject. For example, Latif emphasises his passion for physics to set himself apart from his classmates:

> "I would like to talk about physics, but I don't exchange ideas much, actually not at all, because I don't think my classmates are very interested in it. Or they just don't care or don't want to talk about class. Maybe it's boring for them." (Latif, grade 7; Pos. 155)

Finally, pupils also position themselves in relation to science by means of ability attributions. They describe their perceived skills, challenges in physics and strategies for handling physics tasks. Elza, for example, talks about her confidence when experimenting in physics:

> "Yes, I really like experimenting because you can somehow better understand the whole thing working, so much better than when someone describes how the experiment should have gone or when the teacher demonstrates it in front of you. So, when you experiment yourself, it's just somehow cooler and more practical." (Elza, grade 9; Pos. 105)

Case Analysis – An Example

A second finding is that positioning is highly individual, particularly within these subject-specific modes of positioning. To illustrate this, we present several examples from a single student, Laila.

At the time of the first interview, Laila was in grade 8 and had chosen the science profile at her grammar school. With the start of the new school year, she was placed in a new class, which was challenging for her because she had to make new friends. All her previous friends selected the language branch and are therefore in other classes. When asked why she chose the science branch, Laila expressed a generally positive view of science, presenting herself as a student interested in chemistry and capable of meeting the performance expectations in both chemistry and physics. However, in retrospect, it is evident that she had not anticipated experiencing difficulties with physics:

> "So, for me, it was clear that I would take the science branch. Because I simply wanted to have chemistry lessons as soon as possible, and I find it difficult to learn languages, so the idea of writing school assignments in chemistry and physics, that wouldn't bother me so much (laughing). Except that I already have a few problems with physics. But otherwise, it was an easy decision for me to choose science." (Laila, grade 8; Pos. 47)

When asked about her experiences in physics, she positions herself as 'not a big fan':

> "Oh, (laughing) physics. So, I'm not a big fan. So, at first, when we started, I think last year, I really tried to have fun and so on. So, the topic of light, I had some fun, because there were lots of activities and experiments and doing, and observations. But NOW there are just formulas, and lots of mathematics. And I don't like maths at all. For me, so to speak, physics is now a second maths." (Laila, grade 8; Pos. 67)

Her explanation highlights her conflict with physics: although she enjoys certain topics and scientific activities such as experimentation and observation, the mathematical nature of physics poses a challenge for her. As a result of her experiences in physics lessons, the subject feels like a second mathematics class, which is particularly significant because she dislikes mathematics. Nonetheless, her belief that physics should be enjoyable remains evident.

Her favourite subject at school is a science subject: biology. In the following interview excerpt, she emphasizes the personal relevance and her interest in biological topics, particularly in plants:

> "I like those [biological] topics, they are very interesting. It's fascinating to observe other living beings and see what they do. This is a new world, and I think that's really, really nice. Also taking care. Even if it's just breathing or something, or like plants, just standing (laughing) there. They are also very interesting, because they are simply different. Taking a closer look, has always appealed to me, so to speak." (Laila, grade 8; Pos. 59)

Lailas mother, a geriatric nurse, supports her interest in plants by sharing her knowledge and providing books. In her leisure time, Laila also watches documentations about animals and enjoys drawing characters and stories. After school, Laila spends most of her time at home and rarely meets with friends. She lives with her parents and younger sister, and she considers her mother a role model. Her parents encouraged her to go to grammar school after primary school to ensure she received the best possible education. At the beginning of the interview Laila expressed her desire to become a plant or animal researcher, conducting experiments or observe whether animals can think independently.

Summary And Implications

The category system indicates that students primarily position themselves based on their experiences in science lessons, alongside personal and school-linked factors. While some students reflect on more general scientific experiences, they often illustrate their positioning with concrete subject-specific encounters. The question of why certain aspects are addressed by the interviewees will be explored in an exemplary, reconstructive, in-depth case study.

Main Categories As Core Areas Of (Science) Identities

When learners discuss physics, they refer not only to physics aspects but also to personal and school-related factors, such as being a good student, friendships, or engaging in hobbies. Our analyses suggest, consistent with previous research, that identity negotiations in physics are intertwined with broader identity processes and cannot be considered in isolation (Calabrese Barton et al., 2013; Hazari et al., 2010). Accordingly, the four main categories represent core areas of students' (science) identity development.

In the interview example with Ajala, she identifies structure and rules, or as she calls it a specific "grammar", in both German and physics. However, she values rational justification in physics more than an intuitive approach she experiences in German. By comparing the two subjects, Ajala reveals a facet of her identity through her positioning. Latif faces the challenge of wanting to discuss physics but is struggling to find like-minded peers, as his classmates are less interested in the subject. This sense of uniqueness shapes his positioning. Elza, in contrast, demonstrates self-confidence in experimenting and trusts her ability to acquire knowledge through hands-on activities. The influence of significant others and the importance of group affiliation (illustrated by Latif's experience) align with previous research, which emphasize the role of these factors in identity formation (DeWitt & Archer, 2015). Furthermore, the data suggest that access to science education plays a crucial role in shaping students' engagement with science (subjects) and in the negotiation of their identities.

Science Identities?

Furthermore, students differ considerably in whether they perceive science as a cohesive whole or as a collection of distinct disciplines. References to chemistry are particularly notable, given that, at the time of the first interview, the students had attended no or only a few weeks of chemistry instruction. It should be noted at this point that at the participating schools there is no subject called "science", which complicates discussions of a general science identity. Future research could investigate the validity of assuming the existence of a general science identity versus distinct identities for physics, chemistry, or biology, especially for specific educational purposes. This is particularly evident in Laila's interview. While she demonstrates an ambitious and open-minded stance towards science in general and biology in particular, she struggles with physics at grammar school. Although she initially looked forward to physics with high expectations and continues to enjoy scientific activities, she has distanced herself from physics due to its mathematical emphasis. This case raises a larger question: How does the development of subject-specific identities might align with or conflict with the development of broader scientific identities? It is crucial to empirically investigate the impact of integrated science teaching versus discipline-specific instruction on students' identity development.

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Identifying And Understanding Factors Influencing Students' Decisions Regarding STEM Education Pathways – First Findings

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The research project DynaMINT (Dynamics of STEM-related educational and vocational decisions of children and adolescents) investigates how the self-positioning of children and adolescents towards science, technology, engineering and mathematics (STEM) develops during adolescence (age 13 to 16). This longitudinal study surveys participants over a period of 18 months.

The qualitative study aims to identify factors shaping students' decisions for or against STEM educational pathways, particularly in grade nine and ten. The study examines negotiation processes connected to STEM identity development and how co-curricular and informal STEM activities influence these processes with the goal of a clearer understanding of students' educational decision-making in STEM contexts.

By incorporating longitudinal data collection methods, including interviews and short surveys, the research will provide valuable insights into how students' perceptions of STEM evolve over time. This article presents the theoretical framework, the methodological approach, and first findings with a focus on two case studies.

Keywords: Science Identity, Qualitative Research, Educational Pathways

Introduction

Due to its crucial role in driving innovation, economic development, and addressing complex societal challenges, there has been an increasing global emphasis on STEM education (OECD, 2018). However, participation in STEM subjects remains lower than desired, especially among certain demographic groups, including women, students from lower socioeconomic backgrounds, and those from underrepresented minorities (Anger et al., 2024). At the end of secondary school, German students are at a crossroad in their educational journey, making decisions that will shape their academic and professional futures (Kultusministerkonferenz, 2022). Understanding the factors that influence these decisions can provide valuable insights into how to encourage more students to pursue STEM pathways.

Students' Decisions On Educational Pathways

Educational pathway decisions are shaped by a complex interplay of social, cultural, and institutional factors (Rabe und Krey, 2018). In Germany, early educational tracking requires students to choose between different types of secondary schools, which structure subsequent subject choices and educational opportunities (Kultusministerkonferenz, 2022). Within those school-types students have the possibility to decide on different subjects or different foci (e.g. science-focused or focused on foreign languages).

Besides these institutional aspects, the socioeconomic status and the parents' educational level still play a significant role in the students' decision-making process in Germany. Adolescents whose parents attained a lower educational status are less likely to finish their school career with a certificate that allows them to go to university than children of parents with a higher educational status (Autor:innengruppe Bildungsberichterstattung, 2024). Additionally, socioeconomically disadvantaged students are on average seven times less likely to reach the basic level of

competence in mathematics and science than socioeconomically advantaged students (OECD, 2023).

As can be inferred from the complex interplay of the factors mentioned above, the choice of educational pathways is a process that has no defined beginning or end. „Who one is and who one desires to be […] is always under negotiation and is contingent upon the resources one has access to and the social, cultural, and historical context in which one seeks to author oneself with and against the expectations of others" (Calabrese Barton et al., 2013). In other words, every decision for or against an educational pathway is a negotiation process, that is formed by and in turn forms the student's identity.

Negotiation Processes Within The Framework Of STEM-Identity Development

As the focus of the study lies on negotiation processes regarding STEM in general and on STEM subjects, the research is based on the science identity construct. Science identity research constitutes a broad international field (Danielsson et al, 2023) and provides a suitable framework for integrating multiple perspectives on educational decision-making in STEM. Kang et al. (2019) address how young people come to perceive both their present selves and possible future selves in STEM. Furthermore, the focus can be directed away from the individual towards social, political or even cultural perspectives. For example, what makes a promising STEM learner? Do these factors apply to all learners in this environment? Which factors inhibit or promote learners? (Carlone, 2023; Van Tuijl, 2016)

We focus on two models within this context: 'Framework of students' identification with physics' by Hazari et al. (2010) and 'A model of factors shaping young people's science aspirations and identities age 10-19' by Archer et al. (2020) To use these models in our research, we adapted them to the broader field of STEM-identity.

Hazari et al. (2010) who based their 'Framework for students' identification with physics' on the Model of Carlone and Johnson (2007), define identity as an interplay between three aspects: the personal, the social and the role identity. All those aspects influence each other and affect the student's view on physics. A student's development of their physics identity, which is one role-identity, is shaped by their personal and social sense of self, along with their physics-related perceptions. Four indicators for this perception are: interest (desire to learn and engage with physics), competence (belief in understanding physics), performance (belief in completing physics tasks), and recognition (acknowledgment as a physics person) (Hazari et al., 2010).

Archer et al. (2020) describe the influences on science identity and aspiration in an encompassing model which considers the overall influence of structural inequalities of gender, ethnicity and social class. Further, they name capital related inequalities (e.g. Science Capital or specific risks like mental health issues), educational factors and practices (e.g. careers education, the role of teachers or educational gatekeeping) and the representations of science (e.g. portrayal of science as masculine and clever).

Further aspects shown to influence science identity development are Significant Persons (parents, guardians, friends, teachers, siblings and well-known personalities from the media (Sjaastad (2012)), Critical Moments (events, that are retrospectively mentioned by students to have had a high impact on their decision towards STEM (Lykkegaard & Ulriksen, 2019)) and co-curricular STEM-activities (Mohr, 2022).

Co-curricular STEM Activities, Informal STEM Activities And Career Education

Co-curricular STEM activities are understood in this research as school-organized activities conducted outside regular lessons and facilitated by non-teaching staff (e.g. out-of-school

laboratories, factory tours, visits to a museum). Studies show that a visit to out-of-school laboratories has a positive effect on the motivational and affective characteristics of the students, but the picture is inconsistent regarding the persistence of these positive influences because the effects are short-term (Tillmann & Wenger, 2021).

Research on informal STEM activities indicates that such spaces provide opportunities for identity development that are often unavailable in formal classroom settings. These spaces allow students to pursue personal interests, develop skills in unique ways, engage with diverse cultures, involve their communities (such as family and friends), and exercise greater agency by directing their own scientific practices. This fosters empowerment and a more inclusive approach to science learning (Hazari et al. 2022).

Overall, co-curricular and informal STEM activities can contribute to students' motivational development, identity formation and agency, thereby supporting processes relevant to long-term career orientation and decision making. The Standing Conference of the Ministers of Education and Cultural Affairs (KMK) (2017) states that career education must be part of the school's curriculum and should be based on the students' interests, skills, and potential. The students should be enabled in a long-term process to make a reflected, self-responsible, cliché-free and active decision for their further education and career path.

Research Questions

Based on the theories and models presented so far, the study focuses on how students decide on their future educational pathways, particularly regarding STEM subjects and aims to answer the following questions:

1. What factors do students perceive as influential on their educational choices regarding STEM?
2. How do students develop their STEM identity (further) during grade nine and ten of schooling?
3. How do co-curricular and informal STEM activities influence students' decisions for or against STEM?

Methodology

To capture the diversity of the negotiation processes pertaining to identity development and educational pathway decisions, this study adopts an individual-centered research approach that foregrounds students' motivations and underlying meaning-making processes. Semi-structured interviews enable an in-depth reconstruction of students' self-perceptions and reasoning processes regarding STEM.

Context And Participants

To account for differences in curricula across German federal states and to reflect varied educational trajectories, students from two federal states and multiple school types are included. Except for Gymnasium students, participants are in their final two years of schooling and are facing imminent decisions about their future educational or vocational pathways; Gymnasium students may either leave after grade 10 or continue for three additional years.

Twenty-four students from six schools were selected by their teachers based on gender and STEM affinity (high/low), indicated by grades, classroom participation, and known extracurricular engagement.

Data Collection And Analysis

Data collection combines two instruments: semi-structured interviews and short written surveys. Interviews focus on students' experiences with STEM subjects, co-curricular STEM activities, informal STEM activities, the development of their STEM identities, and planned and made educational pathway decisions, while surveys capture planned educational pathways and co-curricular STEM experiences. Interviews took place in January/February and June/July of 2025 and will take place in January/February and June/July of 2026, with surveys administered in between to track changes over time and inform follow-up interviews. Due to organizational reasons, in the first interview-wave it was only twelve 9th grade students (seven female and five male) from three different schools. The interviews were transcribed using MAXQDA-Software and then manually corrected and anonymized (locations, names, etc.) in a second and third round.

The collected data is evaluated using qualitative content analysis according to Kuckartz and Rädiker (2022). A multi-stage process of category formation and coding was used. In the first coding phase the coding was carried out along the main categories that were also used in the guideline for the interviews and the STEM subjects were coded separately Within the next coding phase, the categories were developed further into the following categories: social and personal identity, significant persons, perception of STEM subjects, perceived relevance of STEM subjects, perception of STEM outside of school, STEM activities (co-curricular and informal), educational pathway decisions specified by aspired career, already chosen school subjects and career orientation. Before going into the analysis, case-specific thematic summaries were created for the individual students using the coded text passages.

In the cross-sectional analysis, the aim is to identify common patterns and themes (Kuckartz & Rädiker, 2022) based on similarities and differences between the students' narratives with respect to the aspects surveyed. These insights can contribute to sharpening the concept of STEM identity. They will also shed light on the influence of co-curricular STEM activities, informal STEM activities, especially in terms of identifying and describing key success factors.

In the planned longitudinal analysis, the changes in students' perceptions of STEM, STEM lessons and STEM identity as well as their retrospective attribution of meaning to educational pathway decisions are described. The comparison of statements on the same topic at different points in time provides information on how students are influenced by their experiences and evaluations (Rieker et al., 2024). On the one hand, the aspects described in the theoretical model are used, on the other hand it is also possible to identify new aspects and incorporate them into the model. For each student, an individual educational biography can be created and the relevant explanatory patterns for or against STEM (in the context of studies, profession, subject) can be identified.

In this article the findings of the first interviews (February 2025) will be described and discussed focusing on two students who were selected by their teachers because of their high affinity to STEM-subjects.

Findings

STEM Is Not A Unit

Before starting to go deeper into the description of the two students, it is important to note that throughout the twelve interviews the students were asked to describe and explain the term "STEM". Eight of the students didn't know the acronym while the other four said that they had heard about it but couldn't describe or explain it in detail. The interviewer gave all students a

verbal and written explanation of the acronym after the question to build a common understanding of the term STEM for the further interview.

Besides the unfamiliarity with the term STEM, what stood out within the students' answers was, that – even as the teachers who selected them were supposed to do so amongst other things by the affinity towards STEM, there was no student who liked all STEM subjects and in contrast, there also were no students who did not like all STEM subjects.

Mathematics, for example, was on the one hand characterized as easy to understand and to get good grades while time passed by fast and on the other hand the wish for a slower pace and skipping of unimportant topics were mentioned. The understanding of the content depends on the teacher's explanation. Also, students reported blackouts in tests. What stood out in comparison to other STEM subjects was that some students see their difficulties with mathematics as within themselves rather than by the lack of explanation or time. Also, the students perceived it as interesting and important for their everyday life, especially calculating e.g. the change you get in a shop and for diverse vocational fields (electrician, confectioner, insurance and banking sector).

In physics, the dislike and difficulties during class were mentioned. Besides that, it was characterized as boring and too theoretical which leads to difficulties processing the content. Special topics, e.g. electricity, gravity, and optics were described as interesting. Experiments stood out to be especially memorable. The teachers' influence on the liking of physics was rated differently. As in mathematics, the utility for the students' everyday life and their future vocation was mentioned.

Student Profiles And Influential Factors in STEM Positioning and Educational Pathways

In the following paragraphs two students (Julia and David[5]), who were interviewed in February 2025, will be described in detail regarding their positioning towards their STEM subjects, educational pathway decisions and further factors which turned out as influential for them.

"STEM Subjects [..] Run In The Family"

Julia is a 9th grade student who expresses a strong affinity for several STEM subjects, particularly mathematics, physics, chemistry, and the interdisciplinary subject 'computer science, mathematics, and physics'. Biology occupies a more neutral position in her subject preferences. She describes herself as someone who enjoys logical thinking and is able to establish connections quickly, framing these abilities as core aspects of her self-concept.

Family background plays a relevant role in Julia's positioning towards STEM. She reports that "STEM subjects in general run in the family"[6], as close family members have traditionally perceived themselves as competent especially in mathematics, even though none of them pursued a STEM-related profession. Familial recognition appears to contribute to the stabilization of her competence beliefs.

When asked about her perception of STEM, she identifies general competencies attributed to STEM professionals, including rapid comprehension, problem-solving abilities, strong intrinsic motivation, and comparatively weaker language-related skills such as vocabulary learning and memorization. Additionally, she differentiates STEM professionals' appearances across disciplines: biology and chemistry are associated with women in lab coats conducting investigations at laboratory benches, whereas mathematics was represented by a teacher carrying a brown briefcase and wearing a plaid shirt, jeans, and leather shoes.

[5] Names were selected randomly
[6] Direct quotes are translated from German to English.

Julia achieves good to very good grades in her STEM subjects and attributes her success primarily to internal factors such as logical reasoning, rapid comprehension, and sustained interest. She frequently compares her performance to that of her peers and is recognized by classmates as a source of academic support, particularly in mathematics. While this occasionally leads to social tension, it does not undermine her self-confidence; instead, it reinforces her self-positioning as competent in STEM.

Her subject choices reflect a strategic consideration of her perceived abilities, interest, and the anticipated relevance of subjects for future educational and occupational opportunities. Julia emphasizes the everyday relevance of mathematics and computer science, as well as their importance for a broader range of professional fields. Although she is uncertain about specific STEM career paths, she clearly envisions her future self within a STEM-related domain, particularly mathematics or computer science.

Co-curricular STEM activities play a comparatively minor role in Julia's narrative. She does not recall school-organized STEM activities but reports informal engagement, such as watching documentaries or visiting science exhibitions with her family. Time constraints due to multiple non-STEM hobbies limit her participation in additional STEM-related activities.

Overall, Julia's case is characterized by strong and stable competence beliefs, consistent recognition from significant others, and a future-oriented STEM-identity that extends beyond individual school subjects.

"It Just Happened"

David is also a ninth-grade student and expresses a differentiated but more ambivalent relationship with STEM subjects. He reports a strong liking of mathematics and chemistry, while physics, biology, and computer science are described as neutral. David characterizes himself as a rather quiet person when he is around people who he does not know very well and emphasizes everyday activities and social interactions outside of school.

Despite his positive experiences in some STEM subjects, David does not aspire to a STEM-related career. Instead, he envisions his future in the catering sector or in caregiving professions. These career aspirations are closely linked to professions from his family environment.

He expresses clear, stereotypical images of various STEM professionals: mathematicians are described as wearing glasses, jeans, plaid shirts, and carrying leather briefcases; computer scientists as quietly working at a computer, dressed in jeans and a pullover; natural scientists as wearing white lab coats and gloves; and technicians as performing physical labor in black shirts and work trousers.

David's competence beliefs in STEM subjects are inconsistent. While his performance in mathematics has improved over the course of his schooling and he enjoys problem solving aspects of the subject, he is unable to identify clear reasons for this development. His interest in STEM subjects is primarily topic-specific, for example related to atoms in chemistry or to gravity and electricity in physics, rather than generalized to the disciplines. Consequently, this interest does not translate into a stable STEM-related identity.

When choosing elective subjects, David explicitly decided against STEM-oriented options and in favor of AES (everyday culture, nutrition, social issues) aligning his subject choices with his occupational aspirations. He does not perceive STEM subjects as relevant for his everyday life but acknowledges their instrumental relevance for his future professions, for example mathematics for cooking (measuring ingredients) or biology for understanding the human body in caregiving contexts.

David reports no regular engagement in co-curricular or informal STEM activities. Occasional conversations about mathematics at home occur only when he finds specific topics particularly interesting. Overall, STEM does not constitute a central component of his self-concept or future imagination.

Cross-Case Comparison

Comparing Julia and David illustrates how similar levels of teacher-perceived STEM affinity can lead to fundamentally different educational aspirations. Below the authors conduct a cross-case comparison of the two students from a (STEM) identity perspective.

Competence, Performance, Recognition And Interest:

Julia expresses high competence beliefs, especially in mathematics and physics. She compares herself favourably to peers, helps others, and recognizes herself as a mathematics/STEM person. She attributes her success to internal factors such as logical thinking, quick understanding and inherent interest. Even social tension - friends "get[ting] pissed off" by her in comparison to them, high skills - does not undermine her confidence but it confirms her positioning towards STEM as competent. She chose her subjects by considering her abilities, her interest and the perceived value for her future. Her interest in STEM goes beyond school subjects as she also enjoys the STEM subjects because of their underlying logic and problem-solving nature, not just specific topics. This allows her interest to transfer across school subjects and into future aspirations. Also, she does STEM activities in her leisure time with her family and on her own but not on a regular basis.

David´s competence beliefs are more ambivalent. Although his grades improved (especially in mathematics) and he enjoys solving problems, he cannot identify the success factors for this development. He explicitly names specific topics as interesting but doesn't generalize that to the whole subject. This episodic and topic-specific (atoms, gravity, electricity) interest does not translate into sustained disciplinary identification, as once the topic changes, the interest may fade, too. He isn't involved in STEM activities but sometimes if the topic is interesting, he talks about his mathematics class. His decision against choosing a STEM subject was not due to distancing himself from STEM in general but because it does not align with how he sees himself in the future.

Comparing Julia und David illustrates how similar levels of teacher-perceived high STEM affinity can result in diverging educational aspirations. Julia's STEM identity is inter alia characterized by strong and stable competence beliefs, and consistent recognition from peers and family. This supports Hazari et al's (2010) argument that interest, competence and recognition, both self-recognition and recognition by others, are key stabilizing factors in identity development. Whereas David's STEM identity is characterized by only topic-specific interest and besides his self-recognition as a math-person he does not mention being recognized by others.

Representation Of STEM

Julia's descriptions of STEM professionals reveal some stereotypes, particularly in biology and chemistry (lab coats, working in a laboratory) and mathematics (glasses, Jeans, plaid shirt, leather briefcase) but also, she describes them as understanding things quickly, finding different ways to solve a problem and interested in their own work. A description that fits the image she draws of herself and lets her imagine to be capable of working in a STEM field.

David has also a stereotypical concept of STEM professionals (quiet computer scientist, mathematician with glasses). Even though he describes himself as quiet, he sees himself more as a cook or a caregiver. Professions which he knows from his family surroundings.

Both students' descriptions of STEM professionals reveal persistent stereotypical representations, particularly regarding appearance, work environments, and personality traits. However, these stereotypes function differently in their identity negotiation. Julia's self-description overlaps with her image of STEM professionals, enabling identification despite stereotypical imagery while David, despite partially matching some characteristics (e.g. being quiet), does not perceive STEM professions as something for him. The career he aspires is known by him due to his family members and for that it is probably more imaginable.

Educational Pathway Decisions And Future Selves

Julia imagines her future self in STEM, particularly in mathematics or computer science, even though she is uncertain about specific career paths. She is sure about her aspirations but struggles to map the field.

David imagines his future self clearly non-STEM but recognizes the need for certain topics/skills even for a non-STEM job like cook (mathematics for measuring the ingredients) or caregiver (biology to understand the human body).

Educational pathway decisions in this study appear to be strongly guided by students' future imaginaries and perceived alignment between current school subjects and envisioned adult roles. Julia's uncertainty does not concern whether she belongs in STEM, but rather how to translate her interest into concrete occupational pathways. David, on the other hand, makes a clear decision against STEM subjects not because of rejection or failure, but because STEM does not fit into his imagined future as a cook or caregiver.

Limited Salience Of Co-Curricular STEM Activities

Co-curricular STEM activities played a minor role in students' narratives at this stage. Both Julia and David struggled to recall such activities, and when they did, these experiences were not strongly linked to identity development or decision-making. This finding may reflect limited availability, insufficient integration into classroom learning, or a lack of explicit reflection opportunities. It also aligns with studies questioning the long-term impact of isolated informal STEM interventions when they are not embedded in broader educational trajectories (Tillmann & Wenger, 2021).

Discussion And Conclusion

The findings from the first interviews underline that students' decisions for or against STEM cannot be understood as binary choices, nor as a result of isolated factors. Instead, they emerge from dynamic and situated negotiation processes in which subject-specific experiences, social recognition, future imaginaries, and structural conditions interact.

A significant finding of the preliminary analysis presented in this paper is that students do not perceive STEM as a coherent or unified domain and most students were unfamiliar with the term STEM itself and even after clarification, their attitudes and identifications varied strongly across individual subjects.

David's narratives demonstrate that identification is constructed at the level of specific classroom experiences, topics, and perceived demands rather than at the level of an abstract STEM category. This differentiated positioning towards STEM subjects aligns with Hazari et al.'s (2010) emphasis on subject-specific identity components such as interest, competence beliefs or recognition. On the contrary Julia's narratives demonstrate that she sees her current and future self as a STEM person linking this self-description to a more abstract level of STEM categories like quick understanding and logical thinking.

The study contributes to STEM identity research by empirically illustrating how similarly perceived high STEM affinity can lead to divergent trajectories and by highlighting the importance of reflexive sense-making in identity stabilization. Methodologically, the longitudinal approach holds promise for capturing how critical moments, experiences, and interpretations accumulate over time.

However, the findings are based on a limited, selective number of interviews and should therefore be interpreted cautiously. Future analyses will benefit from the full longitudinal dataset, allowing for a more nuanced understanding of negotiation processes and probably the delayed impact of co-curricular and informal STEM experiences.

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EUROPEAN SCIENCE EDUCATION RESEARCH ASSOCIATION ESERA 2025 Copenhagen

Queer In STEM Queering STEM: The Story And Insights Of A Trans, Ace, White Woman In Chemical Engineering

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*This case study explores the intersections of trans*ness and STEM through a combined framework of queer theory, intersectionality, the construct of figured worlds and science identity. The study uses a life-history approach to characterize the trajectory of Cassandra, a trans, ace, white woman in Chemical Engineering. We collected data through in-depth, semi-structured interviews which we analysed in three rounds using narrative analysis, artefacts, such as the River of Life, and a focus group consisted of queer and trans individuals, including Cassandra, to identify aspects of STEM education that constrained or supported the participants' trajectory and to offer strategies for queering STEM educational spaces. The findings of this study include data of the participant's reflections on her STEM trajectory as for example, the course of her life as she moved towards or away from STEM. Moreover, the findings illustrate the exclusionary cultural models of the figured world of STEM, that were shaped by cisheteronormativity, sexism, white supremacy, ableism, defined by neoliberal values and depoliticized. Finally, the findings highlight the importance of transforming a) the culture of STEM, b) the image of STEM, c) the curriculum and pedagogies, and d) the teacher-student relationships, to foster more inclusive and affirming environments. The study aims to challenge cisheteronormative frameworks, promoting a reimagined and supportive learning environment for all students.*

Keywords: Gender equity, Inclusive Education, Science Identities

Introduction

Broadening STEM participation is a central focus within the STEM education community. Research indicates that enduring inequalities in STEM perpetuate the dominance of white males, while women, people of colour, and individuals with disabilities face underrepresentation (NSF, 2021). Queer individuals have also been recognized as an underserved group. Despite limited data, studies reveal that queer individuals face exclusion, discrimination, and harassment in STEM, which affects their careers, prompting the need to examine both the mechanisms that marginalize them and the factors that sustain their persistence, and leading to a push to reimagine academic environments and transform STEM education spaces (Marosi, 2024). Addressing inequalities in STEM is essential for reducing disparities and fostering inclusive, sustainable development (UNESCO, 2024).

Therefore, this study aims to contribute to the queering of STEM by a) exploring the intersections of trans*ness with the science identity throughout schooling and university, and by b) using a bottom-up approach, prioritizing the voices of marginalized individuals in the process of transforming STEM education. This study is part of a larger project for which we conducted interviews and a focus group with queer individuals, but we currently present the findings relevant to Cassandra, a trans woman in Chemical Engineering. The research questions were the following:

- How did the participant (re)negotiate her science identity throughout her educational trajectory?
- How do the intersections of her social identities shape and interact with the cultural norms of the figured world of science to afford or constrain her participation?

- How does she envision queering science education based on her lived experience?

Theoretical Framework

This study combines queer theory and intersectionality to analyse how power, privilege, and oppression shape the lives of the participant in STEM, using the constructs of figured worlds and science identity to explore her positioning in and out of STEM spaces. Queer theory challenges normative binaries of gender (Gunkel 2009), while intersectionality examines the interconnected forms of oppression that shape identity and lived experiences (Crenshaw, 1989). Science identity, a construct tied to how individuals see themselves and are recognized as science participants, highlights the role of recognition and co-construction in fostering engagement and persistence in science (Carlone & Johnson, 2007). Figured worlds frame these identities by establishing cultural models and norms that determine who is valued and recognized within the STEM community, with these models influenced by broader societal structures and localized contexts (Gonsalves, 2014). Together, these frameworks provide a lens to explore how cultural norms in STEM afford or constrain Cassandra's participation and identity development.

Method

We employed a qualitative case study approach. We utilized artefacts (River of Life, a visual exercise that helped participants to map out their science trajectory) and semi-structured interviews which we analysed in three rounds using narrative analysis, to explore participants' STEM trajectories, focusing on the intersections of queerness and STEM. After the interviews, we developed conceptual themes addressing problematic aspects of STEM education and participants' suggestions for queering these areas. An online focus group was then conducted to collaboratively generate ideas for queer-affirmative STEM education from a bottom-up perspective. The participants were purposefully selected from social media. The current study presents the findings relevant to Cassandra, a 27-year-old, trans, lesbian, ace, white woman who grew up and studied in the US and is currently a lecturer in Chemical Engineering in the US.

For the purpose of data analysis, we transcribed the interviews and focus group discussions verbatim and analysed them using Atlas software. Through in vivo and line-by-line coding, we prioritized the participant's direct statements while minimizing researcher interpretation. An inductive and deductive approach was used to identify: a) elements or experiences limiting identification and participation in STEM, and b) ways to queer STEM education. Trustworthiness was ensured through triangulation, verbatim transcripts with in vivo coding to reflect participants' voices, and member checking to validate interpretations with the participants.

Findings

Cassandra's Story

Cassandra, who grew up in a privileged, conservative, all-white town in the US and was perceived as a cis-heterosexual male before transitioning during grad school, was deliberately pushed into STEM from an early age, benefiting from systemic privilege and familial support, which shaped her STEM trajectory despite her awareness of the sexism, elitism, and competitiveness in engineering spaces. Cassandra's experience in engineering was marked by an elitist and competitive culture that promoted the idea of exceptional individual labor while marginalizing certain identities, such as neurodivergent, queer, and trans individuals. Faculty and institutional norms supported exclusionary practices, with high dropout rates and strict expectations for "good students" that had a bigger impact on marginalized groups. Bioessentialism and the lack of queer representation further alienated individuals, as gender and queer issues were largely absent from

STEM spaces, leaving students like Cassandra without visible role models or safe opportunities for expression.

Cassandra's pre-transition years were marked by dissociation and intense academic focus, using her demanding engineering studies as a way to avoid confronting her gender identity. After transitioning, with the crucial support of friends, the queer community, and supportive women in her faculty, she began to feel more aligned with her true self, discovering a passion for teaching engineering that gave her life new meaning despite initial challenges. Cassandra's transition allowed her to live authentically and brought a holistic connection between her mind and body, making her a happier and more empathetic person. Now a lecturer in Chemical Engineering and an advocate for inclusive education, she integrates her lived experiences into her teaching and activism, challenging patriarchal and exclusionary norms in STEM and creating spaces where everyone can bring their full selves into STEM.

Envisioning A Queer Inclusive STEM Education

This section highlights various problematic aspects of science education which hindered participants' progress in science as highlighted by the participants in the interviews and the focus group, namely the a) culture of STEM, b) image of STEM, c) curriculum and pedagogies, and d) relationships and presents their strategies for queering these aspects. In what follows, we present the findings relevant to Cassandra. According to Cassandra, the culture of STEM often reinforces cisheteronormativity, sexism, and bioessentialism, marginalizing queer individuals and perpetuating harmful stereotypes. As Cassandra stated, besides implementing policies that protect queer individuals, "What you shouldn't do is attach our gendered expectations to like cells and molecules and atoms and animals as well [...] maybe we shouldn't assign any agency or passivity to fucking animals," emphasizing the need to challenge gendered biases and adopt inclusive, curiosity-driven perspectives for more accurate scientific inquiry.

The competitive, individualistic, and elitist culture in science often stifles collaboration, fosters harmful competition, and negatively impacts mental health and inclusivity, with Cassandra critiquing this mindset, saying, "I don't want to win so that someone else loses [...] I want us all to win. I want to collaborate." She actively works to counter these norms by abolishing exams in her classroom, implementing labour-based grading, promoting collaboration, and advocating for sharing both successes and failures in scientific research to improve transparency and inclusivity.

Cassandra critiqued the traditional image of scientists as white, middle-class, cisgender, straight men, highlighting the lack of representation of queer and trans identities and the depoliticized portrayal of STEM disconnected from social issues. Cassandra proposed queering this image by integrating social justice into STEM education, emphasizing diverse contributions, promoting authentic self-expression, and redefining success to prioritize mental health, community, and diverse career paths over financial gain or traditional metrics of achievement: "You don't have to be the guy and I do mean guy in this case, who makes 100k," and questioning "What is the point of diversity in STEM? Are we going to try to make more Black Raytheon employees, more female oil drillers, more non-binary forest destroyers?"

She also criticized the absence of queer issues in STEM curricula, highlighting the need to challenge Western science's claim to pure objectivity, advocating for the inclusion of diverse epistemologies, including feminist, Indigenous, and queer perspectives, to reshape both the curriculum and pedagogy. She emphasized the importance of integrating social justice and mental health into teaching, suggesting that STEM education should be more inclusive and adaptable, while also advocating for a rebalancing of tenure criteria to prioritize teaching alongside research: "How do we rebalance that and make it so that teaching is weighted more in the tenure process?"

Finally, Cassandra emphasized the importance of personal relationships in STEM, noting that a supportive faculty member helped her maintain mental stability when she was struggling with her trans identity: "It was because of her, that I didn't completely lose my mind." She also stressed the need to challenge hierarchies in the classroom, advocating for a more empathetic, care-driven approach to teaching that includes affirming students' identities, offering mental health resources, and creating inclusive environments. An example of her behaviour is when she opened one of her classes with a big slide saying: I give a shit about you", underlining her commitment to her students' well-being.

Discussion

In response to the first research question, the cultural models of STEM in the story of Cassandra often reinforced exclusionary norms, portraying fields like engineering as competitive, masculine, and elitist, while marginalizing queer and trans identities and individuals with mental health challenges. This created environments that prioritized individual achievement over collective support and depoliticized social issues. Addressing the second research question, Cassandra's identity trajectory in STEM was shaped by her initial alignment with privileged cultural models as a cisgender, able-bodied, white, middle-class person. However, after transitioning during her PhD, she faced the challenges of navigating a still-exclusionary field. With the support of others, she embraced her transness, which ultimately reshaped her path towards a more inclusive and socially conscious role in academia.

Finally, in response to the third research question, Cassandra emphasized the need to address heteronormativity and sexism in STEM by implementing policies that protect marginalized groups and challenge gendered language and biases. She pointed out that neoliberal and competitive structures in STEM promote individualism and elitism, which hinder collaboration and innovation, and called for education reforms such as labor-based grading contracts and a greater focus on interdisciplinary work. Additionally, she argued that true diversity in STEM requires more than superficial representation; it necessitates a shift toward inclusive perspectives, alternative career paths, and the dismantling of traditional norms and capitalist-driven roles. Recognizing the depoliticized nature of STEM education, she advocated for queering the field to reintroduce discussions on power, social justice, and exploitation, while challenging capitalist and gender norms. Furthermore, she emphasized the importance of dismantling hierarchical structures in classrooms by fostering personal, empathetic teacher-student relationships that promote inclusivity, respect, and safety, particularly for marginalized groups.

Implications

This study emphasizes the marginalization of trans individuals in STEM and calls for the redesign of learning spaces, the exploration of intersectional identities, and the implementation of inclusive policies, support networks, and queer-inclusive pedagogies to foster diversity and inclusion. It also suggests further research on integrating critical theories, inclusive curricula, and alternative assessments to address systemic barriers.

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A Multiple Case Study Of Translanguaging And Systemic Functional Linguistics In K-12 Science Education

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This multiple case study explores how science teachers interact with and respond to translanguaging as it naturally occurs among English Learners (ELs) who bring varied levels of English proficiency into distinct classroom contexts. The study focuses on two participants working in linguistically diverse public schools: one 6th grade biology teacher who is monolingual English-speaking and identifies as White/Caucasian, and one 10th grade chemistry teacher who identifies as Hispanic/Latine and is bilingual in English and Spanish. Using a Systemic Functional Linguistic (SFL) framework as a lens, we examine how translanguaging manifests within the three metafunctions of language: ideational, interpersonal, and textual. Classroom data included audio and video recordings of both teachers and students (n = 88) during routine science instruction to analyse when and where translanguaging occurred, to whom it was directed towards, and how instructional tasks created space for its use. Semi-structured interviews offered further insight into how teachers understood and navigated linguistic diversity in their classrooms. Findings suggest that translanguaging emerges through fluid, collaborative classroom discourse and is shaped by teachers' language-related decisions, including how they (1) use language to scaffold scientific reasoning, (2) attend to the functional purposes of language in content learning, and (3) affirm bi/multilingual expression as a resource for students' meaning-making in science classrooms.

Keywords: Classroom Practices, Languages and literacies in science education, Multicultural Education

Introduction

In the United States (U.S.), schools test multilingual students upon entry to determine whether they need language support to succeed. If they do, they are classified as English Learners (ELs). ELs in U.S. science classrooms face the dual task of understanding scientific content while simultaneously developing English proficiency (Garza & Arreguín-Anderson, 2018; Meskill & Oliviera, 2019). This cognitive and linguistic demand can hinder their ability to fully engage in ambitious science learning practices, which require reasoning, argumentation, and evidence-based explanations (Windschitl et al., 2020). Translanguaging, a pedagogical approach that encourages students to use their entire linguistic background to inform meaning-making processes, has emerged as a promising strategy to address this gap in learning environments (García & Lin, 2016; Wei, 2018). However, little is known about how varying instructional practices either encourage or impede translanguaging in science classrooms.

To address this gap, systemic functional linguistics (SFL) provides a valuable critical lens for understanding how teachers use or encourage translanguaging to guide ELs through scientific reasoning and discourse. SFL views language as a semiotic tool for meaning-making and emphasizes the importance of helping students navigate the linguistic features (e.g., terminology) of academic disciplines, such as science (Schleppegrell & Oteíza, 2024; García & Kleyn, 2016). Central to SFL are the three semantic metafunctions: (1) the ideational, which focuses on how language represents and organizes experiences and knowledge; (2) the interpersonal, which examines how language facilitates social interactions and expresses attitudes and relationships;

and (3) the textual, which explores how language creates cohesive and meaningful communication (Banks, 2002). We position SFL as a theoretical framework to analyse how teachers and students use language in the classroom. Through this framework, we examine how teachers and students leverage their linguistic backgrounds to connect prior knowledge to new scientific concepts (ideational), engage in argumentation through collaborative learning (interpersonal), and organize thoughts cohesively to communicate scientific ideas (textual). By investigating teachers' pedagogical strategies, we aim to understand teachers' (1) purposes for language use in science classrooms and (2) how they legitimize translanguaging as a linguistic tool for meaning-making. Therefore, we are motivated by the following research question: *How do science teachers create opportunities for translanguaging in their varied learning environments to support English Learners in science classrooms?*

Methods

Participant Selection

Participants included two science teachers from different U.S. school districts in the Midwest: 1) Aaron, a 6th-grade biology teacher in a small rural city with a monolingual English background, and 2) Maria, a 10th-grade chemistry teacher in a suburban Midwestern city, who grew up as a dual-language student, speaking both English and Spanish. They were selected due to their experience teaching science and simultaneously teaching ELs and monolingual English speakers in the same classroom. Both teachers worked with ELs from different linguistic backgrounds, including Spanish and Arabic, at varying levels of English proficiency. Student participants included 64 students from Aaron's biology classes and 22 from Maria's chemistry class (N = 88).

Data Collection

We employed semi-structured interview and observation protocols (Authors, 2013), including audio and video recordings of teachers' science classes. In the first stage (individual interviews), we met virtually with Aaron and Maria to discuss their teaching background, views on language use in their schools, and their students' linguistic and learning environments. Sample interview questions included: "How do your students translanguage (fluidly switch between English and Spanish or other languages) during learning?" "When and where does this likely occur?" and "Why do you feel that your students do this?" Additionally, we asked, "How do you encourage and/or scaffold translanguaging practices during instruction?" In the second stage (classroom observations), we observed 10 classroom periods over the span of four days. To highlight pedagogical strategies and language use, we used 8 hours of video and audio from both classroom observations and individual interviews.

Data Analysis

We employed a multiple case study design (Román, 2013) to examine science teachers' perspectives on working with ELs and the factors influencing their translanguaging practices. This method let us capture individual differences and shared approaches in how teachers used translanguaging strategies to support ELs during science instruction. Applying an SFL lens, we used a priori codes derived from the ideational, interpersonal, and textual metafunctions of language to code the notes from observations and interview transcriptions. This allowed us to investigate how teachers' translanguaging practices support meaning-making, social interaction, and coherence in science classrooms.

Results

Ideational: Connecting The Language Of Science To Real-World Contexts

Aaron led a project where students designed reusable cups using recyclable materials and tested how well they maintained drink temperatures as a way to examine thermal energy transfer. He tapped into the ideational metafunction of language by connecting the concept of thermal energy transfer to his students' real-world experiences. For instance, Aaron problematized the design challenge by explaining how iced drinks from coffee shops often warm up too quickly on sunny days, prompting students to think critically about an innovative design solution. ELs in Aaron's class used translanguaging to connect this knowledge to the scientific concept of energy transfer. For example, three students, Nora, Ryan, and Maya, discussed using aluminum foil to contain more heat inside the bottom of their cup (see Figure 1).

Figure 1. Transcript on English Learners' Interactions Representing the Ideational Metafunction.

Nora: *Oh Ryan, you gave me an idea. When I make this thing, right? [points to the fabric intended for the bottom of the cup] we put the aluminum in the bottom.*
Ryan: *Mucho? A lot?*
Nora: *Maybe, yeah maybe.*
Ryan: *Alright, but we are not gonna use this [points to fabric] in the bottom.*
Nora: *No, like. Porque mira, dame eso [Ryan hands Nora the fabric]… okay so it's gonna be like this right? [shows the fabric material] And we put alumino aquí right? [points to the inside of the fabric]. I don't know.*
Ryan: *Mmm I don't think so.*
Maya: *I don't know.*
[All students think for a moment]
Ryan: *I don't think that will work … probably actually .. yeah it probably would, yeah*
Nora: *Pick, pick right now. Yes or no? Are you sure?*
Ryan: *Yes.*
Nora: *Positive? Seguro? Si?*
Ryan: *Yes, yes, yes*

In the figure above, Ryan invites translanguaging into meaning-making when he uses "Mucho?" followed by the English version of the question, "A lot?" This shows students all language varieties are welcomed. Nora then uses Spanish later on, "Porque mira, dame eso," to ask Ryan to hand her the fabric while continuing to make sense of the phenomenon without worrying about *what language* counts as the language of science.

Similarly to Aaron, Maria's teaching focused on reducing cognitive load and making scientific concepts accessible to her ELs. In her 10th-grade chemistry unit on the electronegativity of atoms, she used Spanish to support her ELs, explaining, *"My expectation for them is to try and write in English, but that doesn't necessarily happen because they can't really express themselves very well in English. We teach all the vocabulary in English, so I expect them to use those words… but I allow them to produce in their home language using a Chromebook to translate."* By providing key vocabulary in English while allowing students to produce work in their home languages, Maria helped students construct scientific meaning while navigating English as an additional language.

Interpersonal: Building Collaborative Translanguaging Spaces

Despite being a monolingual English speaker, Aaron created opportunities for interpersonal interactions by intentionally pairing students with varying levels of English proficiency in small groups during classroom instruction (e.g., students with higher English proficiency worked with students with lower English skills). We noticed that ELs with varying levels of English proficiency spoke predominantly in Spanish when forming the majority in their small groups, particularly after being prompted by the research team to use whatever language they feel comfortable with. On day two of our observations, Aaron reflected on this, stating, *"I had never heard them [group of ELs] speaking Spanish before this. It's great."* Although Aaron did not explicitly encourage his students to use their home language, his receptiveness to ELs' translanguaging practices highlights his adaptability to foster a classroom environment that embraces linguistic diversity.

In contrast to Aaron's pedagogical strategies, Maria fostered an inclusive environment by leveraging her bilingualism to support her ELs. Early in the school year, she paired students who spoke the same language (e.g., Spanish-speaking students and Arabic-speaking students) to encourage dialogue, while gradually transitioning them to work with monolingual peers to promote English use. Reflecting on the dynamics in her classroom, she said, *"It's frustrating for me because I try to only speak in English to them, but since they know I speak Spanish, their comfort level in Spanish is way higher in my classroom."* While she aimed to speak only in English, Maria recognized that her bilingualism increased students' comfort, especially for those with lower English proficiency who might otherwise avoid engaging.

Textual: Supporting Meaningful Language Use Through Structured Scaffolding

Aaron's use of scaffolding strategies helped his ELs navigate the task of learning science content in their non-native language. For instance, he adjusted expectations for language use depending on the task, stating, *"I have students just write in Spanish if the task is a 'heavier lift' in my class. Final assessments can be completed in Spanish so that students engage more deeply with the content rather than focusing on the language …"* By focusing on how students' linguistic and cultural resources could be leveraged in meaning-making, Aaron enabled students to draw from both their home languages and English to structure their scientific ideas cohesively.

Unlike Aaron, who supported translanguaging between ELs, Maria led a discussion with two ELs about how atoms with higher electronegativity "steal" electrons from other atoms when forming bonds. Following the textual metafunction, Maria used translanguaging as a pedagogical strategy to help Carmela, one of the native Spanish-speaking ELs, articulate her understanding (See Figure 2).

Figure 2. Transcript on Teacher-Student Interaction Representing the Textual Metafunction.

Maria: *Okay so let's talk. So the other one … [points to atom] everything around it was the same, right?*
Carmela: *Mhmm.*
Maria: *It was chlorine, chlorine, chlorine, chlorine [points]. What do you notice about this one? What do you guys think? [points at two Spanish-speaking students]*
Carmela: *This is named, es hidrógeno, es el primero, no?…. Electrones …*
Maria: *Right, and we have a different atom here than chlorine, and you see how it's partially positive. On the other one, everything was partially negative … What's the electronegativity of carbon?*
Carmela: *¿Qué?*
Maria: *¿Qué es la electronegatividad de carbón?*
Carmela: *Ahhh, yo sé son los electrones*
Maria: *2.5, right? And what's the electronegativity of chlorine? So who's gonna steal the electrons?*
Carmela: *Como ellos son los fuertes, ¿le roban a este?*
Maria: *Ahaa, so it's gonna pull a little bit, right?*
Carmela: *Mhm. Ohhhh.*
Maria: *And here we're stealing the electrons. So electrons move this way.*
Carmela: *Ohhhh. Entonces este le quita a este y estos le quitan a este?…"*

In the above interaction, Maria's prompting guided Carmela to connect her prior knowledge to understand electronegativity. When Carmela initially didn't understand the question in English, Maria clarified it in Spanish: "¿Qué es la electronegatividad de carbón?" This allowed Carmela to recall relevant information and respond, "Ahhh, yo sé son los electrones." As the conversation progressed, Carmela used her linguistic background to reason in Spanish. Through a textual lens, Maria demonstrated how translanguaging helped Carmela organize and communicate complex scientific ideas while drawing on her native language and the language of instruction. Unlike a traditional approach, where students in science classrooms construct their reasoning in a single language (e.g., English), Maria allowed Carmela to use her full linguistic background to structure her questions and responses across languages.

Discussion

By situating translanguaging within an SFL framework, this study highlights the interconnected roles of ideational, interpersonal, and textual metafunctions in shaping how language supports science learning. As translanguaging continues to gain recognition as a legitimate pedagogical tool, science educators are encouraged to embrace linguistically responsive teaching practices that empower ELs to participate fully in rigorous scientific inquiry.

Case studies revealed that translanguaging practices are implemented according to science teachers' pedagogical strategies and the teachers' and students' linguistic backgrounds. While Aaron encouraged translanguaging by enabling collaborative group work between students with similar multilingual backgrounds, Maria engaged her ELs in both English and Spanish to support their scientific reasoning. Both teachers demonstrated that, when purposefully integrated, translanguaging can promote conceptual understanding, reduce cognitive load, and create more inclusive science learning environments.

Future research can examine how institutional factors, such as school language policies and curriculum design, further influence teachers' ability to adopt translanguaging practices. Additionally, future studies can analyse content teachers' translanguaging practices across academic subjects (e.g., social studies, mathematics, and language arts).

Ultimately, embracing translanguaging as a pedagogical tool, whether teachers are bilingual or monolingual, can help educational researchers, teachers, and school networks reframe multilingualism as an asset. It fosters more equitable and engaging learning environments for ELs in science classrooms and beyond.

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Exploring STEM Identity Development In Early Science Education In Germany: Gender Differences And The Impact Of Science Capital

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Despite the acknowledged societal relevance of physics, many students distance themselves from the subject, perceiving it as both challenging and male dominated. Such perceptions contribute to smaller, less diverse scientific communities. To better understand science-related educational decisions, this study applies the STEM identity framework in a longitudinal design, integrating qualitative and quantitative methods. The focus is on the early stages of physics and chemistry education at the age of 12-15 years. The longitudinal questionnaire survey presented here, was conducted at 15 German grammar schools with 688 students over two years, using validated scales to assess identity related constructs like self-efficacy and interest. Results show gender disparities in interest and self-efficacy at the beginning of physics and chemistry lessons, with males reporting higher levels. Regarding Science Capital we found that students with higher Science Capital display higher levels of interest and self-efficacy. The gap between the groups became smaller during the observation period, but at the same time self-efficacy and interest in the subjects generally declined, with the exception of biology. However, the downward trend is more pronounced among male students and students with higher Science Capital. These findings highlight the role of gender and Science Capital in shaping early STEM experiences, with problematic trends particularly evident in physics-related constructs.

Keywords: Early Science Education, Longitudinal Studies, Science Identities

Theoretical Framework And Research Interest

Although the social relevance of the natural sciences in general and physics in particular is recognised by a large number of people, many pupils personally distance themselves from physics (Archer et al., 2010). Physics is often regarded as a difficult, nerdy, male and unpopular school subject (Kessels et al., 2006). Accordingly, educational decisions are often made against physics which, among other things, leads to fewer and less diverse young scientists (DeWitt & Archer, 2015).

The construct of identity affords a comprehensive framework for examining educational choices, conceptualizing them as emergent from intrapersonal negotiations (identity work) embedded within an individual's social environment. It allows a wide range of influences and underlying conditions to be taken into account (Lee, 2012; Morf & Koole, 2014). This theoretical premise suggests to integrate qualitative approaches (via narratives, e.g. from interviews) and quantitative approaches (e.g. via psychological constructs from questionnaires). Psychological constructs such as self-efficacy, interest and self-concept in science can be taken as indicators of a comprehensive STEM identity (Hazari et al., 2010; Rabe & Krey, 2018).

With regard to science education, the initial subject classes can be considered a critical phase in students' educational decision-making. In German grammar schools these begin in the 6th or 7th grade and coincide with the onset of adolescence, when identities are strongly (re)negotiated (Schreiner & Sjøberg, 2007). Analysing this phase from the perspective of STEM identity is still a desideratum in Germany (Rabe & Krey, 2018).

Research Questions And Methods

Our research project aims to use the identity perspective to better understand young people's educational decisions and, in particular, to shed light on the identity negotiations in initial physics and chemistry classes. To this end, we focus on the research questions: (1) How do indicators of a STEM identity develop in introductory physics and chemistry classes? (2) How do students relate other identities (e.g. gender) to their developing STEM identity?

To answer the research questions, the project IdentMINT uses a mixed methods approach with qualitative interviews and a quantitative longitudinal questionnaire survey. In the following, we report on the quantitative part of the inquiry.

Surveys were carried out in two federal states of Germany at a total of 15 grammar schools (9 in Bavaria and 6 in Saxony-Anhalt) at three points in time (T1-T3). The surveys cover a period of nearly two years of initial physics (T1-T3) and one year of chemistry (T2-T3) classes. Complete data sets covering all survey points are available for n=688 pupils, 56% of whom identify as female, 43% male, 0.7% diverse or unspecified.

We used established scales to gather data on identity related constructs, including self-efficacy related to physics, chemistry, and biology (Jerusalem & Satow, 1999), interest in physics and chemistry (Frey et al., 2009), perceptions of physics and chemistry lessons, engagement in extracurricular science activities, aspects of gender identity, Science Capital and the perceived attitudes of significant others, such as peers and parents (ASPIRES, 2016). In the following, we report on the constructs of interest and self-efficacy. These scales have undergone validation through confirmatory factor analysis (Hu & Bentler, 1999) and have been tested for measurement invariance (Chen, 2007), which is essential for our cross-sectional and longitudinal analyses. With the validated scales, we conducted cross-sectional mean comparisons (Wilcox tests due to robustness against violation of normal distribution) with comparisons by gender and by the parents' occupational background in natural sciences as an indicator of Science Capital. We distinguished between students having none, one or two parent(s) with an occupational background in science. Effect sizes are reported using Cohen’s d. For the longitudinal analysis, we performed an ANOVA for repeated measurement and then conducted paired Wilcoxon tests between T1-T3 and calculated effect sizes of the longitudinal development.

Results: Development Of Self-Efficacy And Interest

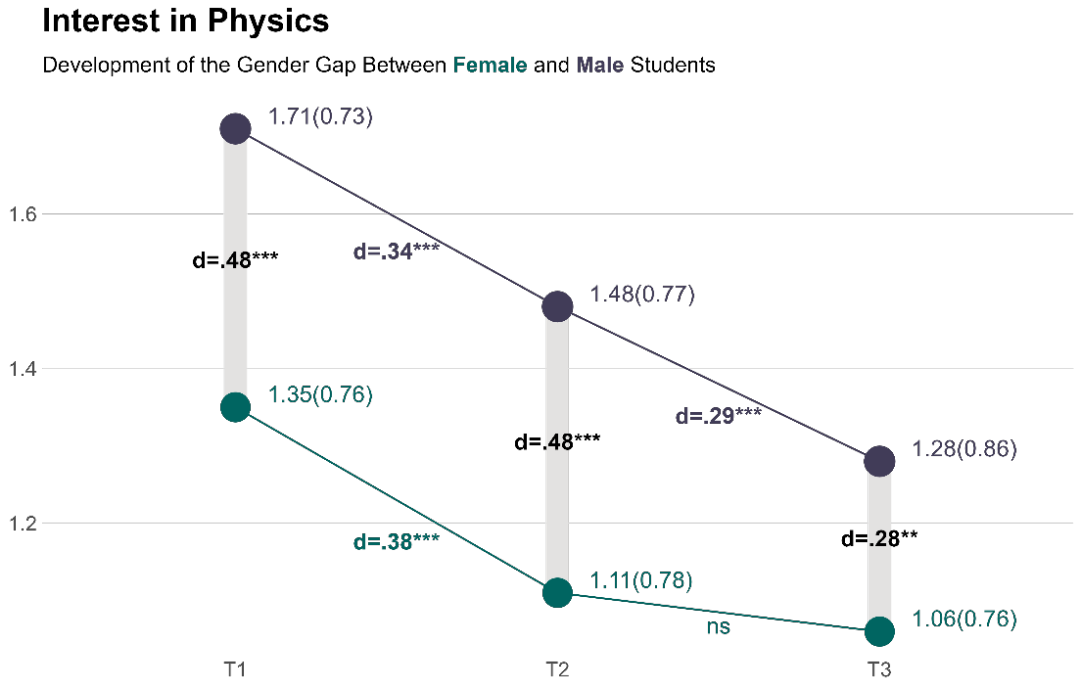
All scales show a satisfactory quality according to Hu & Bentler (1999). Cross sectional measurement invariance with the criterion according to Chen (2007) is given for almost all group comparisons with $\Delta CFI<.01$ (if not, no differences are reported or explicit reference is made to the violation of measurement invariance). Longitudinal measurement invariance across the survey time is given (with $\Delta CFI<.01$) in all groups except for the group with two parents with a background in natural sciences. In the following, we present the developments of self-efficacy in physics, chemistry and biology, as well as interest in physics and chemistry.

Gender Specific Results

Due to the small number of participants who identify as diverse, the gender specific results are only given for male and female students. The results for biology differ significantly from the other two natural sciences: There are no significant gender differences for self-efficacy in biology at T1 and T2 (with no measurement invariance at T3). In physics and chemistry, we find a significant and substantial gap in interest and self-efficacy, with male pupils reporting higher scores at the beginning of the initial lessons. The largest gender gap is found for self-efficacy in physics (d=.62*** at T1) and for interest in physics (d=.48*** at T1 and T2). All observed gender

gaps are smaller at the end of the two-year survey period and are only significant for physics-related constructs. For self-efficacy in physics, the gender effect decreases from medium (d=.62***) to small (d=.38**), and similarly for interest in physics from d=.48*** to d=.28** (see Figure 1). The gender differences in chemistry decrease from d=.33*** to d=.10 for self-efficacy and from d=.28*** to d=.06 for interest and are no longer significant at the end of the survey period. This observation is mainly due to the fact that most of the values decrease in both groups (there is only one slightly significant but very small increase in self-efficacy in biology from T2 to T3: d=.17** all other values decrease or remain unchanged). However, the longitudinal decline is much larger for male students than for female students (e.g. from T1 to T3 for interest in physics for female students with d=.38*** and for male students with d=.54***). The development of the effect sizes of the group differences between female and male pupils is summarised in Figure 4 on the left.

Figure 1. Development of the gender gap in interest in physics (scale 0 to 3) over the three survey points (T1 to T3); for cross sectional and longitudinal effects Cohens' d is shown.



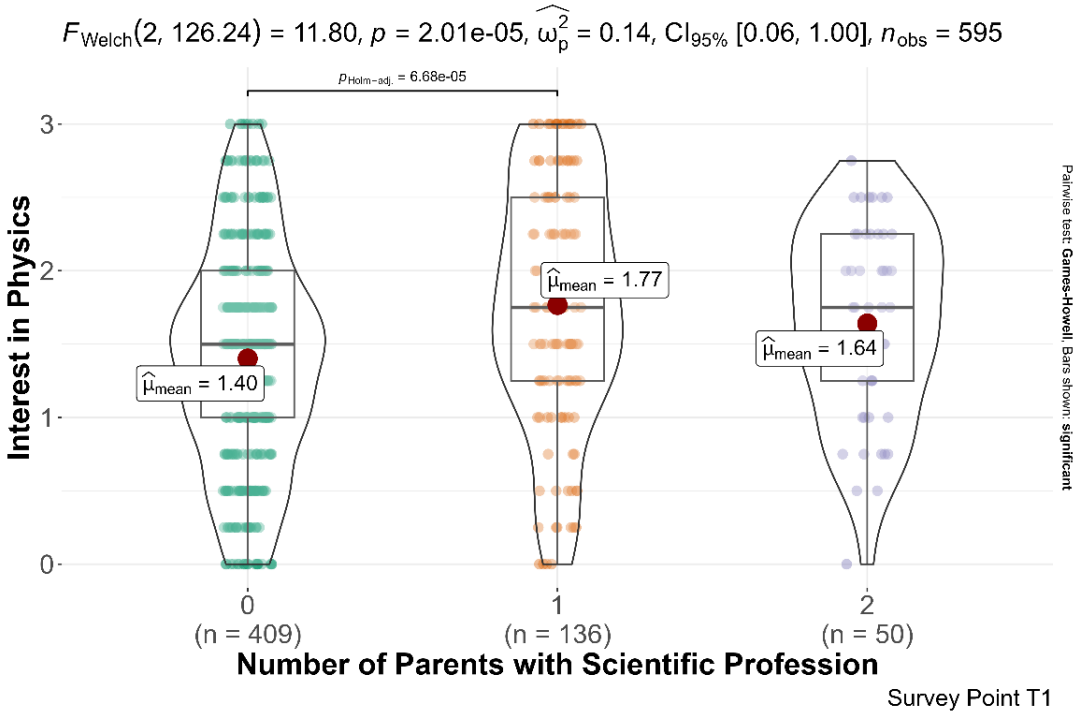
Results On Science Capital

As a means of accessing Science Capital, we examined the professional background of the parents. Participants were asked whether their parents have a job related to science. It is important to note that the survey measured pupils' perceptions of whether their parents' occupations were related to science – rather than an 'objective' classification of specific jobs. From this, we formed groups of pupils without a science-related parent (n=458), pupils with one parent with a science-related background (n=156) and pupils who stated that both parents have a science-related occupation (n=53). In 21 cases, there were no responses or invalid responses. We then analysed whether there are significant differences in self-efficacy and interest and how the constructs develop in the three subgroups over the study period.

In the first survey (T1 for the physics and biology related variables, T2 for chemistry related variables), there are significant differences with medium effect sizes (d>.25*) in all reported variables between the group with one and the group without parents with a scientific occupation.

Students with a science background report higher levels of interest and self-efficacy at all data collection points. The largest differences due to Science Capital can be observed in interest in physics (d=.46*** at T1) and interest in chemistry (d=.39*** at T2). Surprisingly, there are no significantly higher values in the group with two parents working in science-related professions; in fact, for some measures, such as interest in physics the mean values are even lower in this group (see Figure 2).

Figure 2. Interest in physics at survey point T1 showing higher values for students with one parent working in a science-related profession, but no higher values, if both parents have a background in natural sciences.

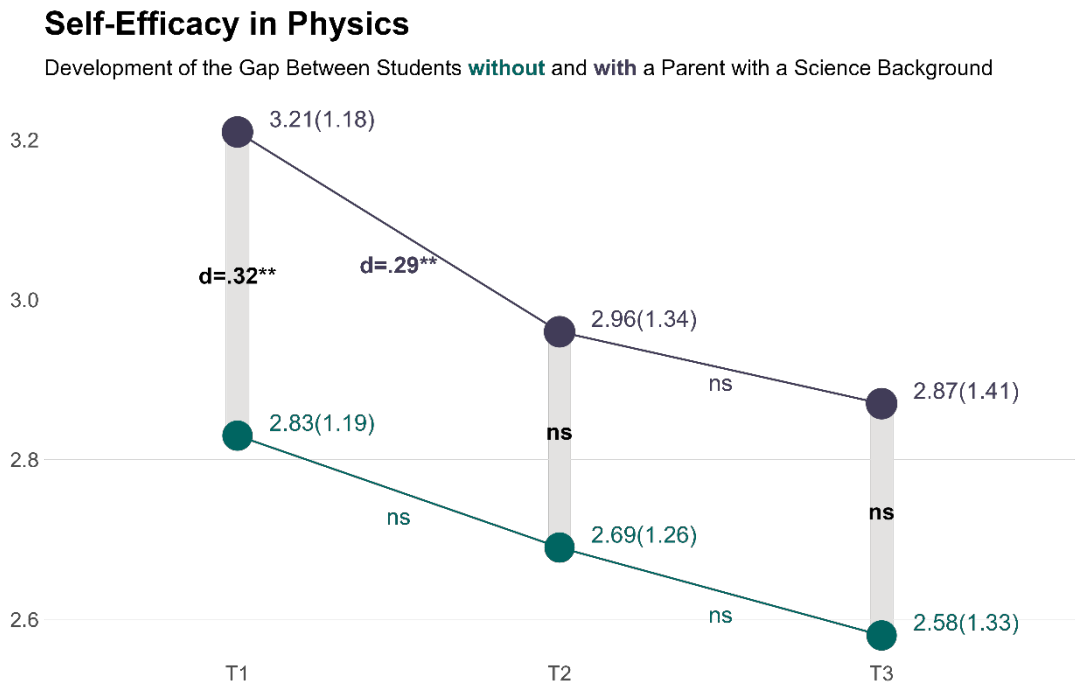


Due to a lack of longitudinal measurement invariance for the group with two parents with scientific professions, the development of interest and self-efficacy is only reported for the other two groups (without and with one parent with a scientific profession).

In contrast to the gender gap, we found a gap in self-efficacy expectations in biology depending on Science Capital (d=.25* at T1 and d=.27* at T2). Almost no significant longitudinal developments can be observed for the self-efficacy in biology. In the group without a parent with a scientific background, self-efficacy in biology increases slightly from T2 to T3 (d=.12*), so that the Science Capital gap at T3 is no longer significant (d=.18).

For interest and self-efficacy in physics and chemistry, we see – similar to the gender gap – that high values (in the groups with high Science Capital) decline the most over the survey period. For example, the decrease in self-efficacy in chemistry is much lower for the group without scientific parents (d=.15**) than in the group with one parent with a science background (d=.35**) from T2 to T3. Due to these longitudinal trends, the differences between the Science Capital groups become smaller and, at the last survey point, are only measurable in terms of interest in physics (d=.40***) and chemistry (d=.27*). All group differences regarding self-efficacy are no longer significant at T3 (see Figure 3 for self-efficacy in physics and Figure 4 for all reported scales).

Figure 3. Development of the Science Capital gap in self-efficacy in physics (scale 0 to 5); Cohen's d is provided for cross sectional and longitudinal effects.

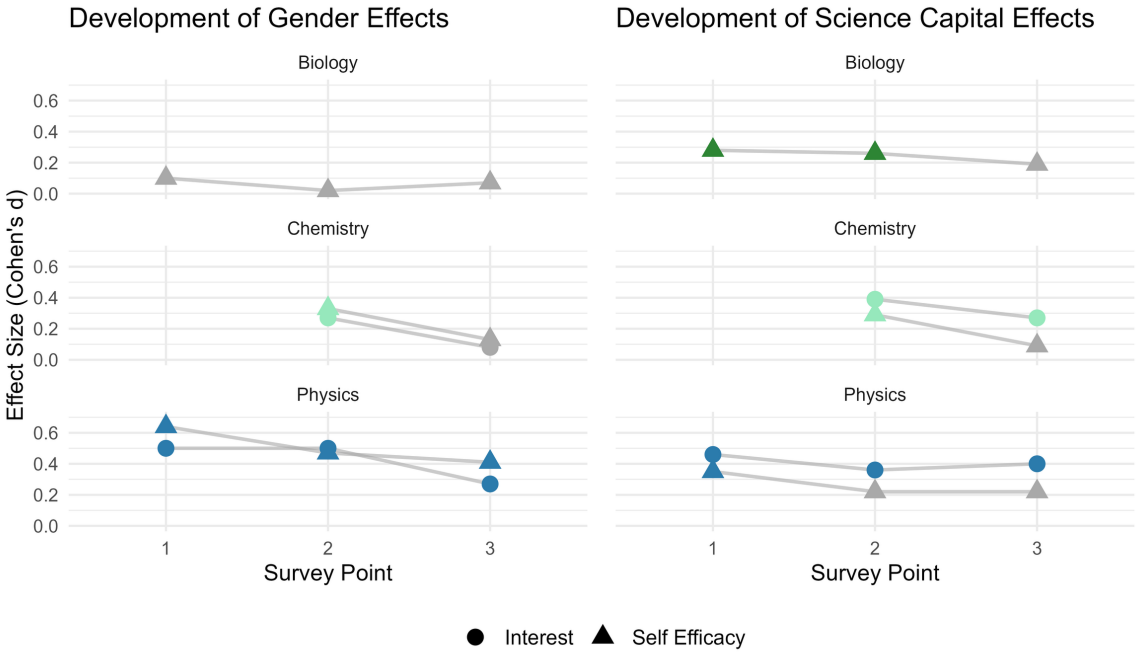


Discussion And Outlook

Our analyses show that gender and Science Capital perspectives are highly relevant in early science education. The findings indicate that the role of gender and Science Capital varies across different natural science subjects and develops differently during initial teaching (see Figure 4). Our results, covering the first two years of physics lessons and the first year of chemistry lessons, indicate that the differences diminish over time, although this is only achieved through a sharp decline in self-assessments that may have been overestimated. Physics-related constructs appear to be developing in a particularly problematic manner. Only in this subject does the gender gap remain significant at the end of our survey. It was also found that students whose parents both work in scientific professions do not exhibit higher self-efficacy or greater interest, meaning that the effects must be considered differently depending on the strength of the parents' scientific background.

In addition to further analytical perspectives (e.g. peer influence, image of science), the next step is to move away from individual constructs and examine a more comprehensive construct of STEM identity (see e.g. Hazari et al., 2020) and its development in early science education. In addition, triangulation with the qualitative data from the project is planned in order to explain the developments identified.

Figure 4. Development of gender gap and Science Capital gap in interest and self-efficacy in biology, chemistry and physics. Grey colour indicates insignificant effects.



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Deconstructing Stereotypes: A Critical Approach To Indigenous Knowledge In Chemistry Education

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Indigenous peoples, estimated at over 300 million across all continents constitute the vast majority of the world's cultural diversity and act as primary guardians of socio-biodiversity, yet their epistemologies remain marginalized by colonial legacies. In the Brazilian educational context, marked by the historical invisibility of indigenous peoples, this research addresses the need to deconstruct stereotypes in Chemistry teaching. Grounded in Law No. 11,645/2008 and decolonial perspectives, the study emerges from the gap in indigenous thematic integration within the scientific curriculum. The theoretical framework is anchored in Critical Meaningful Learning and intercultural theories that question epistemological hierarchies. This paper presents a theoretically validated pedagogical model, focusing on its didactic architecture rather than classroom implementation. The central research question interrogates: In what way can a Potentially Meaningful Teaching Unit (PMTU), structured under decolonial perspectives, provide a methodological framework for integrating Indigenous themes into Chemistry and overcoming curricular fragmentation? By structuring the PMTU through decolonial lenses, this study provides educators with a robust and replicable framework to operationalize the inclusion of Indigenous knowledge, offering a concrete methodology to mitigate the historical invisibility of these epistemologies. The proposal promotes an integrative reconciliation between scientific and traditional knowledge, fostering a contemporary understanding that recognizes epistemological diversity. Designed for adaptation to various global contexts, this framework favours the valorisation of Indigenous peoples and promotes a restorative, truly intercultural science education.

Keywords: Epistemological Pluralism; Interculturality, Epistemic Justice.

Introduction

Brazil, a territory originally inhabited by hundreds of indigenous peoples with millennial linguistic, cultural, and traditional knowledge diversity, still bears deep marks of the colonial process in its educational system. These marks manifest themselves in the marginalization of indigenous history, cultures, and knowledge in school curricula, perpetuating stereotypes and reductionist views, disqualifying traditional methods of knowledge transmission, and privileging Western scientific knowledge; resulting in epistemological violence and historical erasure. Such invisibility compromises the very understanding of Brazilian history by disregarding these peoples' millennial contributions to society's development (Baniwa, 2025; Kayapó, 2021; Munduruku, 2020) and ignores the contemporary, dynamic, and diverse presence of more than 279 indigenous peoples in present-day Brazil (Brazilian Institute of Geography and Statistics [IBGE], 2022).

This dynamic constitutes a profound form of epistemic injustice. As Yarbrough and Smith-Colin (2025) highlight, justice in this context involves correcting the "credibility deficit" imposed on marginalized groups. In science education, this means moving beyond the historical invisibility of traditional knowledge and recognizing Indigenous peoples not just as sources of cultural data, but as legitimate holders of expertise. Addressing this deficit is a restorative act, essential for a curriculum that seeks to repair the historical silencing and the "epistemic violence" often directed at original peoples (Potiguara, 2019; Yarbrough & Smith-Colin, 2025).

In the Brazilian context, this restorative effort finds a concrete expression in the recognition of Indigenous epistemologies. The cultural richness of the Indigenous peoples in Brazil is not

limited to the preservation of ancestral traditions but is manifested in complex systems of knowledge production that engage directly with science. As Law 11.645/08 indicates, the inclusion of this knowledge in the school curriculum is a fundamental step toward an anti-racist and decolonial education. This epistemological plurality challenges the hegemony of Eurocentric thought by highlighting the sustainable management of biodiversity and the social technologies developed by different ethnic groups (Munduruku, 2020; Krenak & Doyle, 2025). In the field of science education, this valorisation allows for what Vanuchi and Raupp (2025) characterizes as a necessary integration between scientific knowledge and Indigenous cosmovisions, promoting a scientific literacy that respects the alterity and cultural heritage of the Brazilian territory. In practice, this integration aligns this research with the concept of epistemological pluralism, which, as Morgan (2011) discusses, involves a shift away from a single, reductionist worldview toward an integrated perspective that values diverse ways of knowing. In Chemistry education, this pluralism acts as a 'corrective' to the limitations of Western science, allowing for a more holistic understanding of reality where indigenous perspectives on the environment and matter are not merely 'included' but are foundational to a broader scientific literacy.

This theoretical framework provides the necessary tools to address a historical context of struggle, where Indigenous and Black social movements have fought for recognition and appreciation of their contributions to Brazilian society's formation, an achievement breaks centuries of silencing and invisibility in the school environment: the enactment of Law No. 11,645 of March 2008, which mandates the teaching of Afro-Brazilian and indigenous history and culture in Basic Education school curriculum (Brasil, 2008). Although enacted nearly 16 years ago, little has been done to change the established scenario. Its effective implementation creates tension for a new positioning that involves questioning an educational model that not only promotes but also perpetuates these peoples' invisibility (Kayapó & Brito, 2014; Marques, 2014).

Furthermore, the challenge of integration is deeply tied to the universalist and Eurocentric view of modern science. However, contemporary studies reveal that Western science has always been spatially situated and dependent on its encounters with non-Western knowledge systems. The case of the Sámi people in Scandinavia demonstrates that "indigenizing" Western science is not about replacing it, but about recognizing it as an evolving intellectual culture that is modified by human and physical challenges posed by Indigenous residents (Wråkberg & Granqvist, 2014).

Under the premise that the inclusion of Indigenous themes is a vital strategy for this deconstruction within the Brazilian context, this study investigates how to operationalize such a dialogue through the following research question: In what way can a Potentially Meaningful Teaching Unit (PMTU), structured under decolonial perspectives, provide a methodological framework for integrating Indigenous themes into Chemistry and overcoming curricular fragmentation? This proposal was conceived as part of a doctoral research project in Science Education, developed at a public university in Southern Brazil.

Bridging The Gap: Challenges Of Law 11,645/08 In Chemistry

Despite legal requirements, a systematic review study (Vanuchi & Raupp, 2022) revealed a significant research gap in science education, where indigenous themes remain concentrated in arts, literature, and history disciplines, failing to achieve the transversality intended by Law 11,645/08. This gap is not merely a technical failure in curriculum design, but a reflection of deeper epistemological barriers. This concentration in non-scientific fields reinforces the stereotype of Indigenous peoples as historical or folkloric figures, lacking technical and scientific

agency. By failing to achieve transversality in Chemistry, the education system implicitly perpetuates the myth that Indigenous knowledge is incompatible with rigorous scientific thought.

Brazilian indigenous intellectuals point out critical challenges in implementing the Law in science education. Gersem Baniwa (2025) shows the persistence of structural obstacles to plural education due to the colonial nature of academic knowledge, while Daniel Munduruku (2019) emphasizes that effective implementation requires a curricular reconfiguration to include historically marginalized indigenous scientific practices. Ailton Krenak adds that the current system reproduces epistemic hierarchies that disqualify ancestral knowledge (Krenak & Doyle, 2025).

According to Eliane Potiguara (2019), genuine change will only occur through truly intercultural education that recognizes Brazilian epistemological plurality. Understanding the roots of this resistance requires considering the perspectives of Indigenous intellectuals who identify the colonial foundations of these educational obstacles. These Indigenous critiques are deeply aligned with the broader academic framework of critical interculturality, which provides the theoretical tools to dismantle the power structures that sustain such colonial resistance.

Interculturality represents a significant evolution in global academic thinking, based on fundamental contributions established in decolonial perspective foundations (Quijano, 2020). The field was enriched by critical analyses of subalternity and power structures that silence marginalized voices (Spivak, 1988), explaining how epistemological colonialism resulted in the exclusion of non-Western knowledge (Dussel, 2019). Furthermore, explorations of cultural hybridity and identity (Bhabha, 1994; Hall, 1996) contribute to deconstructing Eurocentric narratives and promoting knowledge decolonization, significantly influencing education and science (Mignolo, 2011). Such perspectives are essential for rethinking school curricula to recognize and value different epistemologies (Walsh, 2013).

However, there is still a long way to go to effectively incorporate indigenous contributions into pedagogical practices without limiting them to commemorative dates. Insufficient teacher training and undergraduate courses that rarely include indigenous themes remain major hurdles (Bergamaschi, 2012: Oliveira & Almeida, 2023). Teaching materials often reproduce stereotypes (Grupioni, 1995) and invisibilize contemporary indigenous scientific contributions by limiting these peoples to a colonial past (Kayapó, 2021; Munduruku, 2019). This institutional resistance to accepting non-Western epistemologies confirms that the coloniality of knowledge remains a formidable obstacle (Quijano, 2020; Walsh, 2013).

The analysis of these structural and epistemological barriers demonstrates that implementing Law 11,645/08 in Chemistry requires pedagogical tools that operationalize intercultural dialogue. Moving beyond normative guidelines, it is essential to develop strategies that challenge Eurocentric curricula and deconstruct deeply rooted stereotypes.

Proposal: A Didactic Strategy Based On Significantly Critical Learning

Acknowledging that interculturality requires a critical approach beyond simple content inclusion (Walsh, 2013), this didactic proposal is founded on Critical Meaningful Learning (Moreira, 2000; 2011), expanding upon Ausubel's theory (2012) by emphasizing learners' critical engagement with content through questioning its validity and contextual relevance to their sociocultural environment. In the context of this research, Critical Meaningful Learning (CML) is not merely a cognitive process but a political and ethical stance against the coloniality of knowledge. According to Moreira (2000; 2011), CML allows the learner to participate in their culture while simultaneously distancing themselves from it critically. For indigenous themes in Chemistry education, this means that students can recognize the historical stereotypes embedded in their

social fabric while using critical thinking to 'unlearn' folkloric representations—the 'generic indigenous' person—and anchor new meanings based on contemporary indigenous scientific contributions. This process of 'unlearning' serves as an epistemological break, essential for decolonizing the curriculum and acknowledging indigenous peoples as dynamic producers of knowledge rather than figures fixed in the past.

Within the scope of Chemistry education, addressing Indigenous themes acts as a catalyst for intercultural education by challenging the universalist and Eurocentric view of modern science. By integrating traditional knowledge, the curriculum shifts from being a transmitter of abstract concepts to a space for dialogue between different forms of knowledge. This pedagogical practice, grounded in decoloniality, allows students to recognize Chemistry as a plural human construction, where Indigenous social technology is validated as legitimate scientific knowledge. In this way, chemical education contributes to the recognition of alterity, promoting respect for diverse ways of interacting with matter and the environment, which are fundamental pillars for a truly intercultural society.

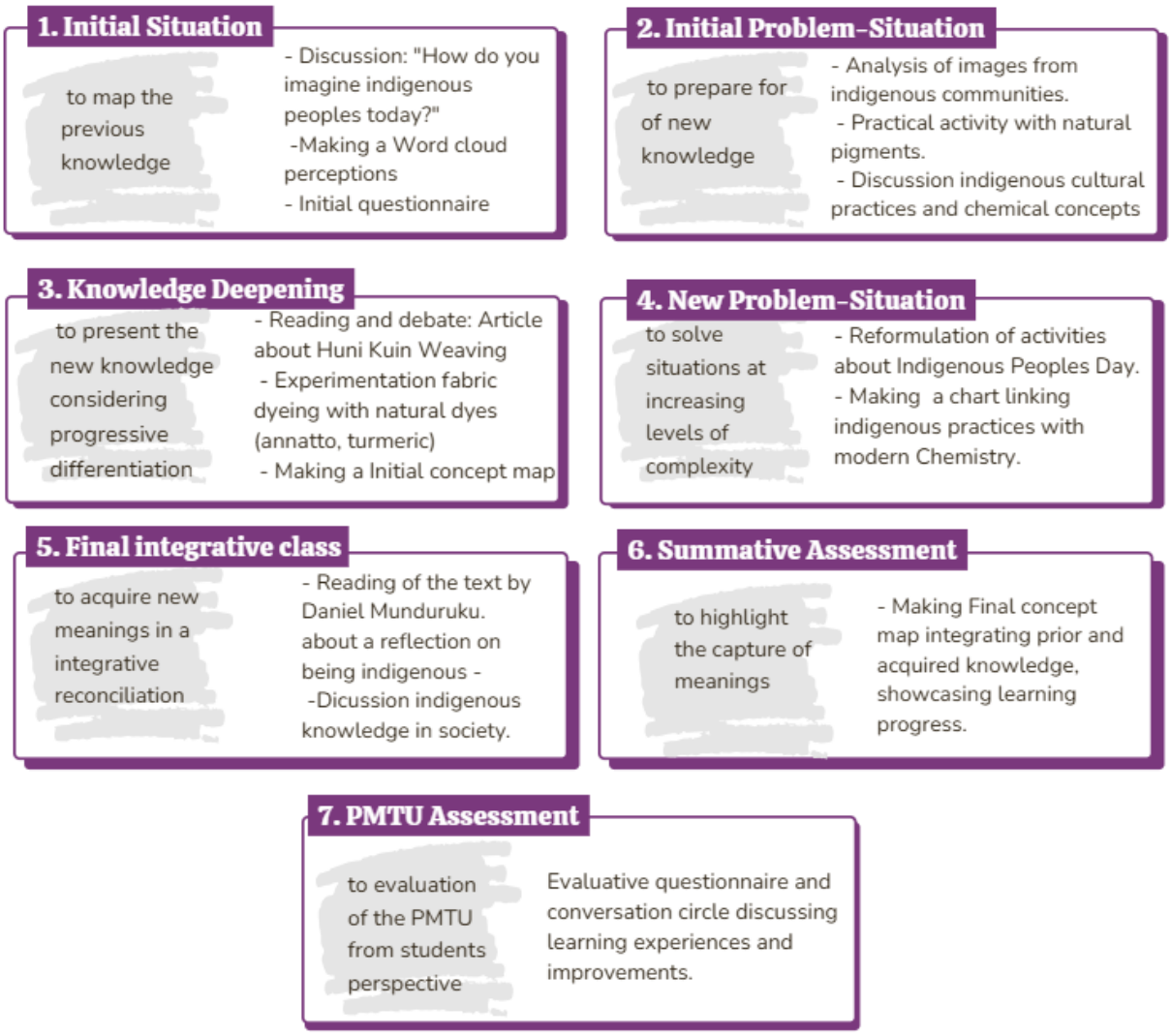
In order to transform this theoretical critique into a structured learning experience, the proposal is materialized through Moreira's (2011) Potentially Meaningful Teaching Units (PMTU) framework. This methodology utilizes logically structured, meaningful materials specifically designed for the target audience to promote meaningful rather than mechanical learning. Consequently, PMTUs facilitate a higher quality of knowledge. Briefly, the PMTU is composed of the initial situation: which aims to map the previous knowledge of students. Initial problem-situation: a problem-situation of an introductory level, seeking to give meaning to the concept. Deepening of knowledge: approach from progressive differentiation. New problem situation: questions with a higher level of depth, evidencing the correspondences and contradictions between the concepts. Individual summative evaluation: test evidencing the capture of meanings. Final integrative class: seeks integrative reconciliation between concepts. Learning assessment: evidence should be sought for understanding meanings and the ability to use knowledge for different situations throughout the implementation of the PMTU, focusing on collaborative activities, and ending it with an individual summative assessment. Evaluation of the PMTU itself: In order to improve teaching strategies, to assess the perspective of students (Schittler; Moreira, 2014).

The PMTU methodology comprises seven progressive stages supported by formative assessment (Figure 1), utilizing problem-based situations to evaluate the acquisition of meanings. Although this proposal is grounded in the Brazilian legal framework (Law No. 11,645/2008), its methodological structure is designed to be flexible, adaptable, and replicable in diverse international contexts. The core objective — the integrative reconciliation between Western scientific language and ancestral epistemologies — addresses a global challenge in science education: the need for pluralistic and intercultural curricula that respect local identities while promoting scientific literacy.

The sequence of activities comprised in the PMTU is detailed below, highlighting the pedagogical intent of each stage and its alignment with the goals of decolonial science education

1. Initial Situation: designed to identify students' prior conceptions, which are often permeated by colonial stereotypes. This diagnostic phase is crucial for the subsequent pedagogical insurgence, allowing the instructor to confront biased views with the complexity of Indigenous social technologies. We suggest three instruments: (1) a collective debate focused on students' perceptions of Indigenous peoples in contemporary times; (2) the collaborative construction of a word cloud using digital tools; and (3) an individual questionnaire exploring the understanding of Indigenous peoples in the present day and the recognition of Indigenous cultural heritage.

Figure 1. PMTU Organization with definition of the seven progressive stages, selected activities and didactic resources.



2. Initial Problem-Situation: the goal is to provoke a critical confrontation between colonial imaginaries and the diversity of Indigenous identities using image analysis (Figure 2). A stereotypical depiction showing reductionist folkloric views (nudity, straight hair, uniform skin tone, headdresses, and life restricted to nature) and Ailton Krenak, who challenges limiting perspectives by occupying prominent spaces, such as the Brazilian Academy of Letters.The proposal operationalizes what Walsh (2013) terms 'pedagogical insurgence.' Methodologically, this stage initiates the process of progressive differentiation, challenging the 'epistemic violence' (Spivak, 1988) that historically relegated Indigenous existence to a static past, thereby opening space for the recognition of Indigenous peoples as contemporary producers of knowledge and science.

The stage suggests an experimental activity (Vanuchi & Braibante, 2021) preparing natural dyes using genipap and annatto - pigments traditionally used by indigenous peoples for ritual and identity markings (Figure 3). This stage operationalizes integrative reconciliation (Moreira, 2011) by connecting traditional Indigenous knowledge with scientific concepts of Organic Chemistry. The preparation of natural dyes from genipap and annatto substances historically used for ritual and identity markings—serves as a critical subsumer.

The role of this stage is to validate ancestral knowledge as complex technoscientific systems, allowing students to understand chemical phenomena (such as polarity and functional groups) from a culturally relevant basis, effectively deconstructing the view of Indigenous knowledge as merely folkloric.

Figure 2: Stereotyped Indigenous Person vs. Contemporary Indigenous Person.

Figure 3: The use of natural pigments in body ornamentations.

3. Knowledge Deepening: discussion of the article about Huni Kuin (Silva et al, 2016) weaving and the complex textile production techniques of this ethnicity, in a progressive differentiation when general concepts progressively broken down into more specific concepts (Moreira, 2011), showing how this knowledge is closely linked to various chemical concepts, such as acids and bases, pH, intermolecular forces, and mixture separation techniques, like decantation and filtration, maceration processes, decoction. Each ethnicity develops its own techniques and symbologies for the extraction and use of pigments (Figure 4) that not only decorate but carry deep cultural meanings.

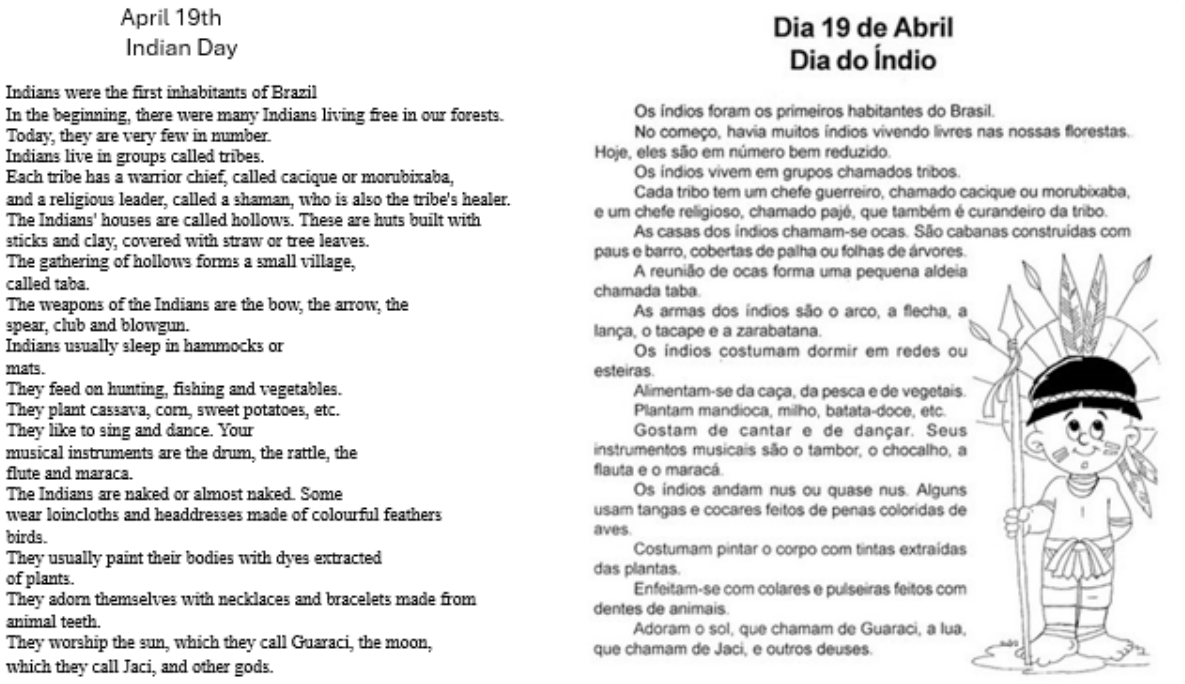
Figure 4. Fabrics dyed with annatto.

The role of this phase is to demonstrate that each ethnicity develops specific methodologies for pigment extraction. This approach reinforces the deconstruction of stereotypes by moving from

a general appreciation of Indigenous culture to a rigorous technical understanding of their scientific contributions

4. New Problem-Situation: in greater level of depth, students will be encouraged to critically reformulate commonly used stereotypical school activities, especially those related to "Indigenous Peoples Day" (Figure 5). After, they will also organize a flowchart that relates indigenous knowledge, natural pigments, and Chemistry principles, promoting an integrative reconciliation between traditional and scientific knowledge.

Figure 5. School activity on April 19th in homage to the First Inter-American Indianist Congress, held in 1940, with stereotypical representations that reinforce misconceptions about these peoples.



April 19th
Indian Day

Indians were the first inhabitants of Brazil
In the beginning, there were many Indians living free in our forests.
Today, they are very few in number.
Indians live in groups called tribes.
Each tribe has a warrior chief, called cacique or morubixaba,
and a religious leader, called a shaman, who is also the tribe's healer.
The Indians' houses are called hollows. These are huts built with
sticks and clay, covered with straw or tree leaves.
The gathering of hollows forms a small village,
called taba.
The weapons of the Indians are the bow, the arrow, the
spear, club and blowgun.
Indians usually sleep in hammocks or
mats.
They feed on hunting, fishing and vegetables.
They plant cassava, corn, sweet potatoes, etc.
They like to sing and dance. Your
musical instruments are the drum, the rattle, the
flute and maraca.
The Indians are naked or almost naked. Some
wear loincloths and headdresses made of colourful feathers
birds.
They usually paint their bodies with dyes extracted
of plants.
They adorn themselves with necklaces and bracelets made from
animal teeth.
They worship the sun, which they call Guaraci, the moon,
which they call Jaci, and other gods.

Dia 19 de Abril
Dia do Índio

Os índios foram os primeiros habitantes do Brasil.
No começo, havia muitos índios vivendo livres nas nossas florestas.
Hoje, eles são em número bem reduzido.
Os índios vivem em grupos chamados tribos.
Cada tribo tem um chefe guerreiro, chamado cacique ou morubixaba,
e um chefe religioso, chamado pajé, que também é curandeiro da tribo.
As casas dos índios chamam-se ocas. São cabanas construídas com
paus e barro, cobertas de palha ou folhas de árvores.
A reunião de ocas forma uma pequena aldeia
chamada taba.
As armas dos índios são o arco, a flecha, a
lança, o tacape e a zarabatana.
Os índios costumam dormir em redes ou
esteiras.
Alimentam-se da caça, da pesca e de vegetais.
Plantam mandioca, milho, batata-doce, etc.
Gostam de cantar e de dançar. Seus
instrumentos musicais são o tambor, o chocalho, a
flauta e o maracá.
Os índios andam nus ou quase nus. Alguns
usam tangas e cocares feitos de penas coloridas de
aves.
Costumam pintar o corpo com tintas extraídas
das plantas.
Enfeitam-se com colares e pulseiras feitos com
dentes de animais.
Adoram o sol, que chamam de Guaraci, a lua,
que chamam de Jaci, e outros deuses.

This stage aims to combat curricular fragmentation and the 'folklorization' of Indigenous themes, which are often restricted to isolated commemorative dates such as 'Indigenous Peoples Day.' By encouraging students to critically reformulate stereotypical school activities, the proposal operationalizes the challenge of moving beyond mere symbolic inclusion. The role of this phase is to promote a final integrative reconciliation, where traditional knowledge and chemical principles are organized into a flowchart of interdependence.

5. Final Integrative Class: discussion of the text "I can be who you are without ceasing to be who I am: a reflection on being indigenous" by Daniel Munduruku in a circle, to reflect on the presence and valorization of indigenous knowledge in/by contemporary society and science.It demands an integrative reconciliation - the construction and reconstruction of conceptual relationships, as new concepts were incorporated into the cognitive structure and need to be reorganized (Moreira, 2011).

6. Summative Assessment: Construction of a final conceptual map with the focal question: What knowledge do you have about Indigenous peoples and their role in contemporary society? By comparing both maps, it will be possible to observe progressive differentiation and integrative reconciliation, as well as identifying changes in students' representations of Indigenous peoples.

7. PMTU Assessment: An evaluative questionnaire for feedback and a discussion circle to reflect on how students' perceptions of Indigenous peoples have changed and how this new perspective has impacted their understanding of Chemistry.

The integration of these seven stages within the PMTU framework transcends a mere instructional sequence; it constitutes a deliberate pedagogical intervention aimed at fostering anti-racist and intercultural chemistry education. By centering Indigenous social technologies, such as the chemistry of natural pigments, this strategy operationalizes what Walsh (2013) defines as 'pedagogical insurgence,' challenging the Eurocentric hegemony that historically silenced non-Western forms of knowing. The iterative cycle of problem-situations and integrative reconciliation provides the necessary scaffolding for students to recognize 'epistemic pluralism' (Baniwa, 2025), acknowledging Indigenous peoples as contemporary producers of scientific knowledge rather than figures of a folkloric past. Consequently, this didactic approach acts as a restorative practice, aligning chemical concepts with social justice to deconstruct racialized hierarchies and promote a more equitable and pluralistic understanding of science (Munduruku, 2019; Quijano, 2020).

Within the scope of Chemistry education, addressing Indigenous themes acts as a catalyst for intercultural education by challenging the universalist and Eurocentric view of modern science. This challenge is supported by the understanding of technoscience, which reveals that Western science has historically been dependent on and shaped by its encounters with non-Western knowledge systems (Wråkberg & Granqvist, 2014). By integrating traditional knowledge—such as natural pigment extraction and textile production techniques (Silva et al., 2016)—the curriculum shifts from a transmitter of abstract concepts to a space for 'indigenizing' Western science. This process transforms colonial science into a tool for emancipation (Baniwa, 2025; Walsh, 2013), where Indigenous social technology is validated as a legitimate scientific contribution that modifies and enriches global scientific practices.

Final Considerations

This research addressed the persistent challenge of integrating Indigenous themes into the Chemistry curriculum, a field historically dominated by Eurocentric and universalist perspectives. By developing a didactic strategy grounded in Potentially Meaningful Teaching Units (PMTU) and Critical Meaningful Learning, we demonstrated that it is possible to move beyond the mere fulfilment of Law 11,645/2008 toward a practice of epistemic justice.

The proposal, by centring Indigenous social technologies, served as a catalyst for decolonizing the science curriculum. This process allowed for the deconstruction of folkloric stereotypes, positioning Indigenous peoples not as relics of the past, but as dynamic producers of contemporary scientific knowledge. A key contribution of this study is the structural flexibility of the PMTU framework, which is designed to be adaptable and replicable in diverse international contexts. This allows the methodology to be tailored to the specific scientific realities and ancestral epistemologies of different Indigenous peoples across various global regions. Although the results of the evaluation of the UEPS have not yet been systematized, this proposal outlines the theoretical and methodological foundations that will guide this stage. The different phases of the UEPS — which range from the assessment of prior knowledge to problematization and integrative reconciliation — were organized to facilitate the identification of possible changes in students' understanding of Indigenous peoples and the chemical concepts addressed throughout the proposal.

In conclusion, this proposal aims to contribute to the global dialogue on Diversity, Identity, and Inclusion in Science Education by offering a validated and structurally flexible methodology. A key contribution of this framework is its potential for adaptation; it is designed to be replicable in diverse international contexts, allowing the pedagogical stages to be tailored to the specific scientific realities and ancestral epistemologies of different Indigenous peoples across various

global regions. Thus, decolonizing Chemistry teaching is presented not only as a local necessity but as a global opportunity to honor epistemological plurality and promote the inclusion of historically marginalized voices in the scientific field.

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How Families' Everyday Engagements Hold Potential For Cultivating Students' Science Capital And Align With School Science

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This study investigates how students' everyday activities outside school, across family contexts, hold potential for shaping distinct forms of Science Capital and how these forms can align with school science. The findings are based on 54 interviews with Danish families of students aged 6 to 15 from five schools.

While family life encompasses a wide range of science-related experiences, these activities are often not recognized or framed as relevant to formal education. Instead, parents primarily value these experiences for fostering lifelong skills, personal development, family bonding, and well-being. In addition, family engagement in science-related activities often involves sensory, creative, and aesthetic interactions with natural objects and phenomena, which contrast with the academic approaches emphasized in science education.

Finally, our results reveal that parents' valued childhood leisure experiences, interests, values, knowledge, and skills, together with opportunities afforded by place and local surroundings, influence how science is approached, discussed, and enacted within families.

Consequently, the ways students engage in science-related activities vary across family contexts, leading to different degrees of alignment between students' science experiences outside school and school science. These findings show that students' family experiences play a critical role in shaping the forms of Science Capital they bring into the classroom and how these forms are recognized within school science. The results highlight the importance of aligning science education with students' everyday lives to foster more relevant and inclusive school science. A "Science Capital Teaching Approach" is discussed as a framework for bridging students' experiences with school science.

Keywords: Family Science Habitus, Science Capital, School Science

Introduction

Science education has been criticized for reinforcing systemic inequalities by failing to recognize and address the diversity in students' family contexts. It has been suggested that the misalignment between students' family engagement and school science maintains disparities in participation, engagement, and achievement (Nomikou, Archer, & King, 2017). Recent TIMSS findings highlight these issues, revealing significant inequalities in science achievement linked to family background. Notably, some countries, including Denmark, have experienced an increase in these disparities in recent years (von Davier, Kennedy, Reynolds, Fishbein, Khorramdel, Aldrich, Bookbinder, Ummugal, & Yin, 2024). To understand these inequalities, this study draws on the concepts of Science Capital and family science habitus, as well as the interplay between the two.

Science Capital

Science Capital can be defined as an individual's science-related knowledge, attitudes, and experiences. It is argued that students' Science Capital plays a crucial role in shaping their opportunities to develop a strong science identity, engage with school science, and pursue future

aspirations (Archer et al., 2015). However, not all forms of Science Capital hold the same exchange value in school science. Certain forms - such as knowing scientific concepts - are more likely to be recognized and valued as Science Capital in school. In contrast, more applied forms - such as engaging in gardening, repairing machines, or cooking - often remain invisible within school science (Nomikou, Archer, & King, 2017).

Family Science Habitus

Families play a critical role in shaping students' engagement with science through their values, attitudes, and everyday practices, which can be understood as family habitus (Archer et al., 2012). Family habitus influences how students perceive and relate to science; however, not all forms of family habitus align equally well with the norms and practices of conventional science education (Archer et al., 2012; Suortti, Havu-Nuutinen, & Kärkkäinen, 2023).

In this way, the concept of family habitus is not only useful for understanding how and why science is embedded in everyday family life but also for examining how its alignment - or misalignment - with school habitus (i.e., the norms and curricular expectations of school science) can reinforce or mitigate inequalities in students' ability to relate to, participate in, and benefit from science education.

The Interplay Between Family Habitus And Science Capital

Family habitus and Science Capital are closely interrelated concepts, and their interplay is important for understanding how family everyday life shapes students' opportunities to participate in, benefit from, and relate to school science. Indeed, it is argued that family habitus cultivates different forms of Science Capital, each carrying varying degrees of potential to be recognized and valued within school science (Archer et al., 2012).

This means that family habitus directly influences students' engagement in school science through its alignment - or misalignment - with school habitus. Additionally, it indirectly shapes the types of Science Capital students develop, which in turn affects their participation and success in science education. Ultimately, these outcomes depend on both the degree of alignment between home and school habitus and the extent to which students' different forms of Science Capital are recognized within the field of school science.

Taken together, students enter science classrooms with varying possibilities to relate to, engage with, and participate in science education, depending on how their family science habitus and the form of Science Capital cultivated in their everyday science engagement align with school science expectations. This leads to unequal opportunities for students to fully access science learning and perceive it as meaningful and relevant to both their present and future lives. Ultimately, the interplay between family habitus, the development of Science Capital, and its alignment with school science has significant implications for students' participation, success, and long-term aspirations in science.

By exploring how family science habitus cultivates different forms of Science Capital, this study addresses a rarely explored perspective in science education research, as called for by the science research community (Wenner, 2024). This article argues that understanding how and why families engage with science-related activities is essential for fostering more inclusive and equitable science education, particularly for a more diverse group of students.

Against this background, we set out to answer the following research question:

How and why do families engage with science-related activities – and in what way does this engagement hold potential for cultivating different forms of students' Science Capital, and how do these forms of Science Capital align with school science?

Research Methods

Data were collected through interviews with families of students from five Danish schools, selected to ensure diversity in geography, urbanity, and students' socioeconomic and ethnic backgrounds. Using a maximum variation sampling approach, 15 students were selected from each school across grades 0, 5, and 8. Of the planned 75 interviews, 54 were successfully conducted. Interviews took place in families' homes, with primary caregivers (predominantly parents) serving as the main informants, while in most cases, the student and occasionally their siblings also participated. In a few cases, interviews were conducted online or at an alternative location chosen by the family for reasons of comfort or practicality.

The interviews were guided by a semi-structured interview protocol and a "family wheel poster", which illustrated physical and temporal aspects of families' everyday lives. The questions were informed by a conceptual framework combining Science Capital and family science habitus (e.g., Jones, Ennes, Weedfall, Chesnutt, & Cayton, 2021). Additionally, families were presented with photos depicting various science-related places and activities to prompt reflections and discussions about their experiences, perceptions, and attitudes toward science.

Throughout the interviews, family members and the interviewer jointly contributed to the family wheel with drawings, comments, and examples. All interviews were recorded, transcribed, and analysed using a combined deductive and inductive thematic analysis approach (Braun & Clarke, 2006). For illustration, an example of a deductive code related to Science Capital was "Access to physical science-related resources" (e.g., 3D printers, greenhouses, pets/livestock). In contrast, an inductive theme that emerged was "Togetherness and Shared Experiences," capturing parents' rationale for engaging in science-related activities with their children.

Results

First, we describe the dominant pattern across families, showing how science-related engagement is embedded in everyday life without being articulated as ‘science’. We then examine how this engagement is shaped by parents’ interests and place, and how it is characterized by embodied, sensory, and lived experiences. Finally, we highlight important variations across families, where some everyday practices come to resemble ways of engaging that align more closely with school science, pointing to differences in how students’ Science Capital is likely to be recognized within school science.

Science As Part Of Everyday Family Life

The findings indicate that, although family everyday life involves a wide range of science-related individual activities (e.g., jewelry crafting, taking mobile snapshots, strength training) and collective activities (e.g., forest outings, cooking, hunting/fishing, gardening, tractor drags, collecting natural artifacts, home repairs), these activities are often not recognized, connected to, or framed as relevant to school science by the families.

Parents’ Interests Shaping Shared Family Activities

Furthermore, while parents support their children’s individual interests, both parent-child activities (e.g., horseback riding, hiking) and organized leisure activities (e.g., team sports, scouting) often reflect parents' own valued childhood pursuits. The following example illustrates how a shared leisure interest becomes a practice passed on across generations within the family:

(Family A; Girl, 7 years)

> Father: “My father collected a lot of model airplanes … and that definitely helped build my interest in airplanes, one hundred percent. If he hadn’t done that, I wouldn’t have had that interest.”
>
> Mother: “…dad is very interested in model airplanes it’s really his big thing. This used to be an old guild hall that we turned into a hobby room, and that’s where he spends time tinkering. He’s very interested in technology. You’re a bit into that too, aren’t you? You also think it’s fun, this whole model airplane camp and things like that, right?”
>
> Girl: “Yes.”
>
> Mother: “[…] she is probably the one who is most interested in the airplane stuff and all of that - I honestly don’t understand a thing about it, but she really wants to.”

Additionally, parents' personal interests (e.g., gardening, building airplanes, birdwatching, and home repairs), values (e.g., viewing nature as a space for well-being and seeing practical skills as important), skills (e.g., recognizing species, using tools), and attitudes (e.g., sharing enthusiasm and inviting children to participate without obligation) strongly influence the shared experiences children are invited to take part in as part of everyday family life. In several families, this became clear through everyday workshop activities, where children participated alongside their parents in making, repairing, and constructing things together:

> (Family B; Boy, 7 years)
> Boy: “Sometimes, when I hear a hammer, I come.”
> Father: “Then we go down to the basement together, and you bring out your toolbox, where you can saw and screw.”
> Boy: “I even have an old-fashioned drill.”

This example shows how parents’ everyday engagement in making and repairing, together with the availability of tools and workspace in the home, naturally draws children into these activities as part of family life.

In another family, this everyday engagement appeared in time spent together outdoors:

> “It is more about observing. I have done that since I was a boy. I was involved in nature associations for young people and the Danish Ornithological Society to watch birds. I am not part of an organization anymore, but I still look for birds. These things still fill a lot for me - plants, animals, mushrooms, birds. We sometimes go on trips to the forest to collect mushrooms or go out to look at birds and plants. If we find a mushroom, I like to show it to the children. There is always a kind of excitement in finding things. I get enthusiastic about it, so I would like to share it with them. They should have the opportunity. If they are not interested, they can just say so.” (Father, Family C; Girl, 12 years)

Together, these accounts show how parents’ own interests, values, skills, and attitudes shape how families spend time together. What began as a parent’s own long-standing interest becomes visible in shared activities, in what the family stops to look at, and in how time is spent together. Whether through shared making in a workshop or shared attention to birds, plants, and mushrooms, children participate in activities that emerge from what is natural to the parents themselves in everyday family life. In this way, children are drawn into these practices through parents’ enthusiasm and repeated shared experiences rather than through planned learning situations.

Nature As Lived, Sensory And Creative Experience

Our data suggest that when children engage in science-related activities within the family, parents do not primarily focus on enhancing their children's school science performance or fostering aspirations in science. Instead, parents value these activities for their perceived contributions to lifelong skills for everyday life and personal development, fostering bonds within the family and friendships through shared experiences, and promoting physical and mental well-being.

One father explained, in response to how nature is approached and valued within the family:

> "Nature is basically the foundation of where we come from. If you become aware that everything around us originates there in its original form, it gives a better understanding of environmental conditions and of how to act responsibly in relation to what we eat and how we cultivate the land. It is also something spiritual and related to well-being. Being in nature gives an inner calm that you do not find in hectic surroundings. But it is difficult to have those kinds of conversations with children because it becomes too abstract. I think it comes by itself without having to say it. You develop an awareness of animals, plants, and the landscape simply by being in it. When we go out to pick blackberries or mushrooms, you get a closer relationship to nature that way."
>
> (Father, Family C girl grade 5)

This account illustrates how nature is understood as a meaningful and lived part of everyday family life. These understandings develop through shared activities rather than explicit explanation, as children participate in practices such as being outdoors and foraging together with their parents.

The Role Of Place And Access To Local Environments

Likewise, family science engagement is strongly shaped by place of residence, as geographical location, urbanity, and community resources influence opportunities. Indeed, access to organized leisure activities, playgrounds, home gardens, and natural areas affects both the frequency, diversity, and content of families' science-related experiences. The following example illustrates how access to local natural environments shaped and continues to shape families' everyday opportunities for science-related experiences:

> "We live in the last row of houses, and then you just walk out onto the heathland and further out onto the spit. It's incredible. I have never seen so many birds as after we moved there […] We have even been out looking for amber in the evenings when it's dark, and it's fascinating how the whole beach changes when night falls […] If the weather was good, we would suddenly go to the beach or go fishing […] We would often just go to the beach together. It takes two minutes and then we are there."
>
> (Mother, Family D; Boy, 7 years)

Or another family, referring to a nearby managed recreational nature park:

> "We have a dog, and I love going for long walks. We walk a lot out there - it's basically our backyard. I love it, so I am outside a lot." (Girl, Family E; 11 years)

Together, these accounts show how proximity to local natural environments makes spontaneous visits part of everyday life and a regular way of being. Rather than organized outings, the local landscape becomes a natural extension of the family's living space, offering ongoing opportunities to notice, explore, experience, and come to value the richness of this environment.

Nature As An Embodied, Sensory, And Lived Experience

In addition, our findings show that most families engage with natural objects and phenomena through multisensory, physically embodied, aesthetic, and sometimes creative approaches:

> "During the storm we were completely covered up with goggles… and the sand was hitting us. It was wild, but also fascinating to be right in it […] We experience so many things… and you don't have time to take pictures. You simply have to be in it […] I enjoy going to the beach and finding things we can use for something - creating something out of what we find."
>
> (Mother, Family D; Boy, 7 years)

Taken together, these accounts illustrate how family engagement with nature can be simultaneously sensory, physically embodied, place-based, and creative. They also show how such experiences are valued as lived moments that do not need to be documented, but rather fully experienced as they unfold.

Everyday Practices Resembling School Science

Finally, although the findings indicate that parents do not explicitly frame or value family activities in relation to school science, they still highlight differences linked to alignment with school science. For example, parents with backgrounds in science, technology, or pedagogy are more likely to engage in science-related activities in ways that resemble a school-oriented perspective. This includes practices such as naming natural objects, fostering curiosity, searching for information, and encouraging children to identify what they encounter in nature:

> "We really enjoy going out to explore and discover new places. It is very much about nature and experiencing different local areas. When the children were younger, they loved going to the pond to look for small animals. In the spring, we would run out and turn over the same tree stump, waiting for insects to appear. They are still very good at noticing butterflies and insects. For example, my son once found a beautiful caterpillar and really wanted to look it up to find out what kind it was. I can even remember the name of it. That is typically what we would do at home - try to identify what we find." (Mother, Family F; Boy, 12 years)

Similar patterns appeared in other families: *"It is mostly when we are out walking that you ask, 'Can you remember what this flower is called*?'" (Boy, Family G, 13 years). "*Yes, because I find it a bit embarrassing if they cannot remember*." (Mother, Family G, Boy, 13 years) or

> "We sometimes go on trips to collect mushrooms or look at birds and plants, and I always bring a mushroom guidebook to figure out what we find. The children sometimes find it exciting to search for things, sometimes they do not." (Father, Family C; Girl, 12 years).

In some families, this school-oriented perspective was also supported through the use of books and shared reading about nature at home as part of everyday activities:

> "When she was very little, we used to read those bird books… she found that really fun […] We would sit with books and read about all the sea animals… and at one point you even said yourself that you wanted to be a marine biologist" (smiling). (Family A; Girl, 7 years)

Together, these examples show how everyday walks and explorations in nearby nature involve paying attention to, noticing, identifying, and sometimes seeking further knowledge about what is encountered - including through books and shared reading at home. They indicate that being able to notice, recognize, name, and know elements in nature holds value within these families. In this way, everyday activities come to resemble the noticing, inquiry-oriented, and knowledge-seeking practices typically associated with school science, even though the activities themselves are not framed as such by the parents.

While some families in this way engage in practices that resemble a more school-oriented approach to science, the overall and more dominant pattern across families is that science-related engagement is embedded in everyday life without being articulated or valued as ‘science’.

At the same time, the findings show that science is enacted differently across families. How children encounter science in everyday life depends on parents’ interests, values, skills, long-standing engagements - often rooted in their own childhood and youth - as well as on the opportunities afforded by place and local surroundings.

As a result, children encounter science in different ways in everyday family life, with varying potential for alignment with school science.

Discussion And Conclusion

Our findings show that families possess substantial amounts of Science Capital, but that this capital appears in highly diverse forms. Rather than being expressed through formal scientific knowledge, Science Capital is embedded in everyday practices shaped by parents’ interests, values, skills, and long-standing engagements, often rooted in their own childhood experiences, as well as by the opportunities afforded by place and local surroundings. In this way, family science habitus plays a central role in shaping how science is enacted, talked about, and experienced in everyday life. As a result, children develop different forms of Science Capital depending on the form of family habitus within which they grow up, and thus enter school with varying forms of Science Capital, each with different degrees of alignment with school science (Archer et al., 2012; Suortti, Havu-Nuutinen, & Kärkkäinen, 2023).

These findings contribute to a more nuanced understanding of how family science habitus cultivates diverse forms of Science Capital. Indeed, this study indicates that family habitus functions as a key mechanism through which certain forms of Science Capital are developed, while others remain less likely to emerge.

At the same time, the findings point to a need for a broader understanding of what Science Capital can look like in everyday family life. In most families, Science Capital is not expressed through explicit science talk, visits to science institutions, or articulated interest in science. Instead, it appears as sensory, place-based, embodied, and practice-oriented engagements with natural phenomena and materials, often without being recognized or described as ‘science’ by the families themselves. These forms of engagement challenge common indicators of Science Capital found in previous research and suggest that Science Capital may be present in ways that remain largely invisible when viewed through traditional lenses.

In line with the Science Capital Teaching Approach (Nomikou, Archer, & King, 2017), our findings point to an untapped potential in linking students’ family experiences, local surroundings, and everyday practices to school science. By personalizing, localizing, and grounding school science in students’ sensory and lived experiences, science education can move towards a more inclusive understanding of what counts as science and who can participate in it.

Such an approach can help bridge the gap between students’ family science habitus and school science habitus by bringing a broader and more diverse range of students’ Science Capital into classroom practice, enabling more students to experience science as relevant to their lives and to recognize their own valuable contributions.

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Barriers In The Planning Phase Of Open Inquiry-Based Learning: Analysis From The Perspective Of Inclusive Science Education

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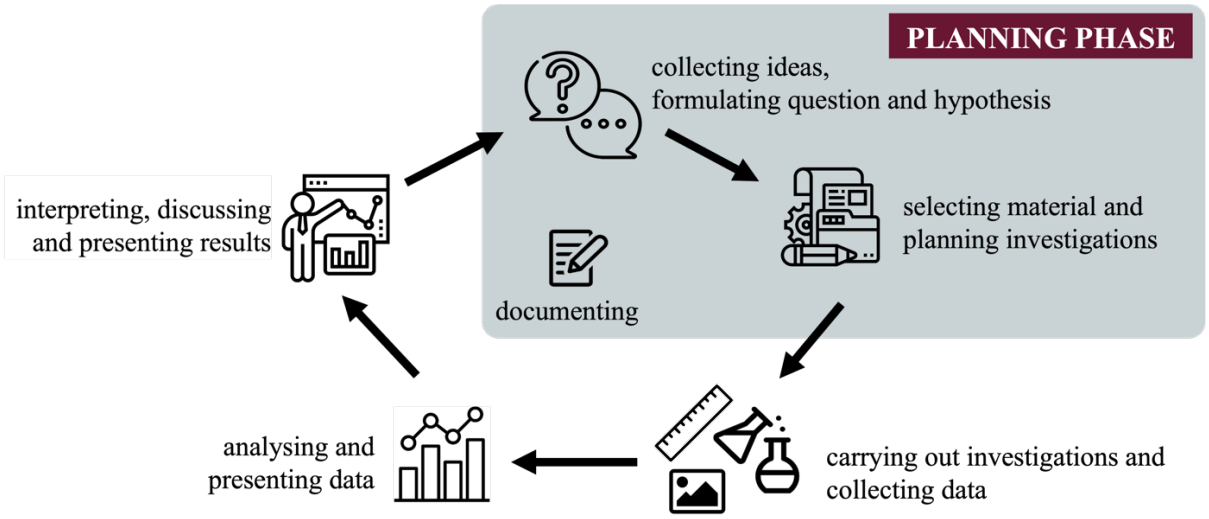
Open Inquiry-Based Learning (oIBL) offers a flexible, inclusive approach to science education by allowing students to construct knowledge through self-directed inquiry while engaging in scientific practices. A critical determinant of successful oIBL is the planning phase, which involves the core activities [A1] generating research questions, [A2] formulating a theory-driven assumption or hypothesis, and [A3] planning appropriate investigations. Challenges in this phase can negatively affect subsequent inquiry stages and student learning, and are often attributed to perceived deficits in student competencies. However, such a student-centred perspective overlooks barriers inherent to the activities themselves. This study addresses this gap by systematically identifying the requirements and challenges associated with the planning phase of oIBL and reframing them as object-related barriers – barriers rooted in the structure and characteristics of the subject matter. Using a scoping review, qualitative content analysis, and AI-assisted rephrasing, requirements and challenges for the three core activities [A1], [A2] and [A3] were extracted, analysed, and categorised. Key findings reveal that many barriers arise from subject-specific demands, methodological constraints, and the empirical nature of inquiry, rather than from students' skills alone. Reformulating challenges in this object-oriented manner supports the development of targeted, inclusive scaffolding materials. Future steps include expert validation, implementation, and evaluation of these materials, which will be made freely available as Open Educational Resources (OER) under a CC-BY license on the platform "twillo". The results highlight the importance of shifting from a deficit-oriented to a systemic perspective in analysing barriers of oIBL, enabling educators to address structural barriers and better support diverse learners in scientific inquiry.

Keywords: Open Inquiry-based Learning, Barriers, Inclusive Science Education, Diversity

Introduction

With the function as an inclusive instructional approach, open inquiry-based Learning (oIBL) can be used to incorporate subject-related aspects of diversity such as different procedural skills, subject specific knowledge, students' interests or prior experience. At the same time, oIBL offers students the opportunity to construct scientific knowledge and engage in scientific practices through an individually planned, self-determined and independently conducted approach in all phases of the inquiry process (e.g., Abrams et al., 2008). OIBL opens up for both individual and collaborative ways of inquiry learning (Liljeström et al., 2013) and promotes the development of problem-solving skills, while also fostering and requiring student motivation and creativity (Chin & Osborne, 2010; Jiang & McComas, 2015). A critical factor determining the success of the oIBL approach lies in the planning phase – the first phase of inquiry (Baur, 2018, 2021; Chen & Klahr, 1999; van Uum et al., 2017). As highlighted in Fig. 1, challenges particularly arise during this initial phase of oIBL, in which several key activities take place that are essential for its success (Hakkarainen & Sintonen, 2002): [A1] generating the research question, [A2] formulating a theory-driven assumption or hypothesis, and [A3] planning an appropriate investigation.

Figure 1. The planning phase of open IBL (adapted from Hofer & Abels, 2025).



Potential problems associated with these activities may not only negatively affect the quality of subsequent inquiry phases but may also hinder or delay students' acquisition of subject-matter knowledge (Hakkarainen & Sintonen, 2002). From the perspective of teaching, another challenge to the successful implementation of oIBL is the high demand placed on teachers in terms of subject-matter expertise and instructional experience. In addition, limited experience with the oIBL approach – on the part of both teachers and students – represents a further difficulty (Brand & Moore, 2011; Forbes et al., 2020; Hofer et al., 2018). Nevertheless, experience and knowledge of the fundamental principles of oIBL are crucial, as they enable the approach to function as intended and in its most effective form, namely as a flexible and adaptive learning environment (Hofer & Abels, 2025; Wischgoll et al., 2015). Such expertise is crucial for teacher-led support of students through appropriate scaffolding measures that are aligned with students' specific demands and needs (Arnold et al., 2014; Baur & Emden, 2021). For the realisation of a holistic oIBL approach combined with effective scaffolding, the teacher's role becomes particularly central – both in terms of designing and adapting the learning environment and in supporting students' individual inquiry processes through adaptive scaffolding (Hofer & Abels, 2025; Mumba et al., 2015; van der Valk & Jong, 2009).

The challenges that arise in oIBL are often attributed to individual students, with a primary focus on the perceived lack of competencies required to accomplish the task at hand (see Tab. 1). This perspective, however, neglects the fact that challenges do not emerge solely from students, but that barriers are inherent in the activities themselves. Abels and Witten (2023) argue that it would be more appropriate to move away from a student-centred perspective toward a systematic one (Köpfer, 2021), in which barriers are not primarily attributed to individual skill deficits but are instead located within the structure and characteristics of the subject matter. This object-oriented perspective suggests that subject matter should be analysed for potential barriers and hindrances that may impede learners' inquiry, while the instructional setting and learning environment are adjusted, adapted, and organised in a way that suits learners' diversity, needs, and strengths – rather than expecting only learners to adapt to requirements (Abels & Witten, 2023).

Table 1. Selected challenges for the activities of the planning phase of open IBL (selected from Kranz et al., 2023)

Phase	Challenge	Description
A1) generating the research question	Stating non-causal research questions	Learners only ask factual type questions that cannot be investigated by means of an experiment. Example of a factual-type question: How is a heart constructed? What is in this lotion?
A2) formulating an assumption or hypothesis	Working without a hypothesis	Learners do not generate hypotheses during the experiment.
A3) planning an investigation	Working without control conditions	Learners are just working with a single test condition and without a control (= results cannot be compared).

With this in mind, the project *PlanFoL – Auf die Planung kommt es an* (*Planning is Key*), which is funded by the Joachim Herz Foundation (2023-2026), aims to develop, test and evaluate practical cross-thematic support materials in order to reduce and address the barriers occurring in the planning phase of oIBL. Furthermore, the project explicitly focuses on a shift in the perspective regarding the attribution of challenges and barriers, respectively.

To do this, it is necessary to first identify the requirements and challenges of the planning phase and derive object-related barriers from them, which can then be addressed by the support materials. This raises the following research questions for the activities [A1] generating the research question, [A2] formulating a theory-driven assumption or hypothesis, and [A3] planning an appropriate investigation:

RQ1: Which requirements and challenges exist for the activities [A1-A3] in the planning phase of open inquiry-based learning?

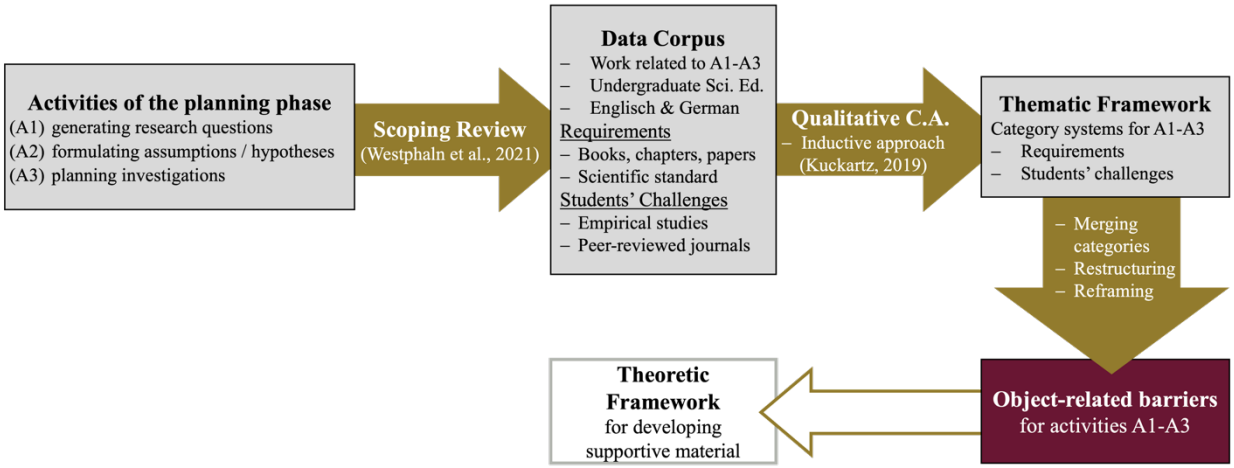
RQ2: What are the object-related barriers of the activities [A1-A3] in the planning phase of open inquiry-based learning?

Method

To identify the requirements and challenges associated with activities [A1]-[A3] in the planning phase of oIBL (RQ1), we first reviewed the existing literature (see Fig. 2). As a comprehensive and relevant systematic review on students' challenges in performing inquiry activities already existed (Kranz et al., 2023), we extracted the results relevant to the activities [A1]-[A3] and used them to address the aspect of "challenges" in the following research process.

To gain comprehensive theoretical insights into the "requirements" of activities [A1]-[A3], we conducted a scoping review following the approach proposed by Westphaln et al. (2021). Initial exploration of the literature indicated that requirements for activities [A1]-[A3] are not addressed explicitly; instead, the literature mainly focuses on practical guidance (e.g., what constitutes a good research question). Consequently, we searched for literature – including textbooks, book chapters, and journal articles – that provides guidance on how to successfully perform activities [A1]-[A3]. This search was conducted via Google Scholar using search strings such as "good research question" and "good research hypothesis". To identify the most suitable and relevant sources, we screened the search results from the first ten pages for each activity [A1]-[A3] and applied the following eligibility criteria: citation count (N>100), academic publisher or provider, demonstrated expertise of the authors, language (English or German), and relevance of content, taking into account different research disciplines.

Figure 2. Overview of the research design.



After selecting the relevant sources, we conducted a qualitative content analysis following an inductive approach (Kuckartz, 2019; see Fig. 2). In the first step, we identified relevant text passages related to the requirements and analysed them using the chat function of the AI Assist in MAXQDA (version 24.11.0), the posed questions for this analysis are listed in Tab. 2. The AI Assist is designed to support users in identifying patterns within documents (e.g., desirable and undesirable characteristics associated with activities [A1]-[A3]) and is therefore suitable for facilitating the initial phase of text analysis (Kuckartz, 2019). The results emerging from this initial analysis were then summarised across all documents and further analysed using an AI chatbot (u:ai chatbot GPT-4o – University of Vienna) with the following prompt: "Please summarise the results from these three lists in the form of qualitative content analysis and inductive category development" (see Tab. 2). The resulting summaries were subsequently compared, leading to the development of a preliminary category system, which was then applied to the data and iteratively refined and expanded (see Fig. 2).

The challenges identified by Kranz et al. (2023) were formulated from a student-centred and predominantly deficit-oriented perspective, i.e., what students are not able to do. To adopt a more systemic perspective, these challenges were reformulated in an object-oriented manner (Abels, 2026). For this purpose, AI was used as a supportive tool for rephrasing (see Tab. 2), enabling multiple reformulations to be generated simultaneously.

Table 2. Overview of AI application for data analysis.

Aspect	Purpose of application	AI tool	Prompt
Requirements	Initial text analysis	MaxQDA 24.11.0 with AI Assist	"Please answer the following questions by presenting the answers in numbered lists: What are the requirements for a good [A1-A3]? What should one obey when [A1-A3]? What are features of a bad [A1-A3]? What should one avoid when [A1-A3]?"
	Creating inductive categories	u:ai ChatbotGPT 4o (University of Vienna)	"Please summarise the results from these three lists in the form of qualitative content analysis and inductive category development."
Challenges	Object-oriented rephrasing	Model: Meta Llama 3.1 8B Instruct, temperature: 0, top_p: 0.05	"Rewrite the following sentence making clear that the requirement comes from the subject itself and not from the students. Please note that the tone is academic, is scientific in nature, and that the sentence is rephrased in such a way that it is easy to understand and informative. Give me a list which is numbered like the original sentence. The original sentence is. …"

The results of the analyses of requirements and challenges were finally related to each other and reinterpreted as object-related barriers (see Fig. 2).

Results & Discussion

Due to the large scope and high complexity of the results, we will present, explain, and discuss one key result for each of the activities [A1-A3]. Tab. 3 provides an overview.

Table 3. Overview of selected results.

Activity	**Category & Subcategory**	**Source material** (paraphrased and summarised)	**Object-related barrier**
[A1] generating the research question	**Category**: Feasibility & Practicality **Subcategory**: Empirical testability	**Requirement** Research questions should be answerable through systematic observation, measurement, or data collection.	Research questions that aim to identify causal relationships between variables often require a specific type of inquiry, one that is empirically testable and grounded in the subject matter. In some cases, questions may be more descriptive or factual, rather than causal, which can limit the scope of investigation and the potential for meaningful conclusions.
		Challenge Students do not state causal research questions, but factual type questions which are not empirically testable.	
[A2] formulating a theory-driven assumption or hypothesis	**Category**: Consistency & Integrity **Subcategory**: A-priori Statement & Immutability	**Requirement** The hypothesis should be formulated before the research begins and must not be adjusted or changed throughout it.	The iterative nature of the scientific process often requires revisiting and refining hypotheses as new information becomes available. However, the modification of hypotheses without thoroughly testing can compromise the validity of the conclusions drawn.
		Challenge Students change their hypotheses during the process without having tested them first.	
[A3] planning an appropriate investigation	**Category**: Experimental Design & Control **Subcategory**: Test and Control Approaches	**Requirement** Experimental designs should include test and control approaches (qualitative design) or a series of measurements (quantitative design).	The investigation of complex phenomena requires consideration of multiple factors, including control of variables and the conduct of test and control trials. However, many experiments in school or everyday life lack these fundamental aspects, which can compromise the accuracy of the results.
		Challenge Many students experiment without a test or control trial and neglect the control of variables strategy (CVS).	

[A1] Generating The Research Question

The results indicate that one fundamental requirement for oIBL is the formulation of research questions that are empirically answerable and allow for systematic observation, measurement, or data collection. One typical form of such questions addresses relationships between variables, what provides a clear basis for selecting appropriate methods of investigation. In practice, however, a key challenge arises because students often tend to formulate descriptive or factual questions rather than causal research questions. These questions may focus on identifying or describing phenomena but do not readily support empirical testing or systematic inquiry. But instead of attributing students, we take a systemic perspective, which leads to an object-related barrier located in the research question itself: When research questions are oriented toward causal relationships, they constrain the type of inquiry that can be conducted (especially regarding methodological requirements) as there is a necessity of empirical testability, being anchored in subject-matter knowledge. However, research questions that students find interesting (or in different science disciplines) may also be more exploratory or descriptive in nature. This can limit the scope of investigation and reduce the potential for producing explanatory insights and meaningful conclusions. When teachers and teacher educators know about these object-related barriers, they can think of ways to enable participation in oIBL.

[A2] Formulating A Theory-Driven Assumption Or Hypothesis

One crucial requirement of activity A2 is the formulation of a hypothesis prior to the start of the investigation, with the expectation that this hypothesis remains unchanged throughout the research process. In this way, the hypothesis serves as a stable epistemic reference that guides the design of the study, the selection of methods, and the interpretation of the collected data. However, several studies found that students frequently revise or replace their hypotheses during the inquiry process without having systematically tested the original ones. Such modifications are often driven by emerging observations, unexpected results, or uncertainties during data collection and analysis. If we take a more systemic view, we can derive a barrier regarding the coherence between hypothesis, methodological approach, and empirical evidence. When hypotheses are altered without prior empirical testing, their role as structuring and validating objects of inquiry is weakened and results are limited in reliability, transparency, and explanatory power of arguments. Teachers and teacher educators who know that phrasing hypotheses is really difficult, can prepare scaffolds in advance to support students' science learning.

[A3] Planning An Appropriate Investigation

The findings show that one fundamental requirement for planning investigations [A3] is the implementation of well-structured designs that allow systematic approaches. In qualitative experiments, this entails the inclusion of test and control approaches, while in quantitative studies, it involves conducting a series of measurements that enable reliable observation of changes in variables. These strategies are essential for ensuring that differences in outcomes can be attributed to specific factors rather than uncontrolled influences. However, empirical results show that students often fail to adhere to this systematic approach. Several challenges arise because many students carry out experiments without including test or control trials and frequently neglect the control of variables strategy (CVS). As a result, multiple factors may vary simultaneously, making it difficult to determine which factor is responsible for the observed effects. Relating requirements and challenges to each other, the following barrier can be derived: When experiments are not carefully structured to control variables and provide appropriate comparisons, the investigation of complex phenomena becomes limited. Such designs compromise the accuracy, reliability, and interpretability of results, reducing the potential for drawing valid, meaningful, and generalizable conclusions from the inquiry process. Teachers and teacher educators can inform their students about these barriers and work on them instead of seeing students as the ones who fail the challenges.

Discussion

A key insight from the scoping review is that the requirements for individual activities [A1]-[A3] are often highly specific to particular disciplines, even within the natural sciences (e.g., biology vs. chemistry). Explanations frequently reflect a form of tacit, community-specific knowledge that is either imprecisely stated (e.g., the research question should be 'investigable') or not explicitly articulated at all. For instance, guidance often refers to 'relevant questions' or questions that 'contribute to the field' of research without providing concrete criteria. Additionally, the literature provides little clarity on when activities [A1]-[A3] should be considered 'successful'. This creates a significant challenge in educational contexts, particularly in science education at the school level, where uncertainty and high difficulty are prevalent. Part of this difficulty arises from scientific requirements being transferred into school contexts (e.g., the application of the Control-of-Variables Strategy (CVS) in elementary schools; Chen & Klahr, 1999). Addressing these aspects requires well-prepared and knowledgeable teachers, effective scaffolding within oIBL, and an appropriate attitude toward the inquiry process and inclusion.

Moreover, the literature highlights the importance of a perspective shift for successful inquiry, although most reported challenges are person-related and deficit-oriented, as shown in Tab. 1 (Baur, 2023; Kranz et al., 2023). Focusing on the identification and categorisation of barriers in the inquiry process (adapted from Krönig, 2015) reveals that relatively few challenges need to be located in the "Self" domain (barriers that are caused in the persons themselves), whereas the majority emerges from the subject matter itself. This indicates that many barriers are not caused by students' lack of skill or experience but are inherent to the structure of activities [A1]-[A3]. Consequently, a more systematic and accurate approach to barrier localisation requires reformulating student-centred barriers into object-related barriers, as illustrated in Tab. 3. This shift in perspectives could also help teachers to stop being constantly overwhelmed by oIBL because they focus on their students' lack of knowledge and skills and instead become capable of addressing these barriers – as strived for in the project *PlanFoL*.

Summary And Outlook

Across the analysed literature focusing on the requirements and students' challenges in the planning phase of oIBL, studies that explicitly address the numerous and diverse subject-related demands are rare. To enable a more accurate and systematic approach that both helps to identify barriers and supports students during their inquiry process – in the sense of an inclusive approach – it is necessary to reformulate and re-categorise students' challenges into object-related barriers. The process of reinterpreting barriers in this way is demanding, requiring extensive epistemic knowledge and expertise. One effective method for reframing students' challenges into object-related requirements is the use of AI.

The next steps involve finalising and validating the object-related barriers with experts and using the rephrased barriers to develop inclusive materials for the planning phase of oIBL. These materials will then be implemented, evaluated, and refined according to the observed barriers. Ultimately, the developed materials, along with guidance on their use, will be made freely available as Open Educational Resources (OER) under a CC-BY license on the platform *twillo*.

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The Challenges Of Inclusive Science Education From Teachers' Perspectives

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International assessments, such as PISA, consistently show that many students in Germany and other countries lack key competencies, with a significant portion underperforming. Germany has also not fully implemented an inclusive school system in line with the UN Convention on the Rights of Persons with Disabilities, partly due to teachers' competencies in inclusion. Given these challenges, it is crucial to find ways to ensure all students can develop their competencies by enhancing teacher professional skills. This study investigates in-service teachers' perspectives on challenges in inclusive science teaching. By identifying competency requirements for teacher training that align with educational policies and inclusive practices, this research aims to enhance teacher preparedness for inclusive science education. Differentiating between subject-specific and general pedagogical challenges helps define targeted improvements in science teacher education. Using a qualitative-explorative methodology, guided interviews were conducted with 19 teachers to capture their experiences and perspectives. The findings reveal, for instance, challenges with learner prerequisites, individual competence development, selecting content and methods, enabling participation, using methods and media, as well as challenges related to experimentation and scientific language. This study highlights the urgent need for targeted teacher training programs that integrate both general pedagogical skills and subject-specific didactics, ensuring that science educators are better equipped to foster inclusive learning environments.

Keywords: inclusion, teachers, challenges

Introduction

International assessments like PISA show that many students lack scientific literacy, with a significant number underperforming (OECD, 2023). Additionally, the implementation of inclusive education remains insufficient (Klemm et al., 2023), partly due to teachers' competencies in inclusive pedagogy (Pit-ten Cate et al., 2018). Teachers play a crucial role in the success of inclusive education (Boer, 2012), and their professional skills significantly impact students' learning outcomes (Blömeke et al., 2022). However, teachers continue to face difficulties in fulfilling the additional requirements for inclusive science teaching (Pit-ten Cate et al., 2018). This study aims to explore these challenges and propose competency requirements for teacher training.

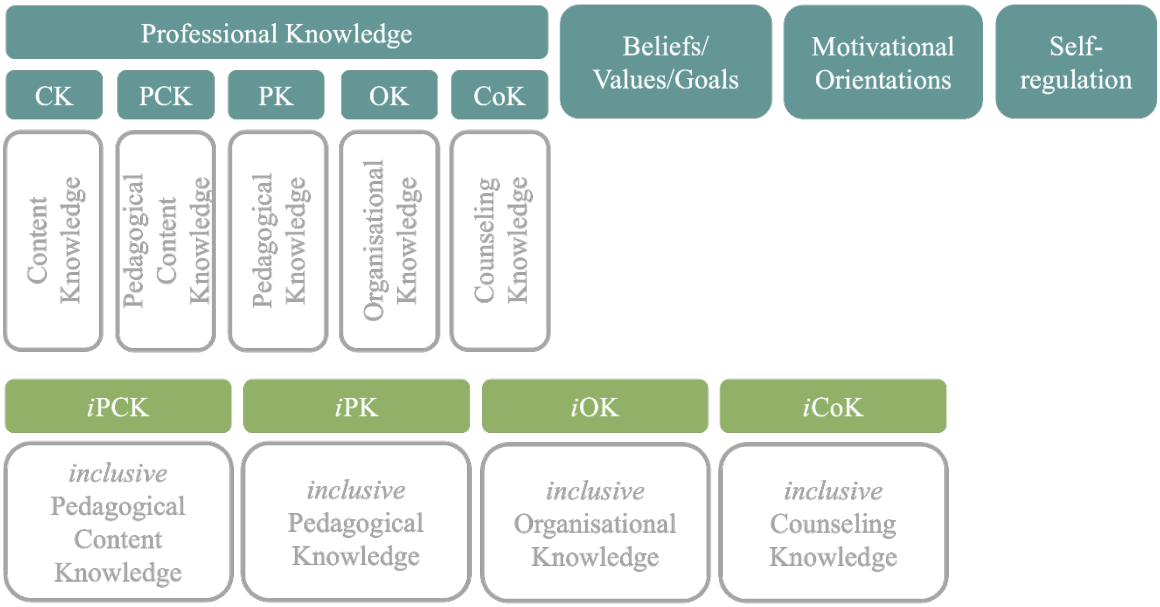
Theoretical Framework

Professional Competency Models

Despite policy efforts toward inclusion, teachers struggle to implement inclusive science teaching effectively (Moser & Lütje-Klose, 2016). Teaching expertise is shaped by knowledge, professional values, beliefs, motivation, and self-regulation skills (Baumert & Kunter, 2013). The competency model (see Figure 1) developed by Baumert and Kunter (2013) includes four aspects of professional competence: 1) Beliefs/Values/Goals, 2) Motivational Orientations, 3) Self-Regulation, and 4) Professional Knowledge. These aspects are further divided. Professional Knowledge is categorized into Content Knowledge (CK), Pedagogical Content Knowledge

(PCK), and Pedagogical Knowledge (PK), and expanded to include Organizational Knowledge and Counseling Knowledge (Baumert & Kunter, 2013).

Figure 1. Extended Competency Model for Inclusive Teaching Based on Baumert and Kunter (2013).



König et al. (2019) and Bertram et al. (2020) have expanded this model to include competencies specific to inclusive education. König et al. (2019) introduced inclusive general pedagogical knowledge (iPK) and inclusive organizational knowledge (iOK). Their review identified four key areas:

1. Diagnosis (assessment of support needs, initial and progress diagnosis),
2. Intervention (methods for individualization and addressing student diversity),
3. Management and Organization (collaboration with colleagues and external partners), and
4. Counseling and Communication.

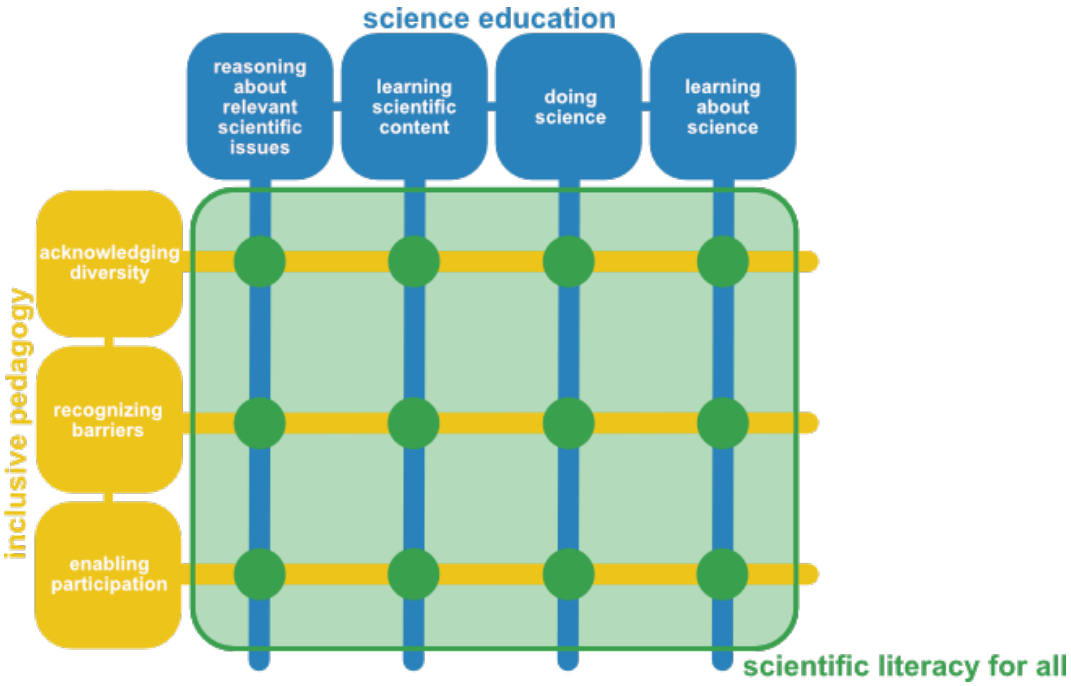
These areas were integrated into the competency domains: inclusive pedagogical content knowledge (iPCK), inclusive general pedagogical knowledge (iPK), inclusive organizational knowledge (iOK), and inclusive counselling knowledge (iCoK). Bertram et al. (2020) further refined the model, adding areas in iPCK (e.g. knowledge about learners' conceptions), iPK (e.g. methodological repertoire), iOK (e.g. school development processes), and additional areas in beliefs/values/goals, motivational orientations, and self-regulation.

The competency model for inclusive teaching (see Figure 1) (König et al., 2019, based on Baumert & Kunter, 2013) has been validated and was transformed into a category system (Bertram et al., 2020). For this study, the model and category system had to be adapted for (inclusive) science education.

NinU Framework

The NinU Framework (Stinken-Rösner et al., 2020) offers an initial theoretical orientation for adapting the competency model for inclusive teaching (see section before) to (inclusive) science education. This framework (see Figure 2) integrates inclusive pedagogical considerations with a scientific perspective in a unified model.

Figure 2. NinU Framework, Adapted from Stinken-Rösner et al. (2020).



The vertical axis of the NinU Framework emphasizes firstly the acknowledgment of student diversity. Teachers recognize the potential and resources of each student and incorporate these into their lesson planning (Booth & Ainscow, 2016). In a second step, the framework recognizes potential barriers, that can exist in teaching materials, classroom conditions, or even in the behaviour of the teachers themselves (Stinken-Rösner et al., 2020). Lastly, the framework's goal is adapting teaching methods accordingly to enable the participation of all students.

The horizontal dimension of the NinU Framework addresses the goals of science education, following Hodson (2014), including reasoning about scientific issues, learning science content in the sense of a conceptual understanding (Taber, 2013), doing science (engaging with scientific methods and procedures), learning about science (understanding the processes of science itself; Millar, 2006), and the use of digital media for accessibility (Abels & Stinken-Rösner, 2022).

State of Research and Research Questions

Although the competency model for inclusive teaching (based on Baumert & Kunter (2013) and expanded by König et al. (2019) and Bertram et al. (2020)) offers a strong starting point, it does not sufficiently capture the subject-specific demands of inclusive science instruction. Furthermore, the second dimension of the NinU Framework, "Recognizing Barriers", is currently addressed primarily through individual studies.

Overall, the field still lacks a shared definition of inclusive science teaching, and subject-specific criteria for required affordances remain underspecified. Some authors have outlined characteristics of individual scientific disciplines that might provide insights into their specific affordances (Hoffmann & Menthe, 2015). However, a coherent normative catalogue of subject-specific affordances is still missing. Therefore, the aim of this study is to explore the specific challenges teachers face in inclusive science lessons to define key competencies for teacher education. The research questions include:

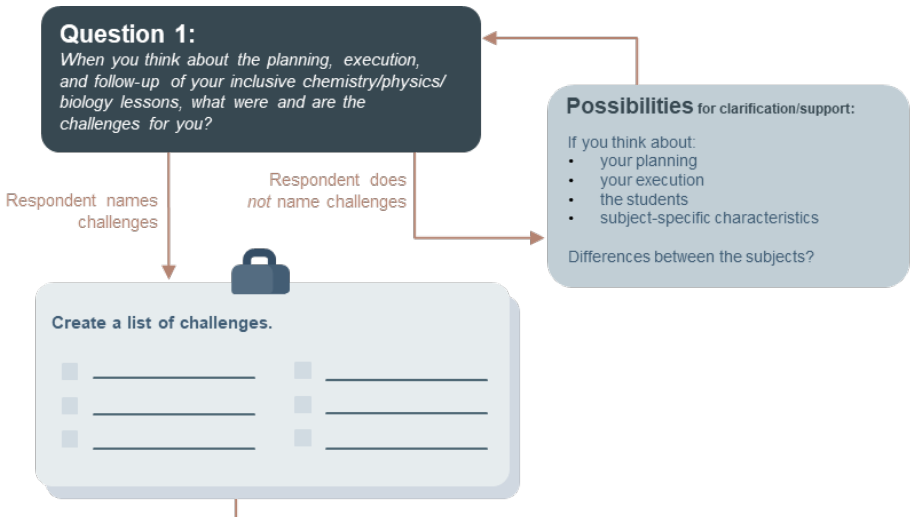
- What general pedagogical challenges impact inclusive science teaching?
- What subject-specific challenges do teachers face in inclusive science lessons?

Research Method And Design

A qualitative-explorative research approach was adopted to capture teachers' perspectives on the challenges of inclusive science teaching. We conducted semi-structured interviews (Helfferich, 2014) to balance openness to participants' experiences with the possibility of targeted follow-up questions (Kuckartz & Rädiker, 2022).

The interview questions were developed based on the NinU framework, emphasizing barriers to inclusive education (Ferreira González et al., 2021; Stinken-Rösner et al., 2020). The term 'barrier' was replaced with 'challenge' to reduce associations. The interview guide began with the question: "When you think about the planning, implementation and reflection of your [science/physics/biology/chemistry] lessons, what were and are challenges for you?" (see Figure 3), allowing respondents to highlight specific concerns regarding inclusive science education. The respondents' understanding of inclusion is implicitly explored in the further course of the interview.

Figure 3. Excerpt from the Interview Guide with the First Question.



The study focused on in-service teachers in northern Germany, with a total of 19 structured interviews analysed. The teachers were recruited through a network-based approach. Interviews were transcribed and analysed using qualitative content analysis (Mayring, 2022) resulting in the summarization of the interview's core statements into paraphrases. A coding guide was developed based on the competency model for inclusive teaching and the deductively identified categories. The paraphrased data was coded independently by two researchers, achieving an interrater reliability of Cohen's Kappa = .67. Discrepancies were resolved through consensus discussions, ensuring consistency in the categorization of responses.

Findings

The qualitative content analysis (Mayring, 2022) of the interviews yielded 275 codes. Overall, teachers' accounts clustered strongly around challenges that are intervention-oriented—i.e., challenges that arise when planning, enacting, and adapting instruction in inclusive science classrooms, with the largest clusters located in "Intervention iPK" (inclusive Pedagogical Knowledge on Intervention) with 122 codes and "Intervention iPCK" (inclusive Pedagogical Content Knowledge on Intervention) with 60 codes. 50 codes were assigned to the category "framework conditions", whereas 43 codes are dispersed across all remaining categories of the Extended Competency Model for Inclusive Teaching.

In the following, the challenges related to iPK and iPCK are discussed in more detail, with particular attention to "Intervention iPCK", as it is especially informative from a science education research perspective. For a comprehensive analysis and further insights into all categories, see Basten et al. (submitted).

General Pedagogical Challenges Impacting Inclusive Science Teaching

"Intervention iPK" includes general pedagogical knowledge. Inductively, challenges were grouped into the following subcategories:

Learner Prerequisites

Teachers frequently described the difficulty of addressing a wide spectrum of students' individual characteristics, prior knowledge and beliefs/conceptions about a topic.

> "The presence of diverse resources across multiple domains—such as pre-instructional experiences, values, prior knowledge, and reading and writing skills—can constitute a challenge both for the teacher and for the learner themselves." (HI-002; F15)

Individual Competence Development

A major challenge concerned supporting students' individual learning progress in a way that is feasible in everyday teaching. Teachers emphasized that "adequately support[ing] each student in the learning process according to their individual level of learning progress" requires continuous adaptation and individualized support structures.

> "It constitutes a challenge for the teacher to create a safe environment in which even introverted students feel confident to participate and verbalize their solutions." (2022-LG-011_F8)

Topics And Contents

Teachers often described challenges in preparing lessons that motivate students. In addition, didactic reduction was mentioned as demanding—particularly when adapting science content for students with special educational needs.

Participation

Many statements addressed the challenge of ensuring that all students—especially those with special educational needs—can participate in learning activities. Teachers reported "additional support efforts for students with special educational needs".

Methods And Media

Teachers highlighted the challenge of identifying working methods and materials that meet diverse needs while remaining inclusive (and not excluding students with special educational needs).

> "Taking into account individual support needs and the accompanying necessity for instructional adaptations (for visual impairment: larger illustrations, magnifying glasses for reading texts, etc.; for learning difficulties: texts in simplified language, temporal adjustments) constitutes a challenge for teachers." (LFG; HI-002; F17)

Communication

In the last subcategory, some teachers reported challenges in adapting to heterogeneous language needs in science lessons. One example concerned dealing with language accuracy during learning processes, such as the perceived difficulty of "correcting language errors immediately".

Subject-Specific Challenges In Inclusive Science Lessons

"Intervention iPCK" focuses on pedagogical content knowledge specific to science teaching. Here, teachers' statements concentrated on three inductively formed subcategories:

Experiments

Experiments emerged as a key challenge in inclusive science teaching. Teachers referred to difficulties across preparation, implementation, and follow-up, mainly regarding time and materials. They reported that extensive preparation and set-up time competes with time needed for in-class support, and that clean-up/follow-up often cannot be completed immediately due to everyday time pressure. The prevailing 45-minute lesson rhythm was described as incompatible with longer inquiry cycles, including experimentation and consolidation phases.

Beyond time constraints, teachers highlighted material and organizational demands, such as compiling experimental materials for an entire class and selecting experiments that fit both the topic and the learners' age and needs. Teachers also emphasized the inherent unpredictability of experimental outcomes and the dependence on external conditions, which complicates planning and inclusive scaffolding.

From an inclusion perspective, experimentation was described as requiring continuous adaptation to heterogeneous learner prerequisites, including different competence levels and, in some cases, limited experimentation skills on the learners' side. Teachers additionally reported challenges in classroom management during experiments (e.g., increased noise and unrest, especially in younger classes) and in finding a productive balance between allowing exploration and providing sufficient guidance.

Finally, several paraphrases pointed to safety and specific support needs: teachers described the difficulty of keeping all students in view during potentially dangerous experiments, enabling participation of students with disabilities (including autism spectrum conditions), and supporting anxious students during hands-on activities.

> "Including students with autism spectrum disorder in experimental lessons constitutes a challenge." (2022-LG-016_F10)
>
> "Keeping all students in view during dangerous experiments constitutes a challenge." (2022-LG-016_F4)
>
> "Designing experiments in a way that allows students with disabilities to participate." (2022-LG-10b)
>
> "A restless learning group constitutes a challenge during experiments." (2022-LG-012_F2)
>
> "Finding a group composition favorable for all learners during experiments constitutes a challenge." (2022-LG-012_F2)

Scientific Language And Scientific Methods

Teachers described scientific language as a major challenge, especially for students with German as a second language, where "technical language may make it difficult […] to understand the content". At the same time, teachers framed this as a tension: they need to respond to learners' linguistic prerequisites while also promoting the development and active use of scientific terminology. Paraphrases also indicated that the distinction between everyday language and scientific language remains challenging even in higher grades, requiring repeated and systematic language work. In addition, teachers associated subject-specific accessibility with reading and

text difficulty: due to low reading levels textbooks in primary science are perceived as too complex.

> "The teacher faces the challenge of enabling students to master and use subject-specific language." (2022-LG-011_F7)

> "In summary: the low reading level of students constitutes a challenge, as the texts in elementary science textbooks are often too difficult." (2022-LG-008_F2)

Beyond language, teachers also reported challenges related to scientific methods, for instance scaffolding inquiry processes and helping students approach a research question, raising the issue of how to prepare students for inquiry-oriented phases.

> "The prerequisites of students for guiding them toward the research question vary in heterogeneous classrooms." (2022-LG-009-F001)

Presenting Information

Another subject-specific challenge concerned the appropriate presentation of information, including responding to students' misconceptions and missing foundational prerequisites. Teachers noted situations in which students lack key conceptual foundations (e.g., "when children have no concept of quantities"), which makes it difficult to introduce or build scientific explanations without extensive preparatory conceptual work. Closely connected, teachers described didactic reduction and student-friendly representations as demanding, especially the need to simplify without introducing inaccuracies, which was perceived as particularly challenging in physics and chemistry.

> "Didactic reduction—simplifying without making errors—constitutes a challenge for the teacher; this is more pronounced in physics and chemistry than in biology." (2022-LG-008_F1)

> "Student-appropriate presentation constitutes a challenge for the teacher; this challenge is greater in physics and chemistry than in biology." (2022-LG-008_F1)

> "Demonstrating the relevance of the subject to students through everyday and societal topics (such as climate change, the environment, ecosystems)." (2022-LG-13-F004)

Additional iPCK-Related Challenges (Emerging Themes)

Beyond the three main clusters, some paraphrases pointed to further subject-specific inclusive demands: handling sensitive topics such as evolution and sexuality education in relation to students' religious/worldview backgrounds; conveying the societal relevance of science topics; teaching interdisciplinary science formats; and implementing short excursions or out-of-school learning activities.

> "Topics such as evolution and sex education pose a challenge for teachers and students, as they are not necessarily compatible with religious beliefs or worldviews." (LFG; HI-002; F13)

> "Planning and alignment of out-of-school learning sites relevant to the science domain (e.g., weather) constitutes a challenge." (2022-LG-005-F003)

Overall, the iPCK paraphrases depict inclusive science teaching as highly dependent on teachers' capacity to design and manage resource-intensive science practices (especially experimentation and inquiry) while simultaneously ensuring linguistic accessibility, conceptual scaffolding, and safe participation for all learners.

Discussion And Implications

Overall, the findings indicate that many teachers feel insufficiently prepared with regard to both general pedagogical and subject-specific didactic skills necessary for effectively implementing inclusive education in science classrooms. The prominence of intervention-related challenges suggests that teachers particularly struggle with translating inclusive aims into concrete classroom practices (e.g., differentiation, participation, scaffolding experiments and inquiry, and language-sensitive science teaching). Accordingly, the results point to a need for targeted professional development that strengthens these specific, practice-oriented competencies.

More than fifteen years after the UN-CRPD, its implementation in schools remains inadequate. Recent monitoring reports suggest that political and societal commitment to inclusive education is currently weakening (Lepper & Steinmann, 2024). At the same time, teachers report substantial workload and pressure, which are associated with frustration and an increased risk of burnout. Against this backdrop, it appears particularly urgent to systematically identify the concrete challenges teachers face and to address them through coherent support structures. Our findings suggest that one major gap concerns knowledge and skills related to concrete lesson design in inclusive science classrooms. Consequently, initial teacher education (including university-based coursework) should place greater emphasis on evidence-informed, feasible instructional approaches and resources that enable teachers to plan and enact inclusive science lessons under real-world constraints.

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Youth's Environmental Attitudes And Use Of Digital Media And Social Networks: A Comparative Exploration From Seven Spanish-Speaking Countries

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This study presents an international comparison among seven Spanish-speaking countries on the two main themes of the ESERA-2025 conference: the environmental attitudes (EAs) and the use of digital media and social networks (DM). Both categories are quantitatively and qualitatively assessed from the voices of a large sample of 15-year-old students from seven Spanish-speaking countries. The students answered the questionnaire of an international project (The relevance of science education second, ROSES) that explores some attitudes and experiences of science education. Further, gender and cross-country differences are also checked through the probability of signification and the effect size of the differences. The main overall findings point to students' proactive EAs and moderate DM use in science classes that are also quite parallel across countries, though Argentina and Mexico tend to display more polarized scores on EAs and DM use. Another finding shows generalized gender differences about EAs and DM use across countries. Girls tend to hold more positive EAs than boys across all countries, though their effect size ranges from moderate to small differences. Regarding DM use, boys reported higher overall DM use than girls, though the gender effect sizes are insignificant. The consequences of these results for science education and for research on these issues, the limitations of this study, and the future prospective are discussed.

Keywords: environmental attitudes, digital media, gender differences

Introduction

This study explores an international comparison on the two themes of the ESERA-2025 conference through assessing the environmental attitudes (EAs) and the use of digital media and social networks (DM), as reported by young people from seven Spanish-speaking countries. Further, international comparisons constitute an additional instrument of educational research that contributes contexts to absolute evaluation measurements, thus lending a value-added meaning, thanks to the comparisons between the different contexts (e.g., OECD, 2025). These features frame the relevance and the methodological foundations of this study to science education research and practice.

For decades, the study of attitudes has been a fruitful area of social psychology because attitudes, in addition to their evaluative component (acceptance/rejection), further act as guides to behaviour (e.g., sustainable actions or digital use). Thus, the dispositions (acceptance/rejection) toward the environment, or EAs, guide environmentally sustainable conduct, which also has a long history within science education. Pro-environmental conducts have been gaining research and educational relevance on the global agenda due to the growing impact and social emergency of the increasing environmental deterioration, such as climate change. The UN declared the Decade of Education for Sustainable Development (2005-2014) and then the 2030 Agenda (UN, 2015), which sets out 17 priority Sustainable Development Goals for guiding governments and citizens' actions until 2030, which represent a global challenge for education. Understanding EAs

is crucial for developing strategies for sustainable development through targeted and effective messaging.

The literature on conceptualizing and defining EAs is large and complex to show consensus. Above all, EAs are attitudes and share with general attitudes the same theoretical base, which involves cognitions (beliefs), affects (acceptance/rejection), and behaviours (actions). A current significant consensus acknowledges that EAs involve a single overall attitude to the environment but hold a multi-dimensional structure that organizes a range of environmental topics. However, the field is fragmented by disagreements that include the number of EA dimensions and the nature of the EA specific topics. Thus, some unified definition and conceptualization of EA, the measurement methodology, and even the evaluation survey are highly pursued (Somerwill & Wehn, 2022).

The Environmental Attitudes Inventory (EAI) provides a theoretical reference framework and a comprehensive method of the material currently available in the field, because EAI has been used across a range of contexts and has been found to be highly consistent and reliable (Milfont & Duckitt, 2010). The EAI short form is made of 72 items across twelve first-order factors (dimensions), grouped into two second-order factors, Preservation (seven first-order factors) and Utilization (five first-order factors).

On the other hand, the educational importance of digital media and social networks (DM) arises from the effectiveness and impact of their implementation in the various contexts of education, due to their advantages for the pedagogy, the DM literacy and the skills, and, in general, the relevance of digital learning for science education. Further, the endless risks and drawbacks of digital misuse need to be recognized, addressed, and overcome in science education (Tibaná-Herrera et al., 2018). In particular, a good attitude towards DM, trust in DM, and firm beliefs in their usefulness and their autonomous use had a positive relationship to students' academic performance in mathematics and science (Courtney et al., 2022). Further, similar results have been obtained for the overall digital development of a country and the use of DM at home by students (Skryabin et al., 2015).

Since the first studies, men have shown better attitudes to science than women, though the magnitude of the gender differences ranges from mild to moderate (Osborne et al., 2003; Potvin & Hasni, 2014). Regarding EA, the revision of Gyurián Nagy (2025) found that women exhibited higher EAs, greater awareness of environmental problems, and a higher willingness to change their behaviour to reduce their environmental impact. In contrast, men’s attitudes are more varied, reflecting a broader diversity of opinions.

Gender has not been a frequent variable in DM studies. For instance, the review by Momani et al. (2023) does not mention it. With respect to the opportunities offered by DM, social studies place women in an unfavourable position that displays three digital gaps: unequal access to infrastructures and digital tools, low level of digital skills, and Internet use (Sáinz et al., 2020). Thus, gender is important for DM too.

The international study “The Relevance of Science Education Second” (ROSES) listens to students’ voices and opinions on their EAs and on their use of digital media and social networks at home, school, and in the science classroom, as well as their perceptions of the DM quality for learning (Jidesjö et al., 2020).

The research questions about the exploration of young students’ EAs and DM use in seven Spanish-speaking countries are the following: How much do students hold proactive EAs and use general and specific DM in science classes? What are the main differences across countries about EAs and the DM use? What are the differences between boys and girls across countries?

Methodology

ROSES uses a mixed-method methodology, which involves qualitative and quantitative procedures to analyse the students' answers and to develop comparisons between groups.

Materials

The ROSES-Q is a large survey that was developed by an international team of science education experts to gather diverse affective data that impact science education (Jidesjö et al., 2020). The item wording is direct, simple, and short, and the students are asked to tick the appropriate box number that best fits their attitudes through a four-point Likert format (1-2-3-4). The meaning of the Likert numbers varies across scales (Disagree-Agree, Never-Often, etc.).

The categories about EA challenges and the use of DM at home and school science are analysed here. The category "Me and the environmental challenges" displays 13 items on the personal dispositions towards the environment, asking How much do you agree with the item? All responses are expressed on a four-point Likert scale (1-4), whose extreme points spread from disagree (1) to agree (4).

Six EA items are marked with (-) because they display anti-EAs (e.g., Threats to the environment are not my business), as they are contrary to pro-EA (e.g., People should care more about how to protect the environment). The average scores of the dysfunctional negative items should be interpreted in an opposite way to pro-environmental items. The EAs items correspond with the following dimensions of the short EAI: (2) Support for interventionist conservation policies, (3) Environmental movement activism, (4) Conservation motivated by anthropocentric concern, (5) Confidence in science and technology, (6) Environmental fragility, (8) Personal conservation behaviour, and (11) Ecocentric concern (Milfont & Duckitt, 2010).

The category "Use of digital media and social networks" is made up of 16 statements, which investigate digital experiences from three different perspectives: the time of DM use at school and at home (first 2 items), the use of several digital resources in school science education (10 items), and the appreciation of the quality of DM for learning science (last 4 items). Students were asked in the first two perspectives, "How much do I use the DM?" and in the third perspective, "To what extent do you agree with the following statements?" The responses are expressed on a four-point Likert scale (1-4), whose extreme points are as follows: first perspective, less than 2 hours a day (1) to more than 6 hours a day (4); second, never (1) to often (4); third, disagree (1) to agree (4) (Figure 1).

Participants

The target population of ROSES is 15-year-old students, because they are about to end compulsory education can look back to their school science education and reflect on what they have learned. The participants in this study validly answered the ROSES-Q in Spain (6014), Colombia (1279), Uruguay (729), Chile (729), Peru (470), Argentina (232), and México (191). The country samples are approximately split in halves between girls and boys.

The approval of the ROSES project by the Spanish State Research Agency implied the commitment to comply with the ethical principles and the relevant national, European, and international legislation on human rights. Students were informed that answering meant consent to participate, they could leave items unanswered, and the survey was anonymous.

Procedures

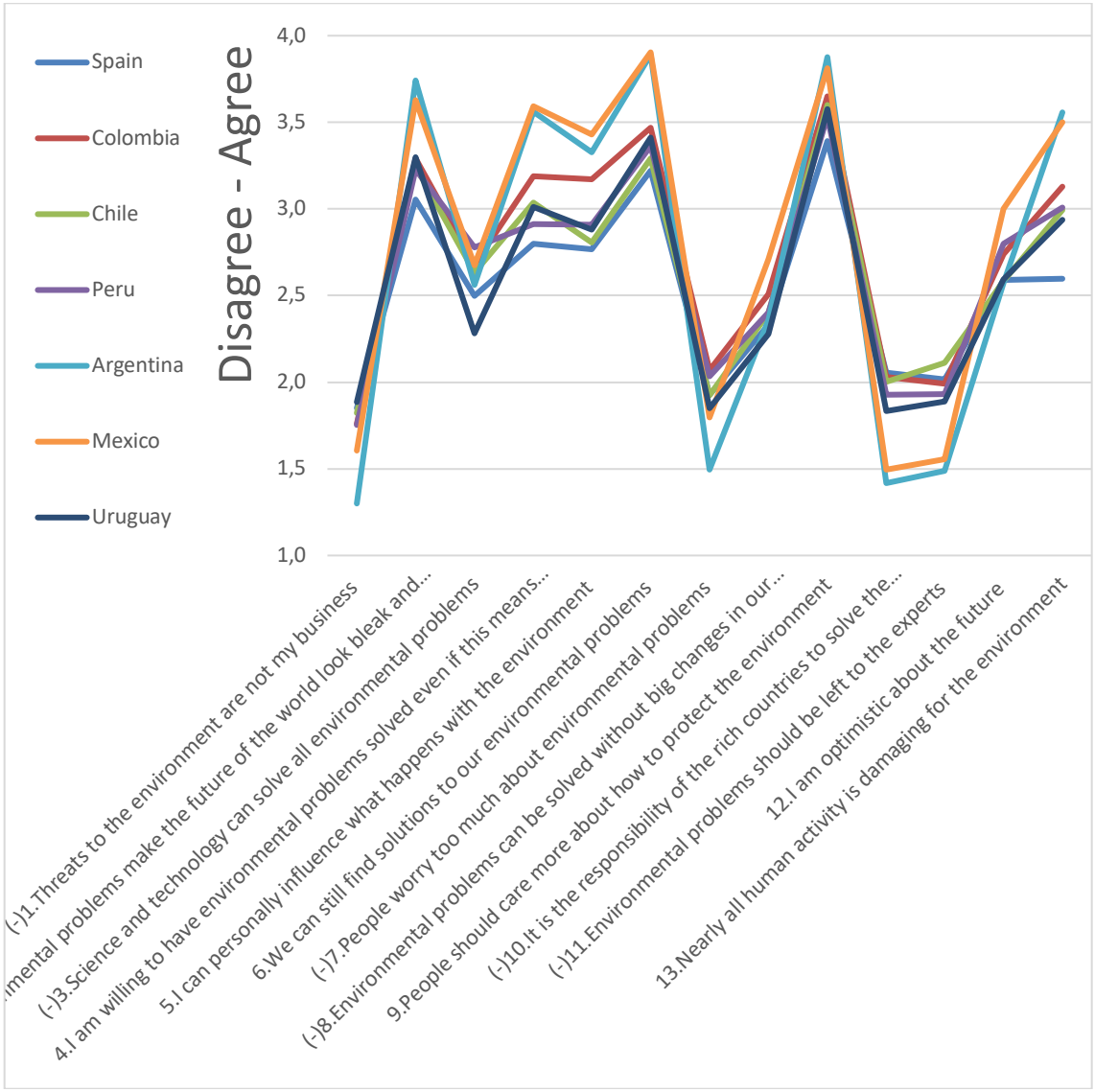
The data gathering took place from 2021 to 2024, and students anonymously and digitally answered the ROSES-Q as a class assignment led and collected by their teachers at each participating school.

The analysis summarizes the four percentages of each item within one single parameter, the item weighted average. The effect size (ES) of the differences (measurement of differences in normalized scores) allows analysis of the magnitude of the differences (low, medium, or large) that go beyond the statistical significance probability test ($p < .05$). Parametric (Cohen *d*) and non-parametric (Cohen *r*) ES tests were computed and interpreted this way: very small (< .10), small (< .30), moderate (< .50), large (> .50), and very large (> .80). ES scores of gender differences are computed as girls minus boys, so that positive differences represent higher scores of women.

Results

The main global qualitative feature exhibited by the EAs item averages of the seven countries shows that the countries' profiles are quite parallel among them. All country lines display their maximum and minimum scores on the same items with some minor exceptions (Figure 1).

Figure 1. Weighted average of environmental items for the seven countries.



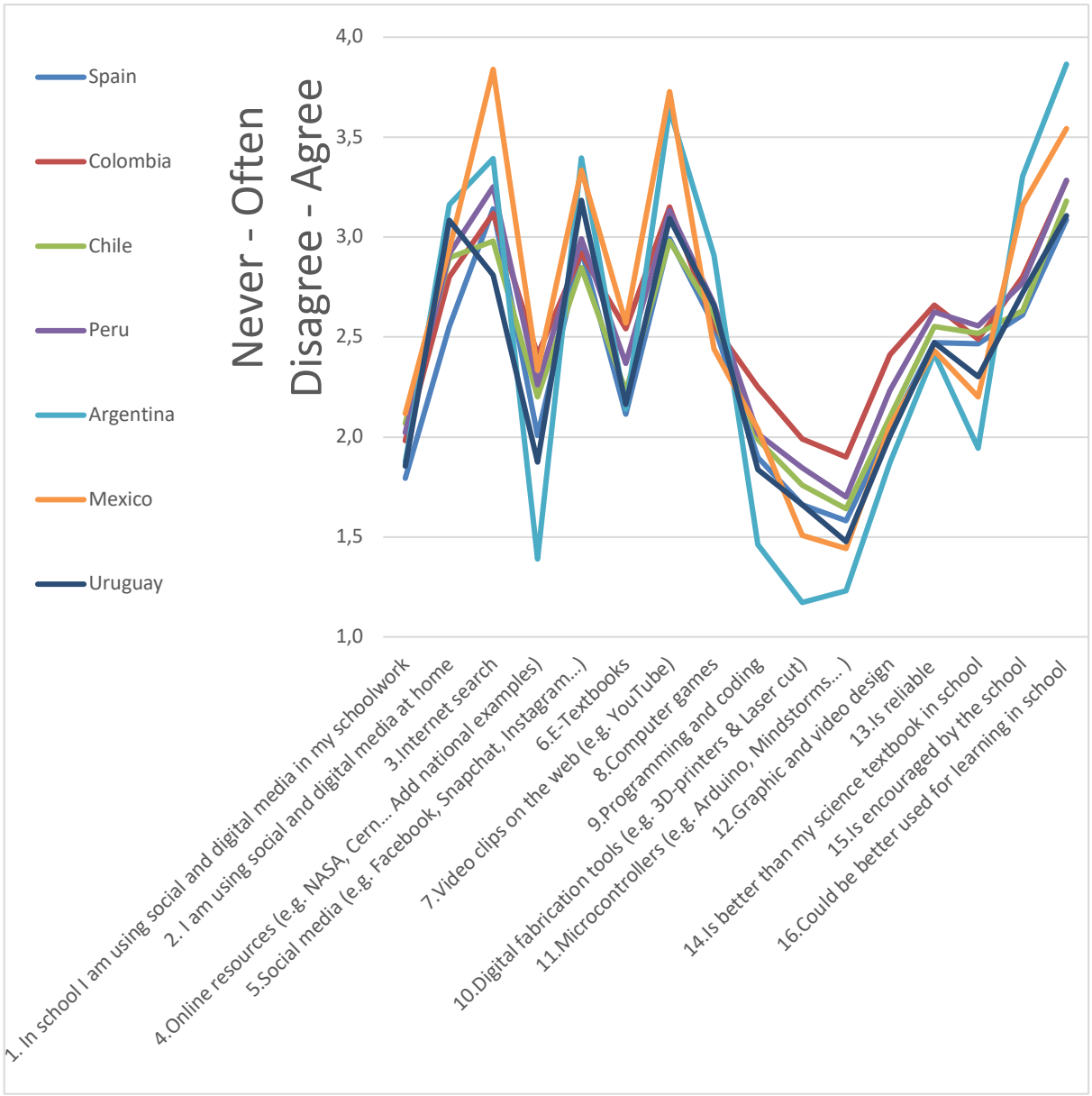
The items with the highest scores (large agreement) are three positive items: item 2 ("Environmental problems make a hopeless future"), item 6 ("We can still find solutions to

environmental problems"), and item 9 ("People should worry more about environmental problems"). Similarly, the points with the lowest scores (large disagreement) correspond to item 1 ("Threats to the environment are not my business"), item 7 ("People worry too much about environmental problems"), item 10 ("The responsibility lies with rich countries"), and item 11 ("Environmental problems should be left to the experts") (all three negative items).

On the other hand, the comparison among countries shows that most EAs items display large differences, which approximately score over one unit of the Likert scale between the country with the highest and lowest score (this difference corresponds to one standard deviation ES). The lowest differences between countries (under one unit of the Likert scale) correspond to item 3 ("science and technology can solve all environmental problems"), item 8 ("problems can be solved without major changes in our way of life"), and item 12 ("optimistic about the future").

The profiles of the seven countries along the 16 DM item averages are quite parallel. All country lines display their maximum and minimum scores on the same items with some minor exceptions, which is their main global feature (Figure 2).

Figure 2. Weighted average of digital media items for the seven countries.



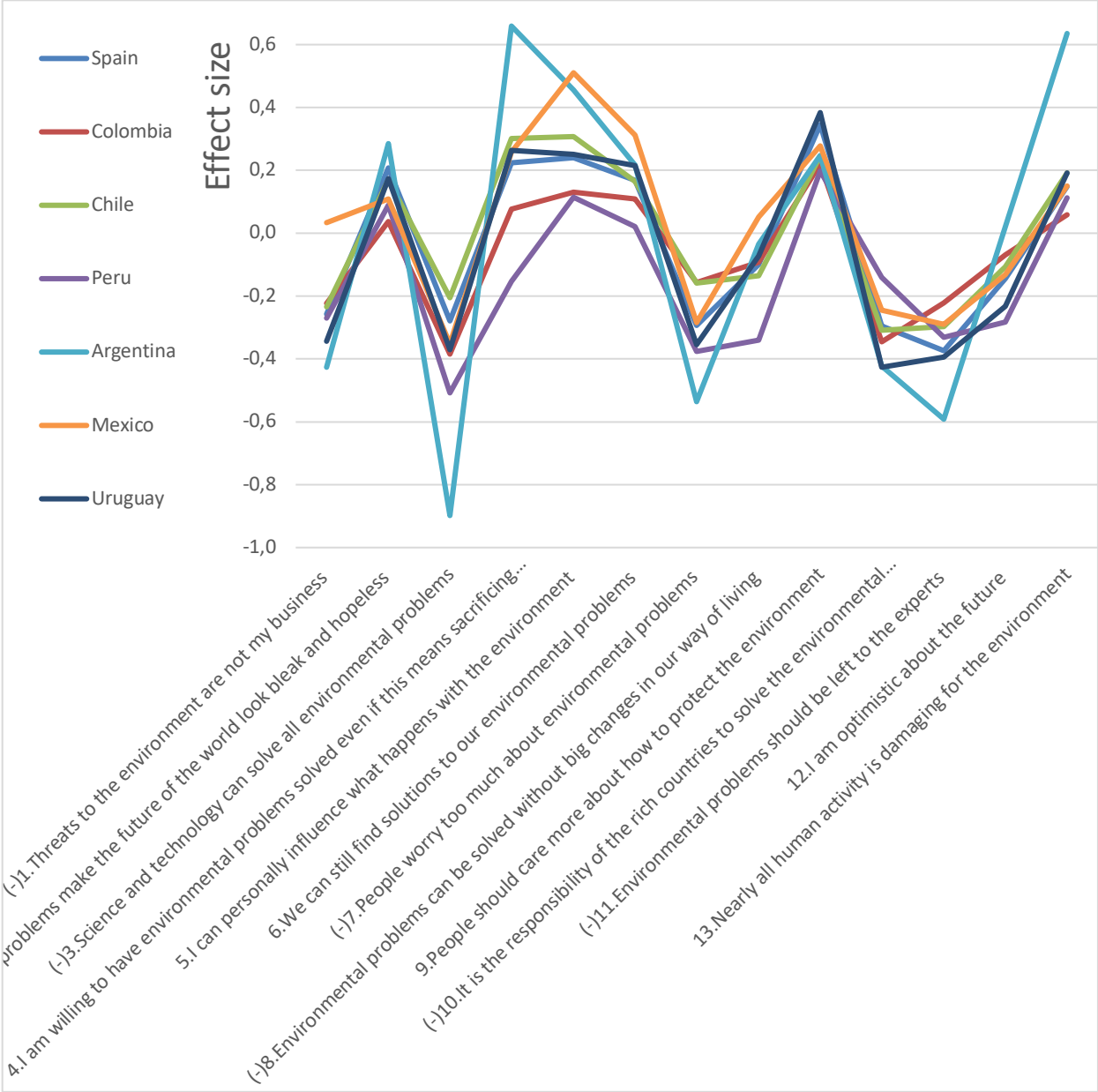
The items that reach the highest scores (largest use) are 2 ("use of social and digital media at home") and item 7 ("Video clips on the web"), and there is large agreement on item 16 ("DM

could be better used for learning in school"). Similarly, the items with the lowest scores (scarcest use) correspond to items 1 ("use of social and digital media at school"), 4 ("Online resources"), 9 ("Programming and coding"), 10 ("Digital fabrication tools"), and 11 ("Microcontrollers").

Further, Figure 2 also shows that almost all DM items display large differences between the highest- and lowest-score countries that are approximately higher than one unit of the Likert scale (over one standard deviation). The lowest differences between countries (under one unit of the Likert scale) correspond just to item 1 ("use of social and digital media at school").

Globally, Argentina's and Mexico's EAs stand out for being more positive than the rest of the countries. Their averages are well above the other countries in the positive items, and they are well below the other countries in the negative items. This result is also observed in the use of DM in science education: Mexico and Argentina tend to score lower than the other countries in the lowest-score items and tend to score higher in the highest-score items.

Figure 3. Effect size of gender differences on environmental items for the seven countries.



Gender differences

Gender differences in EAs and DM use have been assessed using parametric and non-parametric methods for computing statistical significance and effect size. Most items show significant gender

differences ($p < .05$) through parametric and non-parametric tests, even for low effect sizes (< .10). For this reason, the following analysis focuses on effect size statistics that are much more demanding and relevant for practice than the simple hypothesis testing statistics (probability of significance test). Parametric (Cohen *d*) and non-parametric (Cohen *r*) effect size statistics have been compared for EAs and DM use. Both effect size statistics produce highly coincident results, so that Cohen *d* has been selected (Figures 3 and 4).

The EAs (Figure 3) show that many items in many countries do not exceed the threshold of the effect size magnitude corresponding to small differences (-.20 - +.20). However, some items stand out of this interval with moderate to large differences. The items with positive differences (favourable to women) correspond to items 4 ("I am willing to have environmental problems solved even if this means sacrificing many goods"), 5 ("I can personally influence what happens with the environment"), and 9 ("People should care more about how to protect the environment"). These results mean that women agree more than men with the EAs represented in these items. As all these items display a positive formulation (pro-environmental), women hold better EAs than men, and the effect size of the gender differences is moderate to large.

The items with negative and moderate to large gender differences (favourable to men) are item 1 ("Threats to the environment are not my business"), 3 ("Science and technology can solve all environmental problems"), 7 ("People worry too much about environmental problems"), and 8 ("Environmental problems can be solved without big changes in our way of living"). Thus, men agree more than women with the negative (anti-environmental) attitudes represented in these items. The negative (anti-environmental) content of the former items requires a reversed interpretation of their scores, which means that women hold better attitudes than men on these items.

After reversing the scores of the anti-environmental items, the global differences on EAs show that girls have more positive attitudes than boys across all countries, and the effect size of the differences is noteworthy in the EA items mentioned above.

The overall effect size of gender differences on EA items approaches a positive moderate effect size, approximately .20. Exceptionally, Argentina exhibits a higher overall effect size of gender differences (over .40) that nearly reaches significant differences in effect size. This means that Argentine girls stand out for having the highest magnitude of the gender differences in comparison to the rest of the countries. Argentinian girls have much better attitudes than Argentinian boys, and just double the gender differences of other countries on EAs.

Argentinians' averages in the negative items are well below the other countries, yet they are well above the other countries in some positive items. Thus, Argentinian girls display much better EAs than Argentinian boys and double their gender differences in comparison to the other countries. According to this trend, some outlier effect size scores are noteworthy. Argentina scores much higher than the other countries in the positive items 4 ("I am willing to have environmental problems solved even if this means sacrificing many goods") and 13 ("Nearly all human activity is damaging for the environment"). Further, Mexico scores well over the other countries and against the former trend in the negative item 1 ("Threats to the environment are not my business").

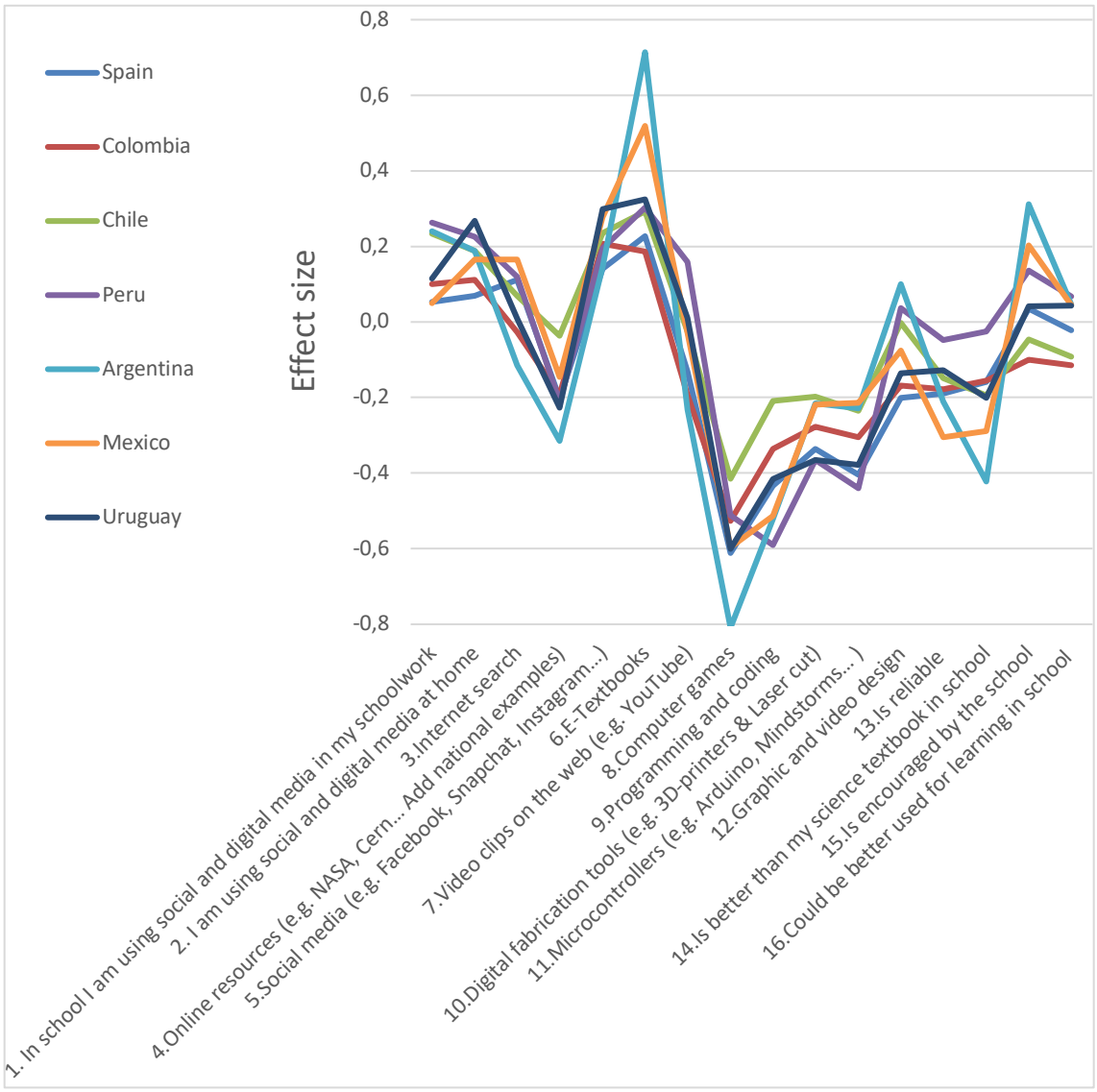
The gender differences in DM use (Figure 4) show that many items in many countries fall well below the threshold of the effect size magnitude, which corresponds to small differences (-.20 to +.20). However, some items stand out of this interval, showing moderate or large differences. The items with moderate or large positive differences favourable to women (positive) correspond to items 5 ("Social media") and 6 ("E-Textbooks"), which means that women report greater use

than men with these DM. Thus, women hold better DM use than men along these two items with moderate to large positive effect sizes of gender differences.

The items on the DM use that reach an overall moderate to large negative gender difference (favourable to men) correspond to items 8 (“Computer games”), 9 (“Programming and coding”), and 10 (“Digital fabrication tools”). Men use more than women the resources depicted in these DM items. Overall, these results allow us to conclude that women and men widely differ between them in the use of the DM mentioned above, giving different patterns tied to gender.

Regarding overall gender differences on DM use, Argentina again stands out for having more extreme scores than the rest of the countries. The effect size average items are well below the other countries in the DM with negative effect size (Argentinian men do use these DM much more than men of the other countries do) and they are well above the other countries in some positive effect size items (Argentinian women do use these DM much more than women of the other countries do).

Figure 4. Effect size of gender differences on digital media use for the seven countries.



Regarding DM use, the global effect size scores of the gender differences are negative for all countries, indicating that boys report a higher DM use than girls. However, these negative scores correspond to very small gender effect sizes. It is worth noting that Argentina displays the highest range of the distribution of effect size across DM items compared to other countries, indicating

that Argentina shows the highest and lowest effect sizes of gender differences across some DM items.

Discussion And Conclusions

The findings of this study answer the research questions about the current EAs and DM use in school science education through surveying students in seven Spanish-speaking countries.

The first finding points to students' overall proactive EAs, as the weighted averages of all EA items are over the midpoint of the Likert scale (after reversing the scores of negative items). Further, the EA items that display the highest and lowest attitudinal strength have been identified (Somerwill & Wehn, 2022). Regarding DM use, the item weighted averages are quite varied, giving rise to the more and less used DM resources (Skryabin et al., 2015).

Second, the students' EAs and DM use in school profiles across the set of items exhibit overall similar qualitative patterns for countries. However, the quantitative comparison between countries within each item shows large differences among countries for most EAs and DM items. Then, the items that display the largest and smallest differences among countries have also been identified and displayed as findings of this study.

Third, the weighted averages of Argentina and (partially) Mexico play the role of outliers in relation to the weighted averages of the other countries; that is, Argentina and (partially) Mexico often score in the top or the bottom of each EA and DM use item. Taking into account the overall scores on EAs and DM use, the seven countries seem to fit the following tentative table league (from top to bottom weighted averages): Argentina, Uruguay, Spain, Chile, Mexico, Peru, and Colombia.

Fourth, the study found generalized gender differences about EAs and DM use and a notable variance among countries. The overall differences on EAs show girls displaying more positive attitudes than boys across all countries, and the effect size of the gender differences is noteworthy in some EA items that have also been identified. The exploration of countries shows that Argentina exhibits the highest effect size of EAs' gender differences, which means that Argentinian girls have much better attitudes than Argentinian boys. Further, the magnitude of the gender differences on EAs just duplicates the gender differences of other countries (Gyurián Nagy, 2025; Sáinz et al., 2020).

Regarding DM use, the global effect size scores of the gender differences are mostly negative for all countries, which means that boys overall report higher DM use than girls. However, these negative effect size scores correspond to insignificant gender differences. Further, these gender differences induce different patterns of DM use that are tied to gender: girls report much more frequent use of e-textbooks than boys, and the reverse pattern applies to computer games, where boys report much more frequent use than girls. Again, Argentina tends to display the highest and lowest effect size of gender differences across many DM items. Overall, these results lead us to conclude that women and men widely differ in DM use.

The findings about students' EAs and DM use project obvious consequences for practice. First, school science education should remedy the weaknesses of EAs and DM use, such as increasing the educational use of computer games or trying to change anti-environment attitudes of the minority of students. Further, research should deepen the analysis within each country and the contrasts between countries (Courtney et al., 2022; OECD, 2024).

The limitations of this study mainly stem from its dependency on the ROSES-Q instrument, as its specific design conditions the results. For instance, the EA items do not develop all the environmental dimensions of the EAI (Milfont & Duckitt, 2010), and the DM does not include

the impact of artificial intelligence. Further, the samples in some countries (Mexico and Argentina) are small and harm their representativeness.

The future of this study envisages practical applications and developments of all the findings presented above for school science education and for research in science education. Particularly, the weaknesses and strengths of EAs and DM use and their gender differences may need future confirmation through new studies with renewed samples and contexts in the different countries.

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